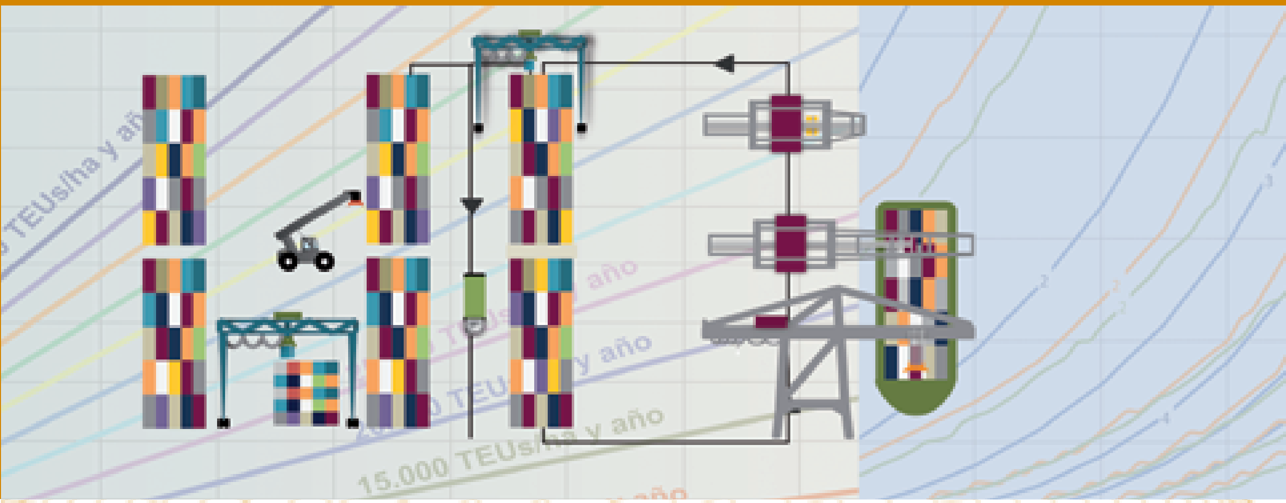
# *Seaport capacity manual: application to container terminals*



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*Seaport Capacity Manual:*
*Application to Container Terminals*

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# Index

## Index of tables

## Index of figures

## Index of graphs

# Acronyms

| | |
|---|---|
| € | Euro |
| AGV | Automated Guided Vehicle |
| ASC | Automated Stacking Crane |
| BSC | Balance Scorecard |
| ca. | *Circa*. Approximately |
| CFS | Container Freight Station |
| cont. | Container |
| CTQI | Container Terminal Quality Indicator (Germanischer Lloyd trademark) |
| CUT | Common-user Terminal |
| DEA | Data Envelopment Analysis |
| DGMM | *Dirección General de la Marina Mercante* (Spain) |
| DRMG | Double Rail Mounted Gantry crane |
| DT | Dedicated Terminal |
| ESPO | European Sea Ports Organisation |
| FL | Frontloader |
| GT | Gross tonnage (volume measurement) |
| GVPA | Green Valley Port Authority |
| h | Hour |
| ha | Hectare |
| KPIs | Key Performance Indicators |
| l.m. | Linear metre |
| Lo-Lo | Lift on – Lift off |
| LoS | Level of Service |
| m | Metre (meter in USA) |
| Max. | Maximum |
| MASPORT | MASPORT: Automation and Simulation Methodologies for the Assessment and Enhancement of Port Container Terminal Capacity, Performance and Level of Service |
| MFOM | *Ministerio de Fomento* (Ministry of Public Works, Spain) |

| | |
|---|---|
| N/A | Not applicable |
| NV | *Naamloze vennootschap* (similar to a Spanish S.A.; or a Public Limited Company in United Kingdom) |
| O/D | Inland origin and destiny trade |
| OHBC | OverHead Bridge Crane |
| OPPE | *Organismo Público Puertos del Estado* (Spain) |
| P | Annual average productivity of vessel at berth |
| PPRISM | Project "Port Performance Indicators, Selection and Measurement" |
| prod. | Productivity |
| R/D | Receipt and Delivery |
| RMG | Rail Mounted Gantry crane |
| ROM | *Recomendaciones para Obras Marítimas* (Maritime Civil Works Recommendations) |
| Ro-Pax | Roll on – Roll off and passengers |
| Ro-Ro | Roll on – Roll off |
| RS | Reachstacker |
| RTG | Rubber Tyred Gantry crane |
| S.A. | *Sociedad Anónima* (Public Limited Company) |
| S.L. | *Sociedad Limitada* (Limited Liability Company) |
| SC | Straddle carrier |
| ShC | Shuttle Carrier |
| SLU | *Sociedad Limitada Unipersonal* (Single-member Limited Liability Company) |
| t | Metric tonne ($10^3$ kg) |
| T+C | Tractor + Chassis |
| TEU | Twenty-foot Equivalent Unit |
| TOS | Terminal Operating System |
| TRB | Transportation Research Board |
| UNCTAD | United Nations Conference on Trade and Development |
| Ut | Unit |

## Notation

| | |
|---|---|
| $\alpha_o$ | Net storage coefficient |
| $\varepsilon$ | Relative waiting time |
| $\Phi$ | Berth Occupancy or utilization factor in the queueing theory |
| $A_i$ | Storage area according to type of traffic *i* |
| $A_Y$ | Storage area or yard area |
| $A_{YN}$ | Net storage area |
| $A_T$ | Terminal area |
| $C_B$ | Berth Capacity |
| $C_Y$ | Terminal annual yard capacity |
| $C_S$ | Static storage capacity |
| $D_Y$ | Storage area density |
| $D_T$ | Terminal area density |
| $g_o$ | Occupancy factor, or peak factor |
| Ground-slots | Number of slots available for a TEU on the ground at a terminal |
| h | Average stack height |
| H | Maximum height of stacks or nominal height of equipment |
| $h_i$ | Stack factor |
| $H_F/H_E$ | Maximum stack height of full/empty containers |
| K | Operational factor |
| $K_F$ | Operational factor for full containers |
| $K_E$ | Operational factor for empty containers |
| $K_{separation}$ | Berthing gap coefficient |
| $K_{YTS}$ | Container yard capacity vs. container berth capacity transformation coefficient |
| n | Number of berths |
| P | Average productivity of vessel at berth |
| Q | Amount of cargo to be handled in a call at port |

| | |
|---|---|
| $s_i$ | Gross unit area required by type of traffic *i* |
| $T_{dw}$ | Dwell Time |
| $T_F/T_E$ | Average dwell time of full/empty containers |
| $T_p$ | Vessel time at port |
| $T_s$ | Service time (vessel berth time) |
| $T_w$ | Waiting time |
| $t_{year}$ | Quay operating hours per year |
| TS | Percentage of transhipment |

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- ARTURO MONFORT MULINAS
- PORT AUTHORITY OF A CORUÑA
- PORT AUTHORITY OF VALENCIA
- CARPORT SAGUNTO S.L. (GRUPO BERGÉ Y CIA., S.L.)

- EUROPEAN BULK HANDLING INSTALLATION, S.A. (E.B.H.I., S.A.)
- FANTUZZI NOELL IBERIA SLU
- HORIZON SINGAPORE TERMINALS PRIVATE LIMITED
- KONECRANES AUSIO SLU
- LIEBHERR-WERK NENZING GMBH
- SBM OFFSHORE N.V.
- SVETRUCK AB
- TERMINAL INTERNACIONAL DEL SUR S.A. (TISUR)

*Que el blanco sea blanco,*
*que el negro sea negro,*
*que uno y uno sean dos,*
*porque exactos son los números,… depende*

*Depende… ¿de qué depende?*
*de según como se mire, todo depende…*

(White being white/ black being black / one and one makes two/ because numbers are exact,…it depends / It depends… what does it depend on?/ It depends on the way we look at it…)

*Jarabe de Palo, 1998*

# 01

## Introduction

The objective of this study is to present a methodology for calculating the capacity of port terminals that can be used as a practical manual to plan container terminals.

The ongoing challenge in relation to planning port infrastructures is to organise and anticipate supply to meet demand of traffic growth or demand over time and to do so in sustainable way, in terms of economic, social and environmental. This normally ends up becoming a document known as the Port Master Plan or the Master Plan for Infrastructures. So, while forecasting demand is not easy, assessing supply capacity is much more difficult than may seem at first glance.

Supply must be planned and developed taking into account sustainability. This means, first, to maximize the use of the existing resources (infrastructure, superstructure, infostructure and labour), and secondly, to have new resources available to cover what the former cannot absorb. This task generally sparks a debate regarding environmental issues and the utilisation of the waterfront. Moreover, in order for the supply created to be competitive, which is a must, there have to be satisfactory and well known levels of service that must also be constantly monitored and controlled.

01

The historical and in fact presently topical interest in studying and analysing port performance is due to the development of several port planning and operating roles. Therefore, this task is necessary, for example, in order to:

- Plan port infrastructure and superstructure (quay, areas and equipment), that is, to plan supply capacity;
- Improve infrastructure and superstructure capacity;
- Establish port handling charges; or,
- Enhance infrastructure and superstructure productivity.

When addressing the task of forecasting demand, the technique called "generating scenarios" has been used from long time ago; and in the case of some of the port services (those to the cargo and the vessels), the use of measures of productivity to estimate the berth and yard needed. Now, it is the time to take a brief look back over the last quarter of the 19th century, taking the Port of Valencia as the common case study.

**Understanding the past**

In 1878, engineer Alejandro Cerdá, the Director (1874-1882) of the Port of Valencia Works Board (old name for the Port Authority), as part of the "Report on the technical specifications of the Port basin", stated that starting with some 250,000 tonnes of traffic that year, he predicted an annual growth since 1883 of 50,000 tonnes up to a total of 1,250,000 tonnes 20 years later (1903). He added that "*should we be able to confirm the handling of 400 tonnes a year per metre of quay line during that time, the port must have 3,125 linear metres of quays for loading and unloading, adding a quarter of this total for stairs, angles, curves and the rest of the quay that cannot be used, in which case, 3,750 metres of quays would be required".*

He also said "*we must insist that this interesting figure is not extravagant, because even if the tonnes handled by the port increased by less than we assume, 400 tonnes per metre of quay line is a maximum that would make it difficult to use the quays*".

Engineer Manuel Maese (1896), Director of the Port of Valencia Works Board (1888-1902 and 1918-1924), in the "Report on the technical specifications of the seawalls for the enlargement and improvement of the Port of Valencia", stated that "*annual traffic has reached 753,000 tonnes and, as this figure has risen by 38,000 tonnes over the period* *dating from 1877 to 1891, it can be expected to exceed 2,000,000 in 30 years time (1921), providing nothing happens that markedly disturbs the output, wealth or economic personality of the country".* The Port of Valencia had little more than 2,000 metres of quays at the time, and Maese argued that if annual performance amounted to 300 tonnes per linear metre, 2,000,000 tonnes would require nearly 7,000 metres of quay, concluding that further works were necessary to be able to construct up to 5,000 metres of additional berths in the future.

Indeed, in the beginnings of the 20th century, productivity per linear metre of quay ranged from 300 to 400 tonnes. Engineer and Professor Pedro Perez de la Sala, included international references in his work entitled "Ports and lighthouses" in 1889:

*"Chevalier, from a study of the main English ports, deduces that a one-metre quay handles between 180 and 430 tonnes, taking 300 as the average. Stevenson adds a table in his treaty of ports that includes broader parameters: the lowest of 154 being found at the Santa Carolina Docks in London, and the highest of 477 in Glasgow. In Southampton the figure was 380, but could easily have been higher. In summary, when a port is well equipped for loading and unloading, it is not extravagant to indicate 400 tonnes per linear metre of quay".*

He added to the above that *"we must not only take into account the dockage and draft when judging port performance; surface area is no less important. In the table referred to above that was published by Stevenson, Tyne Docks registered the highest figure of 90,000 tonnes per hectare, while Southampton recorded the lowest at 44,500 tonnes. Therefore, there is a relationship between the area of a port and dockage. In some cases, such as Genoa, Trieste and Marseille, the length of the quay per hectare varies from 90 to 200. In large commercial ports, such as London, Liverpool, Antwerp and Amsterdam, a figure of up to 350 can be reached in some basins".*

In 1911, engineer José Mª Fuster, director of the Port of Valencia Works Board (1910-1917) stated in the Revista de Obras Públicas (Public Works Journal) that the Port of Valencia had handled 1,083,471 tonnes in 1909 with slightly more than 2,000 linear metres of usable berths (see Figure 1). As a result, *"the annual handling per linear metre of quay amounted to 537 tonnes, an exorbitant figure as it is generally considered that traffic should not exceed 300 tonnes or even 270, according to studies by the Italian Commission in charge of establishing the basic specifications for the construction of ports in that country".* Then, at a rate of 300 tonnes per year and per metre of quay, he estimated, just like Maese before him, that almost 7,000 metres of quay would be required to cope with the 2,000,000 tonnes of traffic forecast in a timeframe of 15 years (1924). A figure of 1,500,000 tonnes was achieved that year with practically the same length of quay.

How was it possible to achieve such extraordinary berth productivity?

It is worth adding that such *"exorbitant"* berth productivity was achieved with a minimum of modern machinery. In fact, in 1912 the port only had 6 electric cranes: two 3-tonne cranes on the quay that runs perpendicular to the outer east quay, another two 3-tonne cranes on the quay that runs perpendicular to the outer west quay and two 15-tonne cranes: one on the quay that runs perpendicular to the inner west quay and another on the west seawall. The port had plans to bring in 4 more at the most, as demanded by the Chamber of Commerce (two 3-tonne cranes and two 5-tonne cranes). However, Fuster himself acknowledged that *"if the construction work on the seawalls and new commercial quays does not progress, there is not enough berth space for ships and it will be impossible to increase the number of cranes"*. He was referring particularly to the problem of *"loading oranges and fruit from the region": "Hopper barges are overused, which leads to high transport costs for boxes, and until barges disappear, tackle will exist, as the agent that has them is interested in using them. When the enlargement of the Western Seawall on the sea side is completed and when the progress made on the outer construction work provides more shelter in the outport, there will be enough berthing space and there will consequently be no excuse for ships not mooring next to the quay"* (Port of Valencia Works Board, 1913).

The "secret" to the aforementioned productivity was the mooring and loading system, which used cranes or floating sheerlegs (locally called "tecles") or ship-to-shore cranes (locally called "caballetes" or "easels" in English), manned in all cases, and hopper barges. As it can be observed in Figure 1 and Figure 2, ships anchored in the basin perpendicular to the quay and were loaded using vessel gear, or vessel gear tackle (cranes and cargo booms). While productivity figures were excellent, the problem was the increase in costs mentioned by the engineer, as a result of double handling.

Figure 1. Port of Valencia. Inner Basin. 1910 *ca.*

Source: Port Authority of Valencia

Figure 2. Port of Valencia. 1920 *ca.*

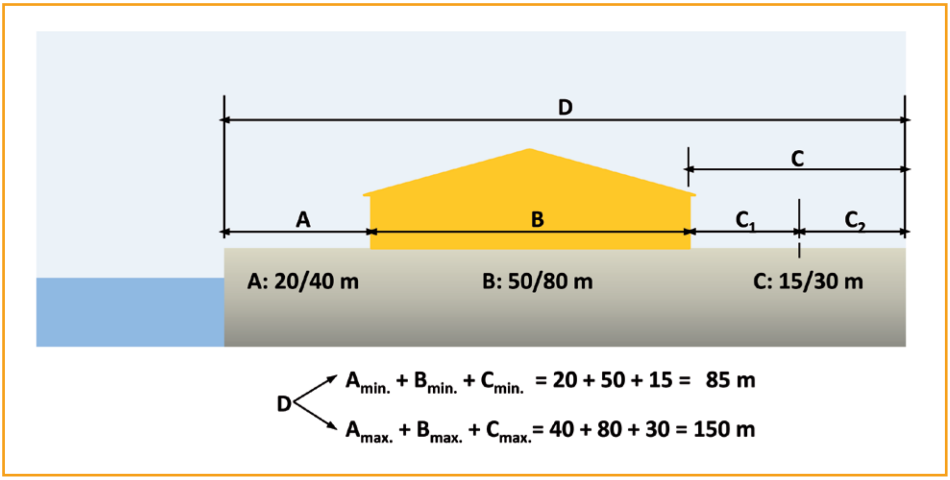
Source: Port Authority of Valencia

The figure of two million tonnes was reached in 1929, but with much more berthing space following the completion of the outport works planned 35 years earlier by Maese, which added 1,300 metres of berth in 1931 on the Eastern and Western Quays. Unfortunately, the Spanish civil war and World War II ensued and the port had to wait until 1958 to recover the figure of 2,000,000 tonnes in traffic.

Fifty years after the forecast made by Fuster, in 1961, Francisco Enríquez, who was also an engineer, published an article in the Public Works Journal entitled "*Port Productivity*", stating in the introduction that *"it would have been better to give the article a title halfway between a good-humoured one such as "port enigmas", and the more pompous and grandiose, but not as compromising title that was actually chosen"*. Enriquez was certainly right, even though the container had just appeared on the scene and the best was still to come. It is worth adding that 30 years later, the same author also wrote a series of monographic articles that address the complex world of multipurpose terminals (Enríquez, 1991).

Finally, after a brief reference to bulk cargo and before "presenting" the real star of the Manual, namely containers, we shall quote Rafael del Moral (1991), Head Engineer (1981-2000) and then President (2000-2004) of the Port Authority of Valencia that *"the 1960s began with a plan for general cargo quays with an annual ratio of 500 tonnes per linear metre"* (see Figure 3).

Figure 3. Quay for General Cargo. 1960-1970



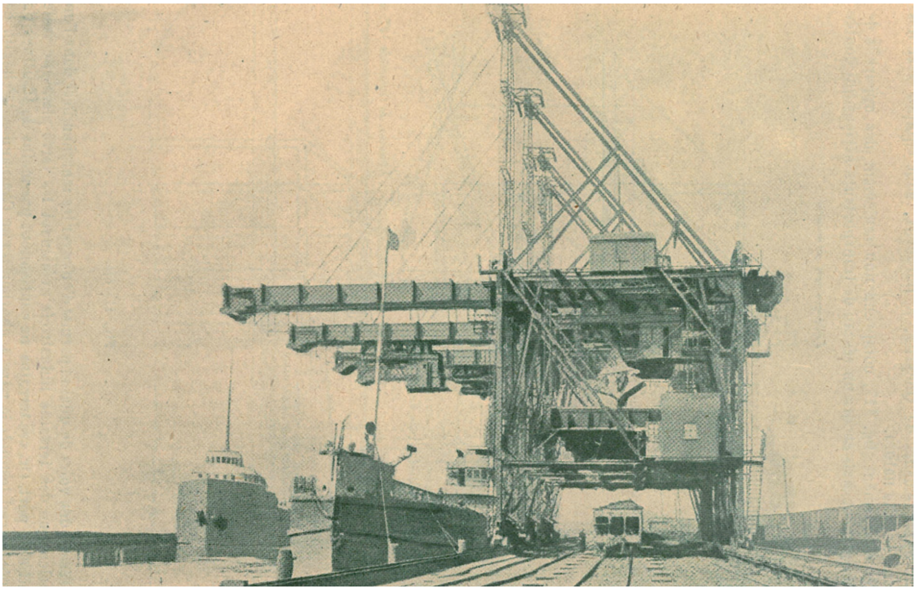

Source: Vigueras (1977)

Berth productivity for general cargo had actually improved very little in more than 80 years (1878-1960).

**Bulk cargo**

Dry bulk and semi-bulk handling was a different story, however, as this format of cargo is easier to transport. Technological advances, which resulted in greater vessel tonnage and also enhanced crane performance, boosted the development of highly productive specialised terminals. By way of example, it is worth mentioning the Hullet system for unloading minerals and coals, which was introduced in 1905. The Cleveland terminal (see Figure 4), which has 4 cranes, managed to unload 11,800 tonnes in three and a half hours. Other more conventional facilities, such as the one at the Port of Rouen, achieved daily unloading averages of 2,000 tonnes per ship-to-shore tower. Semi-bulk cargo, such as posts for mines, also had specialised facilities, as in the case of the Port of Bordeaux.

Figure 4. Cleveland Mineral Terminal (unloading towers)



Source: Bénéfit (1921)

The same can be said of liquid bulk, which was even easier to handle than dry bulk. Technological advances saw oil tankers enlarged from the T-2 tankers in the 1950s to the gigantic oil tankers of the early 1970s, with a capacity of nearly 500,000 DWT.

### The container

The seeds of revolution in ports in the 20$^{th}$ century (containers), invented in the mid 1950s by Malcom McLean (1913-2001), founder of the shipping line Sea-Land in 1960 (see Figure 5), germinated in the 1960s and gave fruit in the 1970s, constituting the start of the race for port space, due to the need for larger storage areas. Indeed, the progressive increase in berth productivity resulted in ships staying less time in port, which in turn led to an increase in the size of container vessels and the cranes capable of serving them, in a self-fuelled process that continues today.

Figure 5. *Tiber* ship from Sea-land Company. First call at Valencia serviced by "the Liebherr" crane at Marítima Valenciana Terminal. 1972


Source: Port Authority of Valencia

Containers first appeared on the scene at the Port of Valencia at the end of the 1960s, but grew rapidly (Monfort, 1994). In fact, the 1972 Annual Report by the Port Board (another old name for the Port Authority) explains the situation during those early years: *"up until halfway through the year, container traffic was handled in conditions that only the ability to improvise could overcome. That year a private terminal station started operations as a result of a contract tender for the management of public container loading and unloading services. In the first six months, this facility has surpassed all the orders stipulated by the contract in terms of minimum number of units handled".* The competitive bidding process referred to was won by Marítima Valencia, S.A. The "miniterminal" was located on the Espigón del Turia Norte Quay (see Figure 6), with a surface area of 0.71 hectares and one crane –"the Liebherr"– for loading and unloading on a 135-metre berth with 9 metres of draft.

**Figure 6. First container crane at the Port of Valencia: "the Liebherr" at the "miniterminal" in 1972**

**Source: Port Authority of Valencia**

## Capacity

Apart from the use of empirical indicators of berth and storage productivity, the most complete reference for Spain in terms of measuring port capacity dates back to 1977. Under the title of "Quay capacity", Fernando Rodríguez produced an extensive text on this subject, that he would later summarise in his book entitled "Managing and operating ports", edited in 1985 by the Autonomous Port of Bilbao (old name for the Port Authority of Bilbao). The very title of the first article evokes the use of port infrastructure in a model known as a "free" or "multi operator" quay (which has fallen into disuse today), whereby several operators worked on the same quay. Progressive specialisation of port traffic and the way it grew faster has brought about a "quay-to-terminal" shift in order to enhance productivity, the new conception of these terminals now involving one sole operator ("single operator" model), generally by way of a concession or another type of contract.

Rodríguez (1977) stated that *"until recent years, capacity was defined empirically establishing the performance acceptable per linear metre of quay (for example, 500 t/m for general cargo, 1,200 t/m for bulk moved by crane, etc.), which is overly simplistic because performance depends on the nature of the cargo, that is, on the make-up of the traffic, the number of cranes allocated, etc. It is true that this simplification could be partly reduced by using a more detailed scale that takes into account the circumstances indicated previously, but even still, this method is inappropriate because it does not take into account the increase in unit capacity that is caused by increasing the number of berths, as theory demonstrates and experience confirms, and such an increase cannot be covered by applying correcting coefficients as they would have to be different for each level of traffic intensity".*

In 1978, UNCTAD stated that *"there has been considerable inaccuracy in predicting container terminal productivity: average throughput in a sample of 21 ports was 442 containers per 24 hours in port, which is considerably less than the figures used by consultants, experts and potential operators in their theoretical calculations".* This was followed by a theoretical calculation that yielded 860 containers in 24 hours, adding the comment that *"the actual average throughput of the sample was slightly more than 50% of this theoretical figure. Clearly, the figures used in this procedure are too optimistic for planning purposes and more realistic figures should be used when calculating ship turn-around time for the economic analyses".*

A few years later, Rodríguez (1985) established the "basic berth ratio" at "*650 t/m for general cargo and 2,600 t/m for containers*". Four correcting coefficients were applied to these figures:

- For quay draft (between 0.5 and 1);
- For average call size (only for general cargo), between 0.5 and 1;
- For concessions and specialised traffic, between 1.1 and 1.2; and
- For number of berths: between 1 and 1.5.

In the case of concession of a container terminal with a draft of 12 or more metres, the ratio would be 2,860 t/m for one berth, 3,718 t/m for three berths and 4,290 t/m for six or more berths.

**Dominance of the TEU**

The tonne quickly gave up its place as the unit of measurement to the dominant TEU (Twenty-foot Equivalent Unit), as containers can be more or less full or empty and they come in different sizes. As a result, a new unit of measurement was required, which ended up "betraying" many authors in their calculations of performance, capacity, efficiency and level of service.

By illustrating a series of indicators for a concession contract for a container terminal, UNCTAD (1998) took 300 TEU per metre of quay as a benchmark when operations began, raising the target to 500 TEU/m by the eighth year of the contract (see Table 17 in Chapter 5).

In 1998, Drewry Shipping Consultants established the benchmark for capacity at 750 TEU/m in the case of terminals with less than 500 metres of quay line, and at 800 TEU/m for larger facilities. In 2002, the same consultancy revised its capacity benchmarks, which then ranged from 800 to 1,700 TEU per metre of quay, depending on the size of the terminal (length of quay) and the characteristics of the traffic (frequency, distribution between export/import and transhipment, etc.). Even then, the Port of Rotterdam used a ratio of 1,500 TEU per metre of quay for the long term planning of future terminals (2020).

If we take an average of 10 tonnes per TEU, the values referred to would amount to 8,000 and 17,000 tonnes per metre of quay respectively; that is, the container revolution would have multiplied the 500 t/m figure from the 1960s by 16 and 34 times respectively.

Another interesting figure, in this case included in the terms of the tender of the Prat Quay at the Port of Barcelona (2006) for a 1,500 metre quay terminal over a contract period of 30 years, literally stated *"minimum performance to be achieved throughout the entire contract period:*

- On achieving maximum berth capacity, berth performance must be in excess of 1,350 TEU per metre of quay line and per year.
- On achieving maximum area capacity, storage capacity must be in excess of 750 TEU per hectare of the storage yard (excluding the space for manoeuvring, rail terminals and other areas not directly used for container storage or receipt/delivery operations). The resulting capacity will be no less than 2,000,000 TEU/year".

Going back to the case of the Port of Valencia, we must provide the figure for containerized traffic achieved in 2010, which stood at 4.2 million TEU (49,029,766 tonnes) and that the productivity of the MSC dedicated container terminal, with 770 metres of berth, amounted to 1,807 TEU per metre of quay (22,384 t/m), which is the equivalent, in this case, of 45 times the 500 t/m achieved in the 1960s. Anyone who had been capable of anticipating this revolution would certainly have been considered a visionary at least.

The challenge of managing a port is to continue advancing along the aforementioned scale of productivity, even though the capacity of a terminal, as this Manual reveals, is not only inherent to the port itself, its dimensions and machinery, but also depends on the type of traffic it will receive and the level of service provided. These variables therefore condition maximum achievable capacity.

Yard storage capacity has occasionally constituted a bottleneck for container terminals, restricting their capacity, the most prominent factors being: the size of the storage yard, static storage capacity in relation to the handling system and, of course, container dwell time.

The methodology proposed in this Manual is the result of a combination of both analytical and simulation methods applied to port planning.

It makes sense to use more or less complex simulation models, depending on the level of abstraction, when assessing the capacity of a terminal that is still in the design stage, particularly when valuing the variety of yard equipment. The same can be said when the objective is to improve a terminal that is already operating. Finally, it is worth mentioning that, as part of the MASPORT Project, the ai2 Institute at the Polytechnic University of Valencia has developed, parallel to the content of this Manual, a powerful simulation model with various levels of abstraction using data from the terminals managed by TCV and MSCTV for the purpose commented previously.

**A draft affair**

Before describing the contents of the chapters in the Manual, here is one last warning for seafarers: when calculating capacity, it is necessary to take into account the water draft and air draft of the facility. However, the objective of this Manual is not to analyse the draft necessary to serve the vessels expected to call. As a result, it is assumed that the facility has sufficient draft to provide services to such vessels.

**Contents of the Manual**

Following this introduction, Chapter 2 tackles the concept of port terminal as a system made up of four subsystems: ship-to-shore, yard-storage, receipt and delivery, and transfer (horizontal). This chapter also provides a classification of the different types of terminals according to cargo presentation, nature and how it is handled, depending on traffic origin and destination and on the stakeholders involved.

Chapter 3 shows the types of container terminals according to the yard equipment of the storage subsystem, describing the basic operations involved. At this point, it is worth indicating that the Manual "*La Terminal Portuaria de contenedores como sistema nodal en la cadena logística*" (Monfort *et al.*, 2011a) delves into the matter of equipment and container terminal classification as well as other subjects that deals with the concept of including container terminals in the logistics chain.

Chapter 4 is devoted to disentangling the concepts for measuring port performance: operating performance, production categories, productivity and utilisation; efficiency, capacity and level of service.

Chapter 5 provides the methodology for calculating terminal capacity based on berth capacity by means of a combination of the analytical and simulation methods; and for calculating storage capacity, which combines the empirical and analytical methods.

A full application of the Manual is provided in Chapter 6, which is intended to clarify the practical use of the Manual, while at the same time illustrating the different variables that influence the variability of container terminal capacity.

The Manual includes four annexes, one about observations and limitations regarding the calculation of berth capacity, another about safe distances between vessels at berth (berthing gap), while the third refers to the graphs and tables of annual berth capacity according to the system and the relative waiting time for berths of 250 and 350 metres in length. The last one indicates how to calculate annual average productivity of vessel at berth ($P$).

Finally, an extensive reference section is provided, including both the bibliographical references in the body of the Manual, along with other supporting documents used in the Manual.

*When something is classified, it means there is a theory behind it*

**Jorge Wagensberg, scientist and popular sciencie writer**

# The port terminal

## 2.1. The terminal as a system

A port terminal is a modal interchange node that normally has a storage area on shore to coordinate the different rates of arrivals of overland and maritime modes of transport (Monfort *et al*., 2001). Its mission is to provide the means and organisation necessary to interchange cargo between overland and maritime modes as quickly, efficiently and safely as possible in both environmental and economic terms.

Similarly, according to Monfort *et al*. (2001 and 2011a), a port terminal can also be defined as an integrated system with a physical and information connection to overland and maritime transport networks. For analytical purposes, port terminals are considered to comprise of four subsystems:

1. The **subsystem of ship-to-shore or berthing facility** is responsible for the maritime interface, including all aspects of infrastructure and equipment this entails (quay, ship-to-shore machinery, etc.), and the interaction necessary at this stage with the players involved.



2. The **storage subsystem** usually covers the largest area of the terminal and is a temporary warehouse for cargo, allowing the

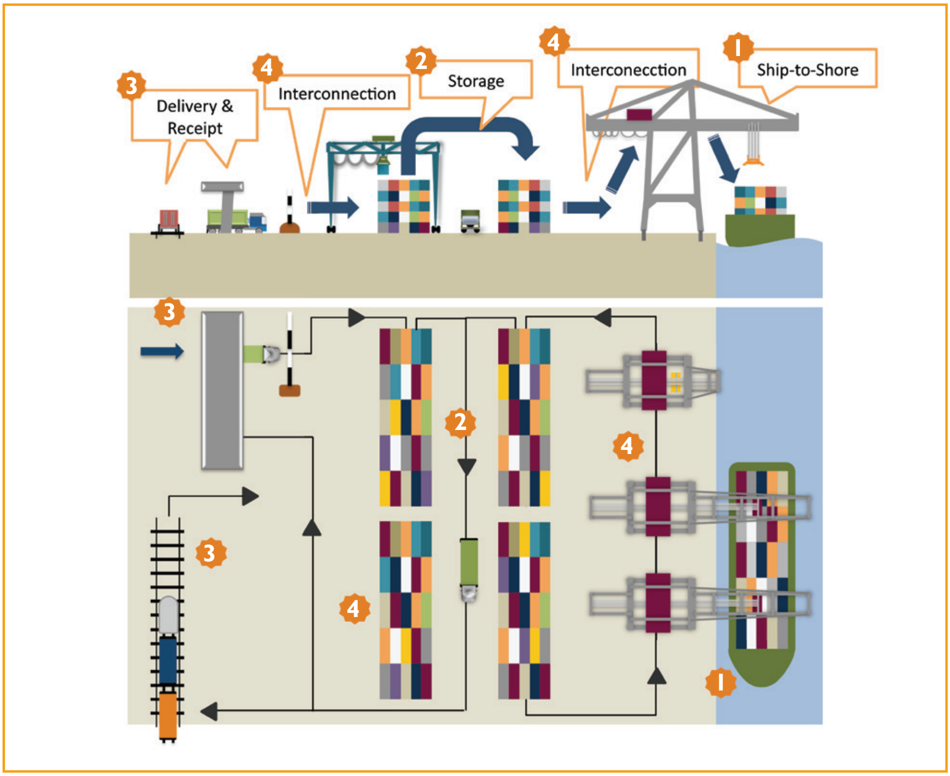
terminal to keep up with the arrival rates and assistances of the various modes of transport. The layout of this subsystem and its size depend on the type of cargo and its format, the traffic throughput, the storage equipment main type and the operational logistics (circulation directions, operational heights and zoning, cargo way of grouping) that are employed.

3. The **delivery and receipt subsystem** is made up of the terminal gates, temporary storage and accesses for trucks and/or railway, pipes or conveyor belts, depending on the case and the facilities used to help capture the large amount of information that is acquired in that area, and the spaces and equipment necessary to undertake the operation.

4. The **transfer subsystem** ensures the horizontal transportation of cargo among the foregoing subsystems. Rather than being linked to a specific physical area (as would be the case with internal transfer roads), this subsystem includes the technological solution adopted in each case for the physical and information movements that are required. Depending on the type of terminal and storage equipment, a certain type of machinery will be employed for each of the movements and for the internal transportation of cargo.

The morphology of these subsystems varies depending on the type of terminal (see Section 2.2). Figure 7 is an example of the layout of a container terminal, with its respective subsystems.

Figure 7. Example of subsystems in a container terminal




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

Two inseparable flows are managed in a port terminal: the physical flow of cargo and the flow of external and internal information. A third flow is the liability flow, which not always corresponds with the other two, and is not often enough considered, till when problems arise.

Each terminal subsystem has different variables that are related to each other:

- Infrastructure,
- Superstructure (equipment, , gates, buildings, lightening and any other physical installation), and

- Terminal Operating Systems (TOS), which are a series of equipment and software for exchanging information and generating the orders necessary to run the terminal. More and more, CIT's are becoming the brain of the CT's, not only for daily operational work, but also for tactical and strategic. Optimization and automation join the pure TOS and make IT's absolutely necessary for a proper, efficient and effective running of the CT.

Some equipment and infrastructure are shared by various subsystems.

The next section presents the various types of terminals, together with the different types of equipment used in their subsystems.

## 2.2. Types of port terminals

There are currently several types of port terminals as a result of traffic specialisation and the handling requirements of different types of cargo. Therefore, port terminals can be classified mainly according to their traffic and the handling equipment they utilise.

With regards to the cargo, different types of port terminals stem from the combination of three classifications related to the nature of the cargo, the format it comes in and how it is handled.

Depending on their nature, ports handle a wide range of cargo, such as liquefied gas, oil products, minerals, foodstuffs, vehicles, wood, paper, electronic products, grain for (or not for) human consumption, etc. In order to classify them, several nomenclatures have been proposed. The one used by the Spanish port system classifies cargo by industry, distinguishing between the following: energy, metallurgy and other minerals, fertilisers, chemicals, building materials, farming and livestock and food, other cargo and special transport.

However, although a large majority of terminals do not specialise in handling one sole type of cargo, they do specialise in cargo formats and handling requirements (see Section 2.2.1). The different types of port terminals are described briefly below according to this classification and to the type of traffic.

### 2.2.1. Terminals according to cargo format and type of handling

This section classifies port terminals considering both the format of the cargo together with how it is handled.

The classification that enjoys the most widespread consensus in terms of cargo format includes two large groups: bulk cargo and break-bulk or general cargo, which at the same time are subdivided into dry bulk, liquid bulk and general containerized and non containerized cargo terminals respectively.

Another way of classifying general cargo is: conventional cargo and unitised cargo. Table 1 presents the different cargo formats in this classification.

**Table 1. Classification of general cargo and transportation format**

| General Cargo | Format |
|---|---|
| **Conventional** | Sacks and bags, boxes…<br>Semi bulk (logs, coils, slabs…)<br>Parts (equipment, structures …)<br>Heavy cargo |
| **Unitised** | Palletised<br>Pre-slung<br>Containers<br>Chassis |

Source: Monfort (2005)

As regards the handling of cargo, it can be distinguished between Lo-Lo operations (Lift on-Lift off) and Ro-Ro operations (Roll on-Roll off). Lo-Lo operations involve either conventional or specialised cranes loading and unloading the vessel above board. Meanwhile, Ro-Ro operations refer to loading and unloading Ro-Ro cargo down a ramp that vessels have to connect its cargo hold to the quay.

Apart from handling Lo-Lo and Ro-Ro cargo, port terminals perform other operations, generally with larger tonne/hour ratios, which are specially designed for loading and unloading bulk cargo that is not crane-lifted or Ro-Ro, but instead transferred by special facilities such as pipelines or conveyor belts, among others.

Table 2 matches cargo format to how it is handled.

**Table 2. Type of handling operation by cargo format**

| Format | Handling operation |
|---|---|
| Liquid bulk | Special facility |
| Dry bulk | Special facility<br>Lo-Lo (conventional) |
| Non containerized general cargo | Lo-Lo<br>Ro-Ro |
| Containerized general cargo | Lo-Lo<br>Ro-Ro |

**Source: Monfort (2005)**

Considering all the above criteria, port terminals are classified as follows: bulk (liquid and dry), general cargo (conventional general cargo, Ro-Ro and Ro-Pax cargo and containers) and multipurpose.

### 2.2.1.1. Bulk terminals

Within the category of bulk terminals, it is worth distinguishing between liquid bulk and dry bulk terminals depending on the manner on which the cargo is presented.

#### 2.2.1.1.1. Liquid bulk terminals

Liquid bulk terminals are port facilities devoted to handling liquid bulk such as oil, oil products, chemical products, liquefied gas, vegetable oils, etc.

Figure 8. Horizon Singapore Terminals. Liquid bulk port terminal (Singapore Jurong Island – Singapore)

Source: Horizon Singapore Terminals Private Limited

The layout, dimensions and operations performed in these terminals depend on their role and the nature of the cargo. They can basically be classified as transhipment and storage terminals or terminals that supply a given industry or refinery and distribute their products.

Similarly, several types of terminals are also defined in accordance with their nature and the location of their berthing operations. In this sense, there are terminals in onshore ports (see the example in Figure 8) and offshore terminals (Figure 9), with or without areas and superstructure for storing products. Despite their structural differences, they have one feature in common: regardless of whether or not there is a storage yard, their operations are performed continuously without the need for any handling equipment other than a network of pipes and a pump system (eventually the only need of heating systems for viscous liquids).

In order to gain a better understanding of their operations, each of these types of terminals is described briefly.

Liquid bulk terminals located in onshore ports and with storage facilities consist of a berthing facility (either a quay or a pier) and a certain number of tanks (see Figure 10). Piers can be I, L or T-shaped and are equipped with mooring dolphins. Onshore port terminals are the most common facilities for handling liquid bulk.

At these types of terminals, once a vessel has moored at the quay or pier, loading and unloading is performed by means of pipes that connect the quay to the storage tanks.

Meanwhile, offshore terminals are made up of single or multiple buoy moorings and a pipeline that runs under the seabed connecting the vessel to the land facilities where the cargo is stored.

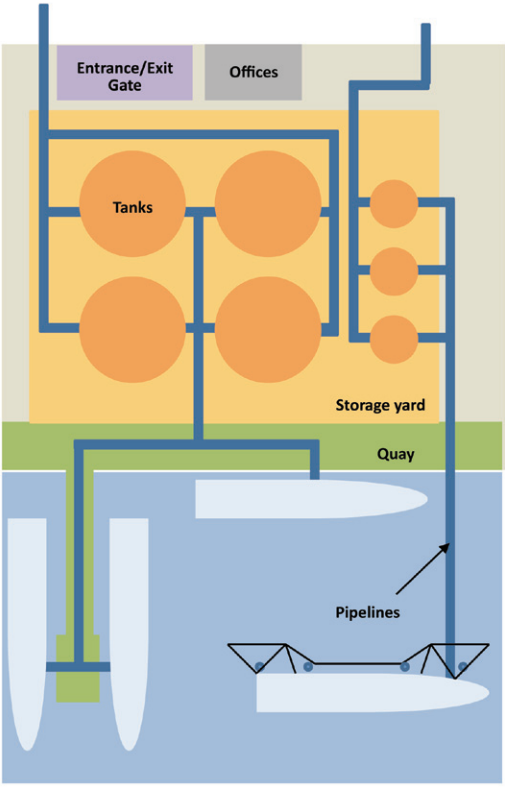
**Figure 9. Offshore terminal with single buoy mooring**


**Source: SBM Offshore N.V.**

Both in the terminals at onshore and offshore ports, cargo is received and delivered by means of a pipeline or by tankers, depending on the amount and the product.

When these terminals are responsible for directly supplying industries and refineries or for loading their products to be distributed, the cargo is stored at destination or origin, respectively. In this case, loading, unloading, transhipment and receipt and delivery operations are performed continuously and using the same means: a pipeline connecting the vessel directly to the industry or refinery.

Figure 10. Example of the layout of a liquid bulk terminal




Source: Fundación Valenciaport

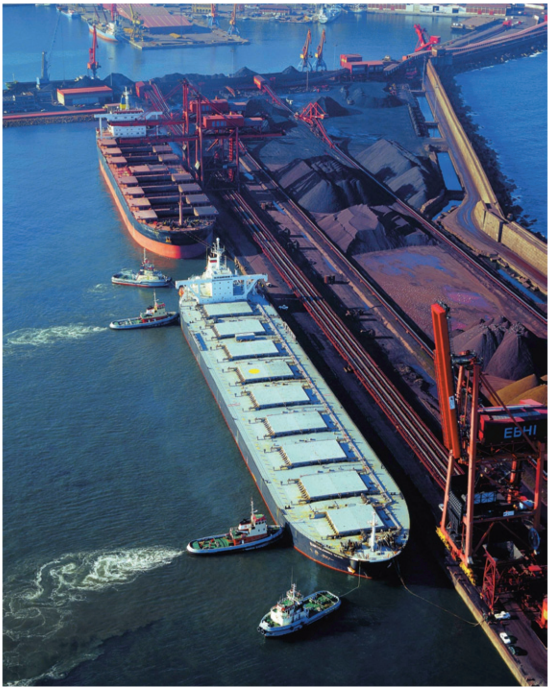
2.2.1.1.2. Dry bulk terminals

The cargo handled by dry bulk terminals mainly includes iron ore, grain, coal, bauxite and phosphates. These products make up a group called main bulk cargo, according to

UNCTAD (1984), while other products, such as metals and minerals for building (coke, cast iron, cement, magnesium mineral and scrap metal) and other agricultural products are grouped under the category of secondary bulk cargo.

Another widely used classification differentiates between dirty bulk and clean bulk. The term clean bulk is related to products intended for human or animal consumption (grain, flour, fodder), whereas dirty bulk is cargo intended for other uses and which normally comes from mining and metallurgy (cement, clinker, coal, iron, etc.). This distinction is important when determining how the cargo is to be stored and handled. The terminal in Figure 5 is a dirty bulk terminal, while the one in Figure 6 is a clean bulk terminal.

**Figure 11. El Musel dry bulk port terminal (Port of Gijón – Spain)**



**Source: European Bulk Handling Installation, S.A. (E.B.H.I., S.A.)**

Figure 12. CHS dry bulk port terminal (Port of Duluth – USA)

Source: Duluth Seaway Port Authority

Loading and unloading operations in dry bulk terminals depend on several factors, such as the nature of the material, the size of the operation, the type of vessel, the weather conditions, the environmental restrictions, the distance between the quay and the storage facility and the type of operation itself, distinguishing between loading or unloading a vessel.

Therefore, apart from the conventional equipment used for performing this type of operation (grab cranes), special continuous ship loading and unloading facilities are employed. Those facilities can be classified as mechanical, pneumatic and hydraulic systems. They can be fixed, mobile or revolving, depending on how they move. When special fixed loading and unloading systems are employed, the vessel must be moved along the quay so that the hold hatch is in the correct position.

As regards loading and unloading operations, there are several alternatives. In the first place, it is possible to distinguish between operations that are performed using equipment located on the quay (the most common practice) and those which are performed using the vessel's own means. In the second place, the loading and unloading process can be continuous or discontinuous, depending on the equipment employed.

The most common systems for unloading bulk vessels are: cranes, pneumatic systems, vertical conveyor belts, bucket elevators, screw conveyors, slurry systems and the self-discharging vessels.

Unloading vessels using cranes is a discontinuous operation. The crane, which is normally on the quay, although it might belong to the vessel, uninterruptedly repeats a cycle whereby it takes the material from the hold of the vessel and drops it directly in the storage area or in a hopper that feeds a conveyor belt or any other type of transfer system. Excavators can be gantry or revolving cranes. As regards the type of bucket used (Figure 13), this depends to a large extent on the type of bulk being handled. Although this system is also used to load vessels, continuous systems are more commonly used for this task.

**Figure 13. Hopper and bucket system in El Musel (Port of Gijón – Spain)**

**Source: European Bulk Handling Installation, S.A. (E.B.H.I., S.A.)**

Pneumatic systems are continuous loading or unloading systems that, depending on how the cargo is driven, are classified as: suction or expulsion. They are used exclusively for light cargo with a low specific gravity and viscosity, such as grain, cement, coal powder and aluminium oxides, among others. These systems can be installed shore-side or aboard a vessel.

Vertical conveyor belts, bucket elevators and screw conveyors are special mechanical devices that extract cargo from the hold of the vessel and deposit it onto a horizontal conveyor belt which takes it to the storage area or in a hopper with buffer systems for direct delivery to trucks or rail.

Hydraulic or slurry systems were invented for the transportation of iron mineral and coal. By mixing their particles with water, these substances can be unloaded using pipes as if it were liquid bulk. This type of operation faces problems later during the mineral decantation stage, as well as environmental problems related to water pollution.

Finally, self-discharging vessels have continuous unloading systems consisting of one or several conveyor belts placed lengthwise in the lowest part of the vessel, where the various holds unload their contents through hatches. These systems increase the price of transport per tonne and make the vessels more prone to mechanical failure. As a result, very few vessels have installed such systems.

Moving on, loading operations in the case of bulk carriers, apart from being carried out by cranes or pneumatic systems (in the same way as unloading operations), can also be performed using special facilities that employ gravity and therefore cannot be used for unloading. These systems, mostly fed by conveyor belts, drop the cargo into the various holds of the vessel.

Nevertheless, in the case of both loading and unloading operations, the quay and the yard are normally connected by conveyor belts or pipelines, which make it possible to move the storage area away from the quay. However, when cranes are used and the storage area is adjacent to the quay, the two are occasionally connected by mobile cranes that move along the quay and load and unload directly from the yard (see Figure 5). On other occasions, special rail cars, cable systems with suspended buckets or all-terrain dump trucks are used.

Another consideration is the energy efficiency of the different systems, as well as the tons per hour capacity that also depend on the density. Reliability and wear is another consideration, which vary a lot. And a last one could be the way to "help" the main system, specially for unloading, with small stacker-reclaimer in the hold when is emptying.

Dry bulk can be stored outdoors, in silos or sheds, depending on the characteristics of the product and how well it withstands the weather, as well as its environmental impact. Normally, products such as iron ore, bauxite, coal, clinker and other minerals are stored outdoors, while, cement, plaster, some mineral , grain and clean bulk are generally stored in silos or sheds.

Silos are differently shaped deposits for storing granular material that must be protected from the inclemency of the weather. In general terms, silos can be vertical or tower silos and horizontal silos. Their shape determines storage and emptying conditions.

Sheds are walled or unwalled warehouses that, as in the case of silos, protect dry bulk from rain.

Outdoor storage is used for cargo that does not decompose easily when exposed to the elements and refers to the creation of either open-air or covered stockpiles. In this case, stock-piling granular cargo must take into account certain environmental criteria. To this end, a series of measures is applied with the intention of avoiding particle propagation, and also some health and safety risks, such as windbreaks or watering the stockpiles. Depending on how close the terminal is to the city, it is frequently necessary to perform storage, loading and unloading operations, together with cargo receipt and delivery (mainly of dirty bulk) under cover (see Figure 14) in order to avoid handling resulting in dust spreading.

**Figure 14. Special bulk unloading facility "Jellyfish" (Port of A Coruña – Spain)**

**Source: Port Authority of A Coruña**

Finally, there are also several alternatives for receipt and delivery operations, although gravity systems are used where possible.

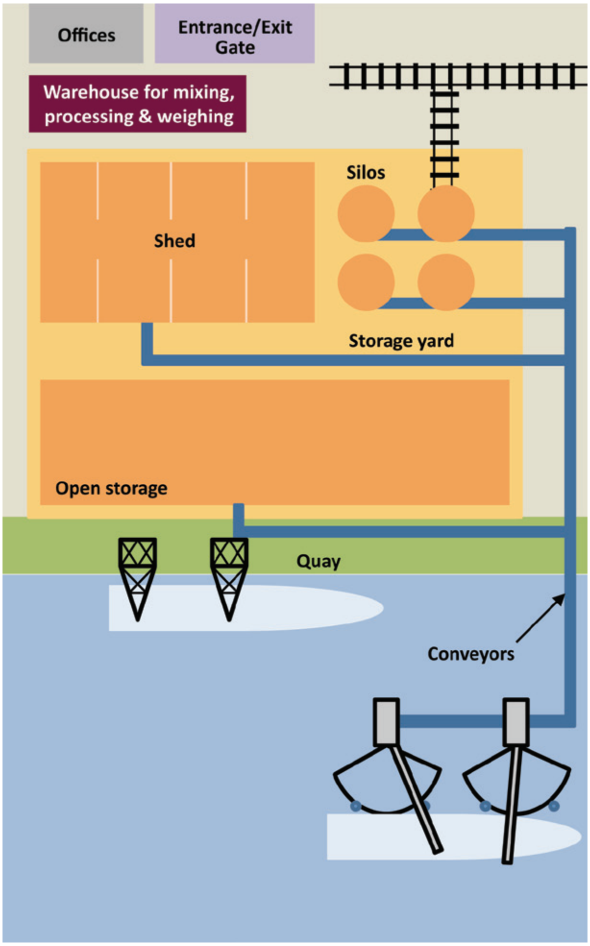
Receiving bulk cargo from trucks is simple, as they are generally dump trucks that can unload directly onto the esplanade or into silos from a raised platform. Trucks sometimes unload at the base of a stockpile, making it necessary to use auxiliary means, usually excavators or bucket loaders, to push the material onto the pile.

Unloading from railway cars is a more complex operation and it can be basically undertaken in four different ways: unloading at the back of the railway car, by circular tilting, lengthwise tilting and pneumatic unloading. The first three methods require cars to be above the stockpile or for there to be a transfer system (conveyor belt) to lift the material once it has been unloaded. The fourth system is similar to the pneumatic unloading system for vessels. There is a fifth system, a "dumper" machine where railway cars hold inside are rotated (one at a time) and then dumped. Dumper hold a car to a section of track and rotate the track and car together to dump out the contents, mainly coal (just USA burns more than 2.5 M tons of coal a day for power generation). It takes around 35 seconds per car in semi-automatic way.

As regards loading operations, trucks or railcars can be placed under the hoppers or vertical silos if the cargo is stored there. When the cargo has been stockpiled on an esplanade, auxiliary means are required to deliver the cargo (excavators or bucket loaders).

Besides the activities that are part of the stevedoring service, dry bulk port terminals also perform cargo mixing, processing and weighing operations before delivery in order to meet certain clients' needs. These operations must also be taken into account when planning the terminal area (see Figure 15).

Figure 15. Example of the layout of a dry bulk terminal




Source: Fundación Valenciaport

### 2.2.1.2. General cargo terminals

General cargo terminals can be classified, according to cargo format and handling procedures, as conventional general cargo terminals, Ro-Ro cargo and Ro-Pax terminals and container terminals.

2.2.1.2.1. Conventional general cargo terminals

General cargo terminals are very old port facilities that were initially designed to move break-bulk. Later on, many of these terminals began to also handle unitised cargo and have become multipurpose terminals (see Section 2.2.1.3). Although terminals exclusively devoted to conventional general cargo have become less important in modern ports (Ligteringen, 2007), they are still necessary and continue operating, particularly in the case of facilities with low traffic levels (see Figure 16).

The layout of these terminals is simple (see example in Figure 17) and they generally do not require large areas, unlike container terminals. The distribution and size of the terminal, as well as the facilities required, depend on the type of cargo the terminal is designed to handle. This type of terminal can have open-air storage together with sheds, silos or warehouses.

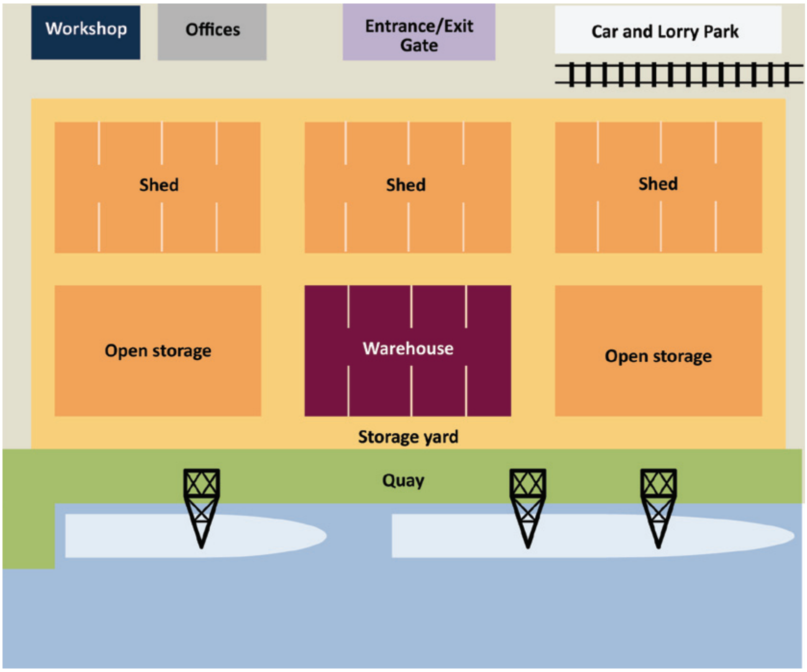
**Figure 16. Marítima Candina general cargo terminal (Port of Bilbao – Spain)**


Source: Image © Eusko Jaurlaritza – Basque Government. © 2011 Tele Atlas. © Google Earth

In addition, the equipment necessary for storage and connecting areas within these terminals depends on the format of the cargo and includes frontloaders, tractor units and platforms or reachstackers. As regards loading and unloading vessels, harbour mobile cranes (HMC's or LHM's) with great elevation capacity (maximum capacity of 140 t, that depends on the working radius) are used.

Conventional general cargo terminals handle a wide variety of cargo: agro-products (wood in logs or sheets, reels of paper…), food products (fruit, sugar, wine, dairy products…), oil derivatives (oils, lubricants…), minerals and derivatives (reels of steel, slabs of steel, iron, cement…), fertilisers (phosphates), chemical products, equipment, etc. These cargoes can come in a variety of forms, including reels, sacks, pallets, pre-slung, individual parts, etc. (see Table 2) and can be handled in a variety of ways.

**Figure 17. Example of the layout of a conventional general cargo terminal**




Source: Fundación Valenciaport

2.2.1.2.2. Ro-Ro cargo and ferry terminals

Depending on the type of cargo handled, Ro-Ro cargo and ferry terminals are classified as Ro-Pax, which deal with passengers and their vehicles and Ro-Ro, which generally handle cargo that can be transported in trailers (without the tractor unit) or which is self-propelled. Occasionally this type of terminals operates fork cargo. Vehicle terminals (Figure 18) are included in the self-propelled cargo category.

The loading and unloading operations in Ro-Ro and ferry terminals are performed using the gangways of the vessel, which can be more than one that are normally located on the bow, the stern, near either, or on one side.

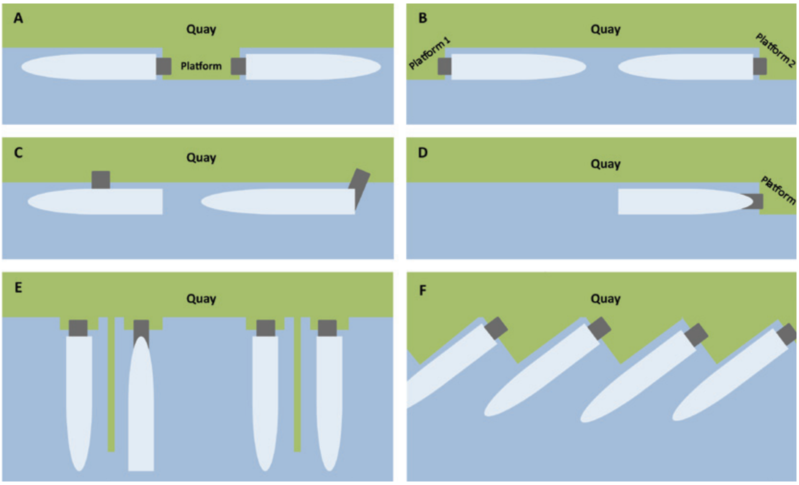
The ramps formed by those gangways when open, which connect the vessel to the quay, must not be too steep to carry out maritime operations safely. For this reason, in ports where the tidal range exceeds 1.5 metres, the vessel ramp is not enough to guarantee that the maximum slope allowed for vehicle entry and exit operations is not surpassed. In some cases, it is needed a shore ramp structure, either fix one or mobile.

**Figure 18. Bergé Carport Sagunto ro-ro terminal for vehicles (Port of Sagunto – Spain)**

Source: **Carport Sagunto S.L. (Grupo Bergé y Cía, S.L.)**

In addition, due to vehicles only being loaded and unloaded on those ramps, the transfer of cargo from the vessel to the quay and vice-versa takes place at specific locations along the berthing facility. In order to load and unload vessels with a gangway on the bow or the stern, the terminal quay must on many occasions have a platform or floating platform to complete the ship-to-shore connection. When a gangway is located on the side of a vessel, any quay is valid, providing it is long enough and free of obstacles (equipment or bollards). Figure 19 shows the possible quay layouts for Ro-Ro and Ro-Pax terminals.

**Figure 19. Quay layouts for a Ro-Ro terminal**



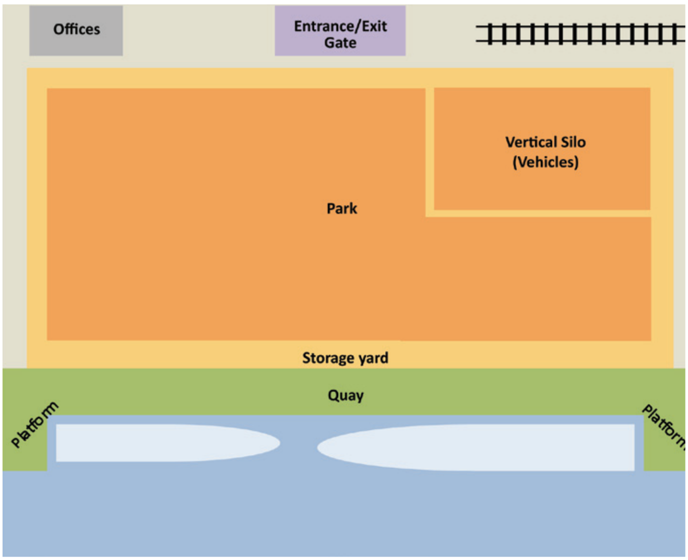

Source: Fundación Valenciaport

In the case of Ro-Ro terminals, it must be differentiated between vessels that transport self-propelled vehicles and those which transport trailers. As regards the former, the vehicles are loaded and unloaded by their own means, while trailers require the terminal to supply auxiliary equipment with the power necessary to move them: tractor units.

The same means are required to connect the yard and the quay in both loading and unloading operations. Self-propelled vehicles, after leaving the ramp, are transferred to the storage yard using their own means. In the case of trailers, terminal tractor units hitch them up and take them to the desired place (aboard the vessel or to the storage yard) where they disengage to be able to go and get the next trailer, thereby completing the cycle.

Layouts in the yard of Ro-Ro terminals depend a lot on the type of traffic. For instance, export cars can be park in blocks just in the same order they have to be loaded, whilst import cars usually have to be park in a way every one can be easily access. Similar issue with platforms and other Ro-Ro units. Furthermore, vertical silos can be placed there for high warehousing, improving capacity per area (see Figure 20). This type of facility also performs added value operations on the vehicle. Area distribution can be diverse, and its size depends on the cargo handled. For example, in some terminals that are used by vessels transporting trucks (tractor unit and trailer), there is no need to storage space either before or after loading and unloading operations. The only indispensable area is a waiting zone for the trucks that are to be loaded onto a vessel. In the case of unloading operations, the trucks leave the port through the terminal entrance/exit gates immediately after disembarking.

Figure 20. Example of the layout of a ro-ro and ferry terminal




Source: Fundación Valenciaport

Finally, receipt and delivery of cargo does not require the terminal to provide its own equipment, except in the case commented in the next paragraph: trucks are ready to enter or leave through the terminal gate, new vehicles are loaded or unloaded from other means of transport (trucks or railcars) using ramps and trailers are moved by external tractor units to the terminal or their final destinations.

Furthermore, Ro-Ro operations can also apply to non "rolling" or fork cargo. In this case, the cargo is loaded and unloaded onto tractor units with chassis or frontloaders (owned by the terminal) and transported from the yard to the vessel and vice-versa. When tractor units and chassis are used for loading and unloading and transfers between the yard and the quay, frontloaders are also required, both on board the vessel and in the yard to transfer the cargo from the deck/hold or the esplanade onto the platforms. Storage, as is the case in multipurpose terminals (see Section 2.2.1.3), depends on the nature of the cargo, its format and its ability to withstand the elements. It can be open-air or in sheds. Finally, receipt and delivery operations for rail and trucks are performed by frontloaders.

As regards **Ro-Pax terminals,** two types of traffic are handled that require separate facilities: one for passengers and another for vehicles. Passengers board and disembark vessels via the fingers of a maritime station, although they can also do so from the quay itself using stairs.

Parallel to this, the vehicles, driven by their owners, enter and leave the vessel using a ramp. This loading and unloading operation requires no storage in the strict sense of the word either before or after the foregoing operations. As a result, only a waiting area is required for the vehicles that are to be loaded onto the vessel. Storage is reduced to summoning the vehicles a few hours before boarding time to organise the loading operation. Once at the port of destination, they leave through the terminal gate as they disembark, without the need for a storage yard. However, it is very important to study the different flows in a terminal of this type: passengers embarking, passengers disembarking, controls (customs, police, etc.), different destinations, luggage embarking and disembarking, ship supplies, crew, buses and taxis areas, etc. Thus, although not extensive areas used, flows are extremely important to avoid mistakes, annoying people, and also for safety and security.

<u>2.2.1.2.3. Container terminals</u>

In container terminals, regardless of the type of cargo, the format is, barring exceptions, the same: containers, as can be observed in Figure 21.

Although there are different types of containers (box, flat rack, cage, half height, high cube, open top, tank-container, reefer, platform, etc.) that may require some special attention, handling operations are generally very similar, which is why they are so fast.

Container terminals can use different types of cranes for loading and unloading cargo from vessels, such as gantry cranes or mobile cranes. The former are specially designed for handling containers, while the latter are multipurpose. Some ports do not have shore quay cranes, and then geared vessels are used in these traffics to serve such ports. Operations with this ship cranes use to be slower and more inefficient, as well as unsafe.

**Figure 21. Noatum Container Terminal Valencia (Port of Valencia – Spain)**

**Source: Fundación Valenciaport**

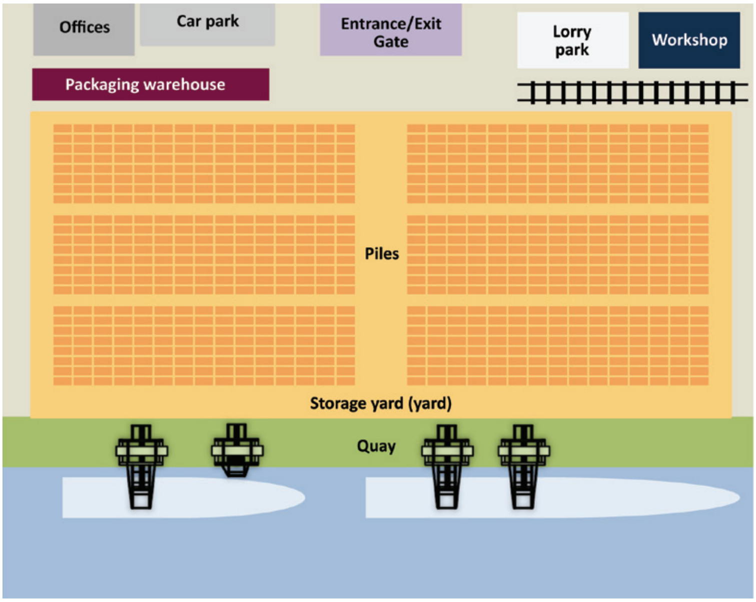
The rest of operations at the terminal, together with the layout of the esplanade or storage yard (total surface area, width and height of container stacks, separation between them, internal roads and aisles, etc.) depend on the handling equipment employed. The most frequently used storage equipment includes: chassis, frontloaders, reachstackers, straddle carriers, RTGs or RMGs (see more details in Chapter 3). Figure 22 shows an example of the layout of a container terminal (that uses RTGs as yard equipment) with its respective infrastructures and facilities.

Furthermore, in a container terminal we must distinguish terminal access, entrance/ exit gate functionalities (number and timetable), from the actual receipt and delivery of containers to stacks or the areas prepared for such operations (for example, rail zones).

Finally, in order to move containers around the different areas of the terminal, a certain type of equipment is used for each of the movements made, which depends at the same time on the choice of yard equipment. The equipments most frequently used for this operation includes: chassis, frontloaders, straddle carriers and AGVs.

Chapter 3 provides a detailed description of the integration of subsystems in a container terminal, together with the type of terminals that exist according to the type of yard equipment they employ and the transfer vehicles used in each case.

Figure 22. Example of the layout of a container terminal




Source: Fundación Valenciaport

### 2.2.1.3. Multipurpose terminals

Generally speaking, growth in traffic has seen port terminals specialise, that is, they handle a specific type of cargo and as a result are equipped with special facilities and equipment to do so. However, there are terminals that handle both containerized and non containerized general cargo. These so-called multipurpose terminals can even handle bulk, albeit infrequent (see Figure 23). Thus, in fact we may say that a multipurpose port terminal can be a combination of several types of the terminals we have already seen.

Multipurpose terminals handle a wide variety of cargo that requires very different operations. The materials moved by multipurpose terminals include: logs, packs of wood, reels of paper, palletised cargo, plates and sheets of steel, cement, phosphates, resins, lubricants, equipment, etc.

These products are presented in a variety of formats ranging from containers to individual units and sacks, boxes, parts, palletised units, heavy loads and pre-slung cargo, which requires the terminal to have versatile handling equipment.

The means employed by multipurpose terminals to solve the ship-to-shore interface depend on the format of the cargo. Generally speaking, these terminals are equipped with mobile cranes that have different engine power and reach to handle cargo of different sizes and weight. Occasionally, cargo is loaded and unloaded using the cranes on the geared vessels. In addition, these terminals normally have a platform for Ro-Ro.

Figure 23. Tisur Multipurpose Terminal (Port of Matarani – Peru)

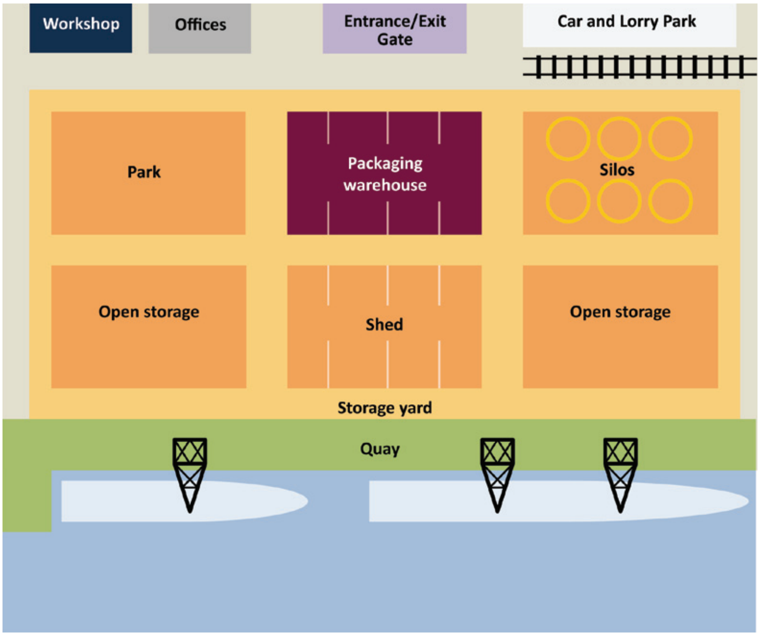
Source: Terminal Internacional del Sur S.A. (TISUR)

Similarly, the equipment used in the transfer subsystem depends on the cargo in question, although these terminals normally have frontloaders to cover the distance between the quay and the yard. For distances greater than 100 metres, they normally use a combination of frontloaders and trucks (tractor unit with chassis).

Storage, depending on the nature of the cargo, cargo format and its ability to withstand the elements, can be open-air, in sheds, or even in silos if we are talking about bulk, as can be observed in Figure 23. In addition, some multipurpose terminals have a packaging warehouse inside the storage yard where cargo is prepared for transportation and delivery to the client.

Finally, where receipt and delivery operations are concerned, these terminals employ auxiliary equipment (such as frontloaders) to transfer cargo from the storage yard to external vehicles. In order to do so, external trucks have access to the storage yard or the area designated for receipt and delivery operations, while in the case of rail transport, this operation is performed next to the tracks. Figure 24 shows an example of the layout of a multipurpose terminal.

Figure 24. Example of the layout of a multipurpose terminal




Source: Fundación Valenciaport

## 2.2.2. Terminals by type of traffic

When considering the type of traffic they handle, terminals can be classified in two different ways: according to the origin and destination of cargo (gateway terminals or transhipment terminals) and according to the number of clients (shipping lines) they serve, distinguishing between public and dedicated terminals.

### 2.2.2.1. Terminals according to origin and destination of maritime traffic

Depending on the primary origin and destination of the cargo handled by each terminal, they can be classified as gateway or transhipment terminals.

In gateway terminals, most of the maritime traffic is bound for or comes from the port hinterland, which implies a significant outward and inward flow of cargo through the terminal gate.

Furthermore, a terminal might be mainly (or exclusively) devoted to imports or exports (for example, some bulk terminals or container terminals in China are basically export terminals).

The cargo handled in a terminal that is mainly devoted to transhipment comes from and is bound for the port foreland, entering and leaving the port by sea, so no modal interchange taking place in the terminal.

Transhipment terminals normally record higher rates of productivity and higher unit capacity than the import/export ones, both in terms of the berthing facility and also storage, due to having very little or no land receipt or delivery activity, which reduces internal traffic in the terminal, enhances efficiency and reduces the amount of yard equipment required. Moreover, yard management is simpler because there are less types of storage areas. All the above makes organising operations easier.

Another factor that boosts the productivity of transhipment terminals in regard to import and export terminals is that usually more cargo is loaded and unloaded per call at port, particularly in the case of container terminals, which results in longer periods of uninterrupted operations. Furthermore, productivity is also higher in transhipment container terminals due to stowage issues that allows massive movements and the possibility of using spreaders with twin-lifts (if the terminal has this equipment).

#### 2.2.2.2. Terminals according to the clients they serve

Depending on the clients they serve, terminals can be classified as common-user or dedicated terminals.

Common-user terminals serve vessels from any shipping line, that is, they are not dedicated to one shipping line exclusively, whereas dedicated terminals only operate with vessels that belong to the company that manages the terminal. Dedicated terminals can be considered the result of shipping line vertical integration.

Dedicated terminals are normally easier to manage, as information flows are generally less complex, vessel arrivals are better controlled and yard management is simplified due to dealing with only one client.

The criteria at management and planning operations in dedicated vs. common-user terminals can be very different. Dedicated terminals may act more based on shipping line needs or demands, whilst common-user terminals have to care on many clients, as well as their own interests and also port demands.

*El que espera, desespera*

(Who is waiting becomes desperated)

***Spanish proverb***


*El patio de mi casa es particular*

(The courtyard of my house is particular)

***Popular Spanish children's song***

03

# Container Terminals

Since emerging at the end of the 1950s, container cargo has grown continuously and significantly due to the great advantages it offers. In this sense, container terminals have certain features that give them the capacity to achieve a much higher degree of systemisation than other types of cargo terminals (Monfort *et al.*, 2001). Such features include:

- Standardisation of a transport format, the container.
- Standardisation of the way cargo is handled.
- Extremely high level of interchanges made.
- Enormous impact of technology on terminal profitability.

Standardisation of containers as a transport format has been accompanied by the specialisation and increase in the size of vessels, due to shipping lines aiming to take full advantage of economies of scale, but mainly due to the need to cope with the huge growth of the demand (world cargo traffic growth). For that reason, handling equipment has also become specialised in order to meet the increasingly large amounts of traffic as quickly and efficiently as possible.

03

As a result of the above, container terminal operations compared to the handling of other general cargo, are cheaper, faster and therefore reduce the length of calls at port, thereby enhancing vessel productivity. In addition, this reduces the risk of breakdowns, theft and cargo losses.

This chapter presents port container terminals according to the yard equipment they utilise. Similarly, operations are described, on the one hand by detailing the integration of subsystems and on the other by presenting the transfer vehicles used to connect the subsystems according to the yard equipment used.

## 3.1. Types of container terminals according to yard equipment

Calculating the area necessary to accommodate expected traffic or the yard storage capacity of an operative terminal, as explained in Section 5.4.2.3, depends on ground slots density, the stacking height of containers and dwell time containers stay in the terminal. The first two factors depend above all on the type of equipment used for yard storage operations, although operation planning and management also influence capacity.

The choice of the yard equipment determines the configuration of the yard: width and height of container stacks, the space separating them and the size of internal roads, as can be observed in Figure 39. For this reason, the aspect that characterises the type of terminal is the equipment used for storage operations, which yields the following classification, ranked from the lowest to highest ground slots density and which is described in more detail in the succeeding sections:

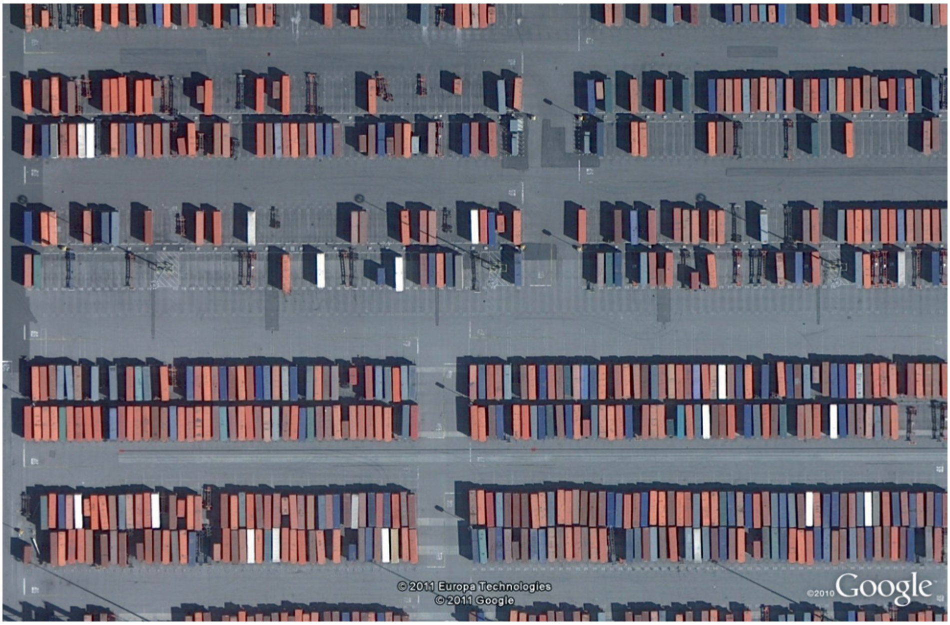
- Chassis
- Frontloaders
- Reachstackers
- Straddle Carriers
- RTGs
- RMGs

### 3.1.1. Chassis

In terminals that use chassis as yard stacking (parking in this case) equipment, containers are stored on the chassis set up in the same way as a truck park (see Figure 25). In addition, when towed by a tractor unit, the chassis are also used as a means to connect the storage yard and the quay.

In these terminals, ship-to-shore cranes unload the containers directly from the vessel onto a chassis. A tractor unit tows the loaded chassis to the yard in order to park it and then goes to a parking area for empty chassis, where it hitches up another and takes it to the foot of the ship-to-shore crane, thereby completing the cycle.

**Figure 25. California United Terminal (Port of Long Beach – USA)**




**Source: © 2011 Europa Technologies. © 2011 Google**

Yard chassis are special trailers and cannot circulate outside the terminal. Furthermore, they are owned by the terminal, not the overland transport companies. For this reason, it is necessary to move containers from external trucks to terminal chassis and vice-versa, for which purpose frontloaders are normally used.

This system uses up a large space because containers cannot be stacked high, wide roads are required to allow space to park loaded chassis and an area for storing empty chassis is also necessary. As a result, ground slots density (TEU/ha) is reduced considerably (see Figure 25). However, and despite the low level of technology required, immobilised chassis in the yard increase the costs of storage considerably.

This system has traditionally been used in ports with a large space or where the cost of land is low. This equipment was the most frequently used in port terminals in the United States, but due to the reasons stated previously, among others, this system is currently losing ground to others. In fact, some chassis terminals are changing or have already changed their yard equipment by other systems.

### 3.1.2. Frontloaders

Frontloaders are yard equipment capable of moving and lifting containers to stack them. Due to how enormously flexible they are, their lift capacity and mobility, they can be used as yard equipment, for transfers, for stacking empty containers, in receipt and delivery operations and as back-up, this is, they are very versatile.

Unloading operations in a terminal that uses frontloaders as yard equipment consist of the ship-to-shore crane depositing the containers on the quay and frontloaders picking them up, transporting them to the storage yard and stacking them. The loading operation is the same, but in reverse order. Eventually, and depending on the distance to run or the ship to shore system demand, also terminal tractors can be used for the horizontal move, and in this case frontloaders. Apart from performing transfers and stacking containers, frontloaders are also responsible for the receipt and delivery and loading and unloading of containers from trucks or railcars.

There are several types of frontloaders that can be used in a port container terminal: frontloaders and their evolution into frontloaders with forks (forklifts), spreaders or semi-spreaders, reachstackers and even straddle carriers, which some authors consider to be a type of gantry crane. Both reachstackers and straddle carriers result in different terminal layouts, stacking densities and operations to those of basic frontloaders. For this reason, it is considered necessary to address them separately (see following sections). Moreover, the original forklift, etymologically, comes from the fork that a frontloader machine used to take the cargo and lift it up, displace it, and then lower it down into the stacking place. In the case of the containers, only 20' are allowed and prepared to be handled with the forks, only when empty. But 40' have always to be handled by the top corner castings, and more specifically using spreaders to avoid horizontal tensions that may damage the container.

Depending on how they hold the containers, frontloaders can be front-loading (if they pick up the container from the front or side using a spreader or semi-spreader), top-loading (if they pick them up from above) or fork loaders (through the forklift pockets of the 20' container) as can be observed in Table 3.

Some frontloaders cannot be used with full containers for reasons owing to mechanical stability problems or because the hitching system could damage the structure of the container. Empty container frontloaders have a greater reach in terms of height, less load capacity and are lighter and faster.

This equipment provides low levels of land use because the piles of full containers are narrow, low and there must be considerable space between them: full containers are stacked two or three high and normally two wide so that all containers are accessible.

For those reasons, only small terminals that handle little traffic use frontloaders as their only yard equipment. Top-loading frontloaders for full containers are being replaced by other equipment that is more stable and has greater load capacity and reach, such as reachstackers.

Generally speaking, all terminals use frontloaders as back-up for operations or for empty containers. In the case of empty containers, stacks can be more than two containers wide because accessibility is not as important. Stacks can be nine containers high, depending on the equipment, although the normal working height is between 5 and 7. Stacking containers too high results in problems related to stability, operation safety and operator visibility. The risk of a single container sliding, or the tilting of a whole row of containers is high at even low wind pressure, and risk increases with the height.

### 3.1.3. Reachstackers (RSs)

Reachstackers (RSs), created by Belotti in 1976, are very versatile machines that can be used both for yard storage operations and terminal transfers, for the receipt and delivery of trucks and railcars, or as back-up for the rest of equipment.

This equipment stems from the specialisation of frontloaders and incorporates a sloping telescopic boom that holds a spreader (see Figure 26). In comparison to traditional frontloaders, reachstackers have greater access to stacked containers, greater stability and are more versatile. Reachstackers can reach containers located in the second row of a stockpile, providing they are at least one height above the containers in the first row, and in the case of empty containers, those located in the third row, if they are one or more heights above those in the second row.

Liebherr has designed and manufactured a reachstacker with a curve-shaped telescopic boom that further improves access to containers in the second and third rows, thereby reducing container shuffling (see Figure 26).

**Figure 26. Examples of reachstackers**

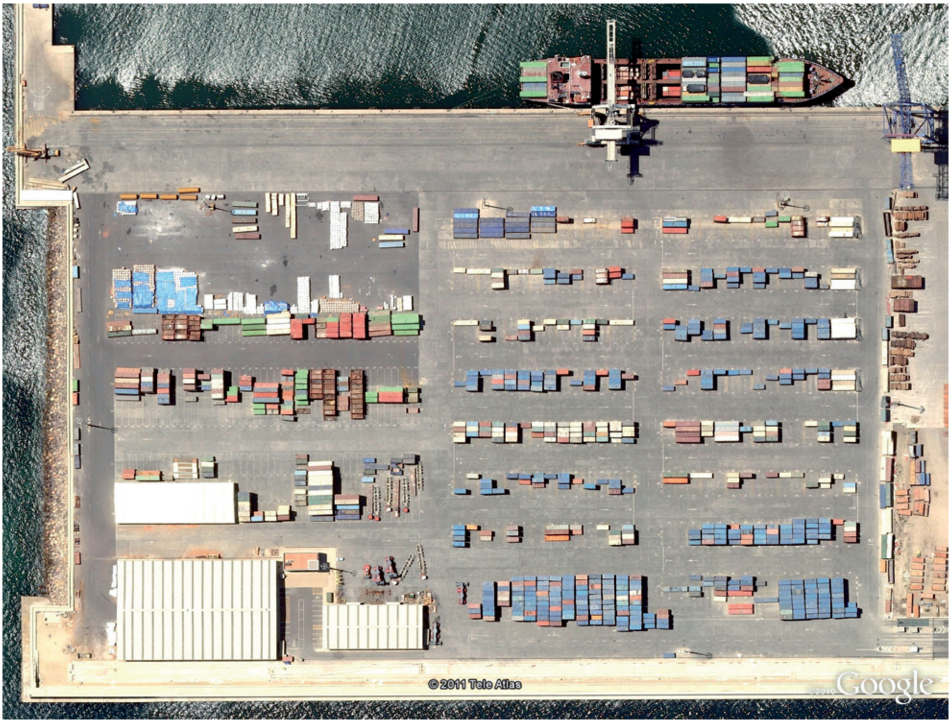

**Source: Fundación Valenciaport** **Source: Liebherr-Werk Nenzing GmbH**

In terminals that use reachstackers as storage yard equipment, the stacks of full containers are normally three or four containers wide (see Figure 27). However, the ground slot density (TEU/ha) of these terminals is still rather low, despite stack width being double that of terminals that use frontloaders.

Unloading operations in a terminal that uses reachstackers are similar to those performed in terminals that employ frontloaders.

In small terminals, reachstackers are used as storage equipment, to transport containers from the quay to the yard and vice-versa and for all other transfers. They are also used for the receipt and delivery of containers to both trucks and railcars in terminals of all sizes. Likewise, large terminals use them as back-up equipment.

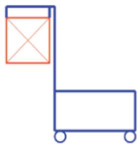
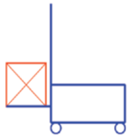
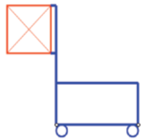
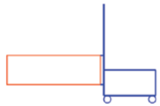
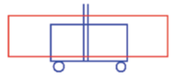
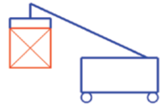
Figure 27. Terminal P. Castellón (Port of Castellón – Spain)




Source: © 2011 Tele Atlas. Google Earth

Table 3 summarises the various types of container frontloaders on the market, considering the reachstackers as a specialised one. All these options result in different yard layouts.

Table 3. Types of Frontloaders

| FORKLIFT WITH SPREADER | FORK LOADER | FRONTLOADER WITH SIDE COUPLING AND SEMISPREADER | FRONTLOADER WITH FRONT COUPLING | SIDELOADER | REACHSTACKER |
|---|---|---|---|---|---|
|  |  |  |  |  |  |
|  Source: Svetruck AB |  Source: Konecranes Ausio SLU |  Source: Fundación Valenciaport |  Source: Fundación Valenciaport |  Source: Fantuzzi Noell Iberia SLU |  Fuente: Fundación Valenciaport |

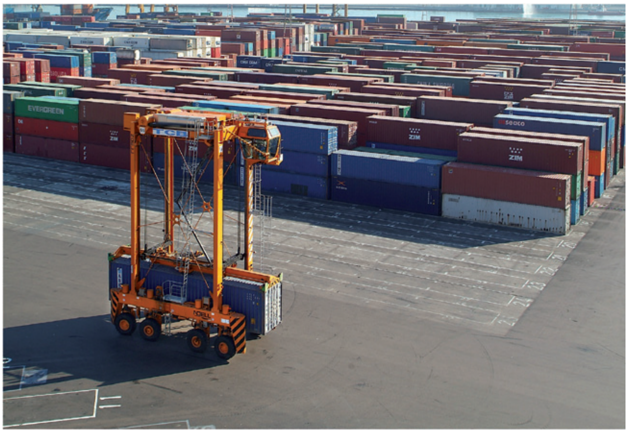
Source: Monfort *et al.* (2011a)

### 3.1.4. Straddle Carriers (SCs)

Straddle carriers (SCs), created by Belotti in 1969, are gantry cranes that pick up containers between their legs and straddle them parallel to the direction they are moving. They can lift containers to various heights (1, 2 or 3) (see Figure 28).

These machines are highly flexible and can perform all the movements necessary to move containers around the terminal store them and receive and deliver them to external trucks. They can even be used to load and unload railcars, although they are not the most suitable equipment for that operation.

**Figure 28. Straddle carrier and storage yard**



**Source: Fantuzzi Noell Iberia SLU**    **Source: Konecranes Ausio SLU**

As in the case of reachstackers, when unloading a vessel, the ship-to-shore crane deposits the container on the quay and the straddle carrier picks it up and takes it to a stack. Land receipt and delivery operations are carried out in an area of the terminal between the terminal entrance/exit gate and the yard where external trucks park. The SCs move the containers from the yard to that area and vice-versa.

Generally speaking, although the stacks created by SCs can be up to 4 containers high (4+1), the average working height of a stack for terminals that use these machines is between 1.5 and 2 containers high (see Figure 28). Stacks are one container wide. There is a 1.5 to 2.0 metre aisle (minimum 1.2 m) between stacks to leave space for the legs of the straddle carriers. Stacks are generally perpendicular to the quay in order to gain productivity and make better use of the space, although this does entail a greater risk of vehicles colliding. For this reason, some terminals have decided to organise the rows of containers parallel to the quay, generating a circular flow that avoids SC route crossovers. However, this system results in the machines having to cover greater distances.

This system makes better use of the space, obtaining greater stack density than chassis, frontloaders or reachstackers. Furthermore, containers are easily reachable and little shuffling is required. It is an ideal system for medium-sized terminals that handle between 100,000 and 400,000 containers a year and which do not need to use the land available intensively.

The main advantages of straddle carriers over the rest of yard equipment are their operational flexibility and speed, as well as less labour demand, while the main drawbacks are stack height restriction and higher maintenance costs.

Shuttle Carriers (ShCs) are similar to straddle carriers, but smaller in size and height 1+1. These machines can be used to lift containers high enough to pass over another container, but cannot be used as storage equipment. However, it is an agile and fast means of connecting the quay and the yard. Using these machines for transfers has the huge advantage that both ship-to-shore cranes and yard equipment can operate without having to wait for internal transport, thereby decoupling subsystem operations (more information on decoupling in Section 3.2).

### 3.1.5. Rubber Tyred Gantry cranes (RTGs)

Rubber Tyred Gantry Cranes (RTGs) are self-propelled cranes that follow straight-line routes over stacks of containers that the machines themselves form between their legs.

RTGs normally form stacks that are between 3 and 5 containers high and 6 or 7 rows wide, plus an additional lane for external and internal trucks (see Figure 29). In order to receive or deliver a container, trucks use that lane, parking next to the stack and waiting for the RTG to perform the loading operation.

In order to unload a vessel, the ship-to-shore crane unloads the container onto a chassis (or another transfer vehicle), which then transports it to the storage stack. Once there, the RTG picks up the container and stacks it. The chassis is then free to get another container from the quay. The vessel loading operation is the same but in reverse order.

The terminals that use RTGs as storage equipment usually employ tractor units and chassis for transfers between, for example, the quay and the yard, although reachstackers and other types of frontloaders can also be used (see Section 3.2).

**Figure 29. RTG yard. Noatum Container Terminal Valencia (Port of Valencia – Spain)**


Source: Fundación Valenciaport

In the yard of a terminal that uses RTGs, the stacks formed by those equipments are normally parallel to the quay and separated by sufficient distance to allow transfer vehicles to pass. These stacks of containers are interrupted after a certain interval of space to give way to roads that allow traffic to circulate perpendicular to the stacks of containers.

This system obtains high stacking density, which increases as the size of the stack grows, as can be observed in Table 30. Although the normal size of stacks is that mentioned previously, some ports in Asia stack containers much higher, up to 1 over 7 containers high and 13+1 containers wide, resulting in much higher stacking densities, similar to those recorded by RMGs, as it is shown in Section 5.4.2.3.

At present, large terminals that are not considering automation usually choose SCs or RTGs as yard equipment, as both provide similar performance, each with advantages and disadvantages in regard to the other (see Table 4).

### 3.1.6. Rail Mounted Gantry cranes (RMGs)

Rail Mounted Gantry cranes (RMGs) are similar to RTGs but RMGs travel on rails to move and are generally larger. Apart from port terminals, this system is also used in many inland (dry ports) and rail terminals.

Ship-to-shore operations are carried in the same way as with RTGs, except in the case of automatic gantries (ASCs), as explained later.

Like RTGs, RMGs also normally serve external trucks at the container stack for receipt and delivery operations. In this case, vehicles circulate on roads that normally run outside the legs of the RMG. As a result, RMGs have an overhanging cantilever to be able to position the spreader over the trucks.

RMG yard stacks are between 8 and 12 containers wide, or even wider, and 4 or 5 containers high. Due to that size of the blocks, one of the main advantages of RMGs is that they make a very extensive use of the yard area.

RMGs are usually used in terminals with a great deal of traffic and little space. They are also used in terminals with significant rail traffic. Furthermore, due to moving on rails, they have less freedom of movement than RTGs and are easier to automate. For this reason, automated terminals normally use this system in their storage yards.

The disadvantages of RMGs include their weight, which requires infrastructure with reinforced foundations, the lack of flexibility due to being mounted on rails and the difficulty involved in shuffling containers if there is a high level of occupation. Furthermore, if there are two or more gantries working on the same stack, they cannot normally cross, which makes operations difficult when receipts and deliveries involving external trucks and vessel loading and unloading operations occur simultaneously, or when one RMG breaks down. This problem has been solved by implementing Double Rail Mounted Gantry Cranes (DRMGs), where one gantry is smaller than another, allowing it to pass underneath. However, this solution increases system installation costs and reduces stacking density.

### 3.1.7. Automated Terminals

Most of the terminals that have implemented automation solutions in their storage yards use rail mounted Automated Stacking Cranes (ASCs) or automated RMGs. These machines operate without a driver in the machine itself and are similar in size to an RTG, between 6 and 10 containers wide and 4 or 5 plus one, high (see Figure 30).

When terminals use ASCs, container transfers between the quay and the yard can be performed automatically by Automated Guided Vehicles (AGVs), although they can also opt for machines with operators such as tractor units with chassis or shuttle carriers.

In contrast, truck receipt and delivery operations are semiautomatic and conducted outside the yard: the trucks park at the head of a stack, in an area separated by a fence. The gantry carries out the operation automatically, except for the last few metres which for safety reasons are supervised by an operator in a tower using a remote control and the cameras installed for that purpose.

Figure 30. Automated RMGs (ASCs). APM Terminals Virginia (Port of Virginia – USA)

Source: Konecranes Ausio SLU

Another system of automatic gantry cranes are the so-called Overhead Bridge Cranes (OHBCs). There is only one functioning in the world, in Pasir Panjang at Singapore since the mid 1990s, but no other terminal has opted to use it. These are concrete gantries that have rails mounted on top for bridge cranes to circulate. The concept is similar to that of the bridge cranes used on industrial premises, although operations are carried out in similar fashion to automatic RMGs.

The main advantage of OHBCs is that they can work with much larger stacks than the rest of equipments, resulting in very high stacking densities. Furthermore, the fact that the structure is rigid makes it a lot easier to automate. The disadvantages of this system include the larger investments required in civil engineering works, the need for much container shuffling.

Table 4 presents a qualitative summary of the characteristics of the container terminal yard equipment described in this section.

Table 4. Description of terminal operations by type of yard equipment used

| | Chassis | Frontloaders | Reachstackers | Straddle Carriers | RTGs | RMGs |
|---|---|---|---|---|---|---|
| **Stacking height** | 1 | 3 (full)<br>6-9 (empty) | 2-3 | 2-4 | 3-7 | 4-7 |
| **Stack width** | N/A | 4 (full)<br>Very high when empties | 1 | 6 (7) | 6 | 8-12 |
| **Area density** | Very low | Very low | High | Medium | High | Very high |
| **Surfacing requirements** | Very low | Very low | Medium | High | High | Very high (rails) |
| **Cost of purchase** | High | Low | High | High | High | Very high |
| **Maintenance cost** | Low | Medium | High | High | High | High |
| **Average service life in years** | 5 | 6-7 | 7-8 | 10 | 10 | 20 |
| **Possibility of automation** | Very low | Very low | Low | Medium | High | Very high |
| **Personnel costs** | Low | Medium | Medium | High | High | Very low |
| **Personnel training** | Low | Low | High | High | High | Low |
| **Container integrity** | High | Low | Low | Medium | Medium | High |
| **Operational flexibility** | High | High | High | Medium | Medium | Low |
| **Enlargement simplicity** | High | High | High | Medium | Medium | Low |
| **Layout change simplicity** | High | High | High | Low | Low | Very low |
| **Energy efficiency** | Low | Low | Low | Medium | Medium | High |
| |  |  |  |  |  |  |

Source: adapted from Monfort *et al.* (2011a)

## 3.2. Description of operations

Container terminals often operate in conditions that on many occasions exceed the parameters they were designed for. Such parameters include annual throughput, container dwell time in the yard, instant occupation or stacking density. As a result, conditions can be defined as design or normal operating conditions or conditions for cases of high occupation.

Clients occasionally impose service conditions regarding call productivity, average number of cranes per vessel, dwell time of containers in the terminal or even performing mass operations involving the loading or unloading of empty containers, which may or may not be drawn out and alter the normal conditions. By way of example, it may be necessary to back up ship-to-shore operations with mobile cranes, increase stacking density either by raising the average height of blocks or by using roads or areas outside the yard for storage. Sometimes, giving preference to maritime operations can result in yard equipment delaying receipt and delivery operations, resulting in queues of external trucks.

As regards the management of yard operations, it can be considered to be two contrasting interests: how easy the operation is on the one hand, and how much it costs on the other. Therefore, working with low occupation densities, low stacks of containers and wide roads implies easy access to containers and that little container shuffling is required, internal circulation is simple and the yard can be divided into many areas, which facilitates loading operations above all and the possibility of serving several vessels simultaneously. However, cost of land encourages terminals to work with high stacking densities. Moreover, this reduces the distances that must be covered by both the yard equipments and transfer vehicles and consequently their consumption. The terminal seeks to strike a balance between these two interests when planning its management strategy.

Similarly, other issues also affect operations and accordingly, the capacity of a terminal. In this sense, despite container standardisation, a certain percentage of containers require special handling, which negatively affects equipment productivity and storage conditions and generally reduces the capacity of the terminal storage yard. By way of example, reefer containers must be plugged to power supply in order to maintain their temperature while in the yard. Terminals have an area with connections to mains for this type of containers. Furthermore, the position of those connections restricts the maximum height of reefer stacks. Other cases include oversized containers for dangerous goods and open top containers that must take up a particular place in container stacks.

**Subsystem Integration**

In container terminals, all machines complete cycles continuously. Furthermore, those cycles interact with others (Figure 31). When dimensioning the terminal, one must calculate the number of each type of equipment required for operations to be optimum, seeking equilibrium of interests between productivity and costs. In general, ship-to-shore cranes are considered the restricting resource, that which sets the pace for the rest, due to being the most expensive equipment. The rest of machines must be assigned so that the ship-to-shore crane does not have to wait for internal transport to remove or supply containers, but without having too many transfer or yard vehicles in order to maintain costs at an acceptable level. A problem arises when labour cost is too expensive, as it is the case of Spain, USA and many EU countries. In this case, keeping busy the STS gantry crane may be too expensive, and productivity is limited.

The role of ship-to-shore cranes is to load and unload containers from vessels and internal trucks (or from the transfer vehicles the terminal uses). The work cycle will be continuous if there are enough transfer vehicles to move the containers that have been unloaded to the storage yard and to take the containers to be loaded to the quay.

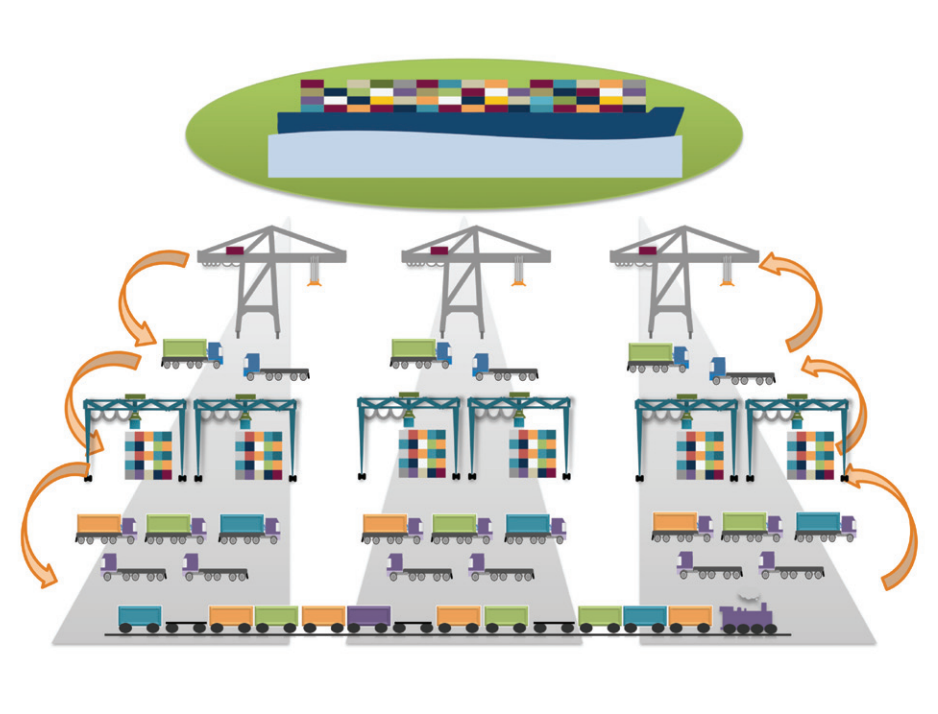
As regards the loop of the transfer vehicles (trucks, SCs, AGVs or others), an unloading operation consists of waiting for the ship-to-shore crane to unload a container, taking it to the yard and waiting there for a yard machine to pick up the container and place it on a stack and finally, returning to the quay. In order to load containers, transfer vehicles wait at a stack for the container to be loaded, transport it to the quay where they wait for a crane to pick up the container and then return to the yard to repeat the process. Transfer vehicle cycles are directly linked to those of ship-to-shore cranes on the one hand and those of yard cranes on the other.

In some cases, operations are performed continuously and the relationship between subsystems is even more evident. For example, in an unloading operation at a terminal that uses frontloaders, reachstackers or SCs as yard equipment, these machines act as transfer vehicles between the quay and the storage yard, as well as being responsible for stacking the container.

Finally, in terminals that use gantry cranes in their storage yards, their activity consists of loading or unloading containers from transfer vehicles and external trucks, stacking them and carrying out housekeeping tasks, involving container shuffling intended mainly to facilitate future ship-to-shore operations.

As a result of these operations, ship-to-shore and yard crane cycles are indirectly related. If there are not enough yard machines, transfer vehicles will not be served sufficiently quickly and consequently, the ship-to-shore crane will have to wait. So, if plan a call, and the preference is vessel productivity (STS), we have to dispose the rest of equipment and labour resources to pace with the above, whilst keeping costs in an acceptable range.

**Figure 31. Relationships between equipments (ship-to shore cranes, internal and external trucks and RTGs)**



Source: Fundación Valenciaport

Terminals have attempted to solve the direct dependence of both ship-to-shore and yard cranes on transfer vehicles. This is known as decoupling. In a decoupled system, ship-to-shore cranes and yard cranes pick up and drop the containers onto the ground, a high platform (made of metallic beams) or a cassette without having to wait for transfer vehicles to arrive.

Decoupling can be total or partial, applied to manual or automatic vehicles and may need the back-up of auxiliary equipment (see Table 5).

**Table 5. Decoupling in the transfer system**

| | Automatic | Manual |
|---|---|---|
| **Decoupling** | AGV-Lift | SC; Shuttle carrier |
| **Decoupling with auxiliary equipment** | AGV-Cassette | T+C with cassette |

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

## Transfer Vehicles

Containers must be moved several times in a port terminal. They are loaded or unloaded from a vessel, transported from the yard to the quay or vice-versa, shifted within the yard and also for receipt or delivery operations. The transfer subsystem is responsible for transporting containers within the terminal, taking into account the requirements of the rest of subsystems in terms of speed, reliability and safety.

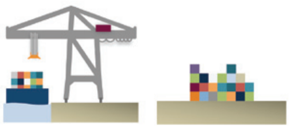
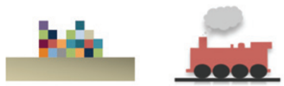
The type of yard equipment determines the type of vehicles used for each of the transfers to be performed:

- Transfer of containers between the quay and the yard;
- Transfer of containers between the yard and the truck receipt and delivery area;
- Transfer of containers between the yard and the railway cars; and
- Other movements, such as positioning for inspection.

Table 6 provides a summary of the transfer vehicles used according to the yard equipment employed for each movement.

Generally speaking, the yard machines themselves are responsible for any shifting of containers within the yard itself, although they occasionally require back-up from other means, including frontloaders or even internal trucks, as is the case with housekeeping tasks, which can entail moving containers from one stack to another.

Table 6. Equipment for transfers between the various subsystems according to yard equipment

| YARD EQUIPMENT |  Quay ⟷ Yard |  Yard ⟷ Truck R/D |  Yard ⟷ Truck R/D | OTHER MOVEMENTS |
|---|---|---|---|---|
| **FRONTLOADERS** | T+C or Frontloaders | Frontloaders | Frontloaders | Frontloaders and/ or T+C |
| **SCs** | SC | SC | Frontloaders | SC or Frontloaders |
| **RTG** | T+C | RTG | RTG and T+C with Frontloaders or RTG/RMG on railramp | Frontloaders or T+C |
| **RMG** | T+C or Shuttle carrier | RMG | RMG with T+C or T+C with Front-loaders or RTG/RMG on railramp | Frontloaders and/ or T+C |
| **ASC** | AGV or Shuttle carrier or T+C | ASC | ASC and ShC or T+C with Front-loaders or RTG/RMG on railramp | Frontloaders |

**T+C: Tractor unit and chassis**
**R/D: Receipt and delivery subsystem**
**Source: Monfort *et al.* (2011a)**

**Measurement is the first step that leads to control and eventually to improvement .If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it.**

**H. James Harrington, engineer**

# 04

# Measuring port performance, efficiency, capacity and level of service

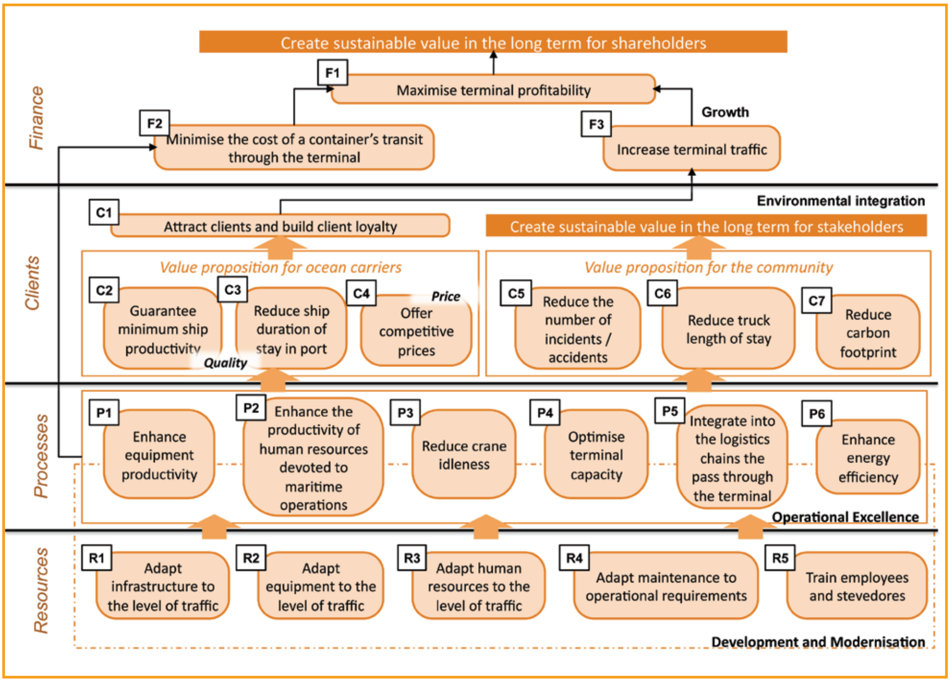
## 4.1. Measuring performance in ports

Key Performance Indicators are quantifiable measurements, agreed to beforehand, that reflect the critical success factors of an organization. They will differ depending on the organization (About.com Management). In a case of ports or port terminals, the management must plan and implement an integrated and integral **system of indicators** that is capable of portraying the activities of the facility as a whole and its resources. The usual way of going about this is to design a **system of indicators** that monitors operations, permits comparison with other facilities and informs the various stakeholders related to the port.

Both in the case of a port and a port system such as a port terminal, the best approach is to define and develop the aforementioned system by deploying a **strategic map** (Figure 32), a **Balanced Scorecard tool** that helps to portray the strategy of the company in terms of objectives, the achievement of which is measured by such indicators in a recurring process of setting in motion different initiatives or projects (Estrada, 2007; Martín, 2010; Monfort *et al*., 2011b).

04

Figure 32. Proposal for strategic map for a container terminal




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

The indicators mentioned above are part of the general area that is concerned with the measurement of **port performance**. Indicators have been classified and analysed for decades (UNCTAD, 1976, 1983 and 1987; De Monie, 1988, etc.) and over the last few years have developed a broader view of the concept of a port within the logistics chain (Bichou, 2004; De Langen *et al*., 2007; ESPO, 2011).

In this sense, UNCTAD (1976) divided port performance indicators into two groups (Table 7): financial and operating indicators, describing the utilisation of port resources, the former in monetary terms (except in the case of "tonnes handled" or t) and the latter in units of output (t, gangs, etc.) and time (hours, days or work shifts, etc.), in several cases in relation to the vessel.

**Table 7. Operative and financial indicators**

| Category | Type of Indicator | Unit |
|---|---|---|
| **Financial** | Tonnes handled | t |
| | Berth occupancy income per tonne of cargo | Monetary Ut/t |
| | Cargo-handling income per tonne of cargo | Monetary Ut/t |
| | Labour expenditure per tonne of cargo | Monetary Ut/t |
| | Capital equipment expenditure per tonne of cargo | Monetary Ut/t |
| | Contribution per tonne of cargo | Monetary Ut/t |
| | Total contribution | Monetary Ut |
| Operating | Arrival rate | Vessels/day |
| | Waiting time | Hours/vessel |
| | Service time | Hours/vessel |
| | Turn-round time | Hours/vessel |
| | Tonnes handled per vessel | t/vessel |
| | Fraction of time berth vessels worked | dimensionless |
| | Number of gangs employed per vessel per shift | Gangs |
| | Tonnes handled per vessel-hour in the port | t/hour |
| | Tonnes handled per vessel-hour at berth | t/hour |
| | Tonnes handled per gang-hour | t/gang-hour |
| | Fraction of time gangs idle | dimensionless |

**Source: UNCTAD (1976)**

It is worth indicating that the indicators referred to above were generally applied to ports and due to their progressive specialisation in terminals, many of them are also used and specified at that level. As indicated in the study by Owino *et al.* (2006), in the case of container terminals, operators basically continue to utilise the same type of indicators in both categories, with a significant presence of operating indicators in relation to financial indicators (87.55% compared to 12.45%).

As part of a project entitled "Port Performance Indicators, Selection and Measurement" (PPRISM), the ESPO (2011), taking a holistic approach to provide a series of groups of stakeholders related to the logistics-port chain with answers, divided the indicators into five categories (market trends and structure, socioeconomic impact, the environmental, logistics chain and operating performance; and governance), selecting a total of 14 indicators (Table 8) from an initial sample of 159. The information from these indicators is expected to be available from the corresponding port authorities.

Table 8. Port performance categories and indicators

| Category | Indicator | Unit |
|---|---|---|
| **Market Trend and Structure** | Maritime traffic | t |
| | Call size | t/GT |
| **Socioeconomic Impact** | Employment | Ut |
| | Value added | Monetary Ut |
| The Environment | Carbon footprint | t $CO_{2e}$ |
| | Waste generated | $m^3/t$ |
| | Water consumption | $m^3/t$ |
| | Environmental management Program | Yes/no |
| **Logistics Chain and Operating Performance** | Intermodal connectivity | Formula index |
| | Maritime connectivity | Formula index |
| | Customs process quality | Formula index |
| **Governance** | Port cluster integration | Formula index |
| | RSC scope | Formula index |
| | Managerial independence | Formula index |

**Source: ESPO (2011)**

The contrast between Table 7 and Table 8, apart from the fact they 35 years apart, is confirmation of the aforementioned evolution towards an integral vision of a port in the logistics chain directed at different groups of stakeholders. However, that does not mean operating and financial indicators are not required for more microeconomic analyses, as in the case of individual terminals.

The body of knowledge on **port operating performance**, including the financial side, employs terms such as traffic, throughput, productivity, occupancy, efficiency, capacity, etc. rather imprecisely, resulting in the use of classifications or particular nomenclatures becoming widespread and, on many occasions, generating an open and consequently not very exact field of knowledge (Monfort *et al.*, 2000; Bichou, 2007). This recurring problem is not easy to solve in a globalised industry such as ports, making it occasionally very difficult to compare supposedly equivalent indicators.

In the scenario described above, this chapter constructs four complementary indicator perspectives in order to provide conceptual organisation to help readers better interpret this handbook on port capacity:

1. **Performance**, linked to measuring terminal output, productivity and utilisation of resources, both in technical and economic terms;

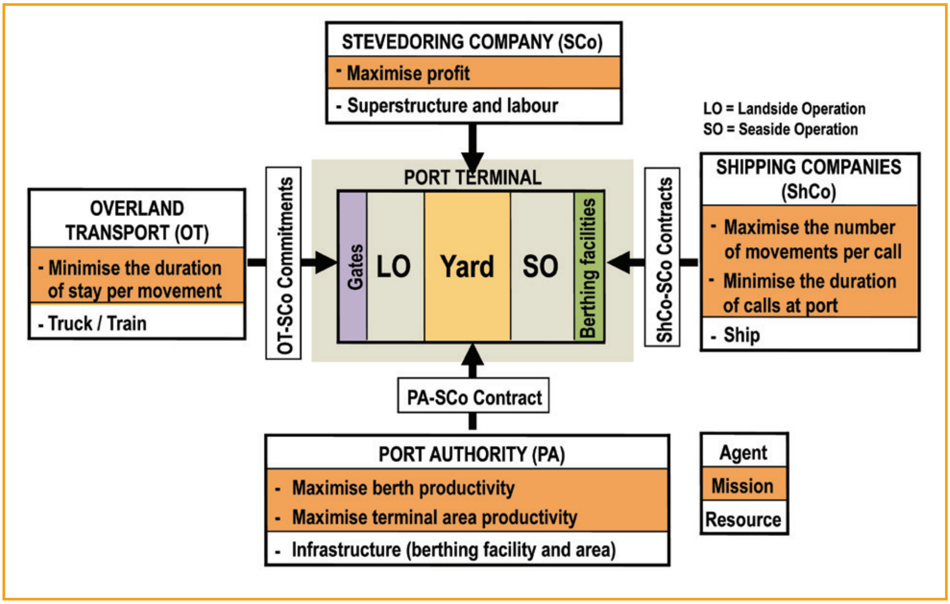
2. **Efficiency**, which addresses the relationship between the resources utilised and the volume of cargo a terminal handles, in terms of optimisation;

3. **Capacity**, related to the maximum amount of cargo the terminal can handle during a period of time; and,

4. **Level of service**, related to the quality of the service provided to clients and terminal users.

The stakeholders directly related to planning and operating a container terminal include: the Port Authority, terminal operator (stevedoring company), shipping companies (or lines) and overland transport companies. Figure 33 provides a diagram of the conflict of interests that arise among the foregoing stakeholders in regard to the contracts and commitments they acquire.

Figure 33. Conflict of interests in a port terminal




Source: Monfort (2008)

It is worth underlining the importance of the operating performance indicators that are normally included in the concession contracts between the Port Authority and the terminal operator. A good selection and definition of indicators will facilitate monitoring tasks and the enhancement of what the facility can offer (UNCTAD, 1998; World Bank, 2007; Kent and Ashar, 2010).

The next section discusses each of the four perspectives in more detail. However, before doing so, it is important to highlight that while the indicators related to operating performance stem from the application of direct and real measures, the other three perspectives require patterns that model specific ideal scenarios in the port or terminal, or even benchmarking approach in some cases.

In the next section, the text refers to the concept of port terminal as the basic element in the calculation of port capacity.

## 4.2. Operational port performance

A port terminal can be considered a production centre (De Monie, 1998) and, as such, must be monitored in terms of output volume, rate, the degree to which resources are utilised and costs.

In this sense, the following categories are defined to measure operational port performance:

1. **Output**: expresses the amount of cargo a terminal handles over a period of time, without specifying the resources utilised. When output is expressed in monetary units, financial indicators are built.

2. **Productivity** is related to the work rate of the various resources a terminal has. That is, productivity can be defined as the amount of cargo (output) that a terminal handles per unit of time and resource.

3. **Utilisation** defines to what degree resources are utilised, that is, the ratio (expressed in percentage form) between the utilisation of a given resource and the maximum utilisation possible over a period of time.

Here below it includes some typical indicators and examples of each category.

**Table 9. Indicator categories, typical Indicators and units**

| Indicator Category | Typical Indicator | Units |
|---|---|---|
| Output | Annual Traffic<br>Throughput | t/year<br>TEU/year |
| Utilisation | Berthing facility productivity<br>Vessel productivity at port<br>Crane productivity | t/m and year<br>t/h in port<br>t/h<br>Movements/h |
| Productivity | Berthing facility utilisation | % of occupancy |

**Note: t is a metric tonne equivalent to 1,000 kg**
**Source: Fundación Valenciaport, based on Monfort *et al*. (2000)**

Therefore, a discrete estimate of terminal capacity per berthing facility (Chapter 5) during the period of time considered is a **measure of output** that results from the product:

- of the **number of berths**
- by a **measure of utilisation** (berth utilization rate as a %) and **by the operating time** (as available working hours per year) of the berth
- by the average **measure of** vessel **productivity** at berth
- the result is the theoretical capacity of the berth per year, which also is related to the **level of service** required (Monfort, 2008).

In the field of measuring container terminal performance, it is worth mentioning the so-called Container Terminal Quality Indicator (CTQI), a new quality management system for CTs that, by way of a global audit (through quality certification), seeks to assess the quality of the results of a facility, paving the way for improvement. It was presented at the beginning of 2008 following a process led by Germanischer Lloyd (GL), together with the Global Logistics Institute (GLI). A highly qualified group of operators and experts related to container traffic cooperated in the construction of the model (Sapiña, 2007). The model is structured in four blocks: management system, internal factors, external factors and performance trend, and includes up to 80 indicators or measures of performance, seven of which come under the category of Key Performance Indicators (KPI), which are compared to the CTQI Standard, determined by benchmarking.

### 4.2.1. Output

The first of the categories for measuring port performance is output, which expresses the amount of cargo handled over a period of time (day of work or shift, day, month, year…) without specifying the resources utilised. The units that measure the amount of cargo handled can include tonnes, containers (of whatever type or measurement), TEU, chassis, euros, etc.

The main indicator in this category is called terminal traffic or throughput. The literature in English includes authors such as De Monie (1998) and CTQI (2008) on the one hand who differentiate the two terms using individual non-coincidental definitions and, on the other hand, institutions (Port Authorities in general, ESPO, 2001) and authors that employ them as synonyms. In the literature in Spanish, both terms are also used with the aforementioned divergence, throughput not being translated. For example, in the case of the CTQI, a large group of indicators are encompassed by the term traffic (imports, exports, full, empty, etc. expressed in terms of containers and TEU), while throughput is confined to being a non-standardised indicator used at local level for statistical purposes and expressed in TEU.

The sense behind differentiating lies in the opportunity to distinguish between various indicators of gross traffic – which include container shuffling, or non productive cargo movements and others – and the net traffic of the terminal or of one of its subsystems; and the method used, for example, to account for the containers being shipped by sea.

In the case of container terminals, a movement is a highly relevant unit of output in the analytical system of measurement. In this sense, in the ship-to-shore subsystem for example, any container shifting linked to a loading or unloading process performed by a ship-to-shore crane counts as a movement:

- Loading and unloading of container/s (depending on the type of spreader);
- Direct vessel/vessel transfer;
- Ship/shore transfer and vice-versa; and
- Loading and unloading of hatch covers.

Using the output indicators as a basis, financial indicators are constructed that express the various production costs over a period of time in monetary terms (€/t, €/loading/unloading movement, €/receipt/delivery movement, €/work shift, etc.).

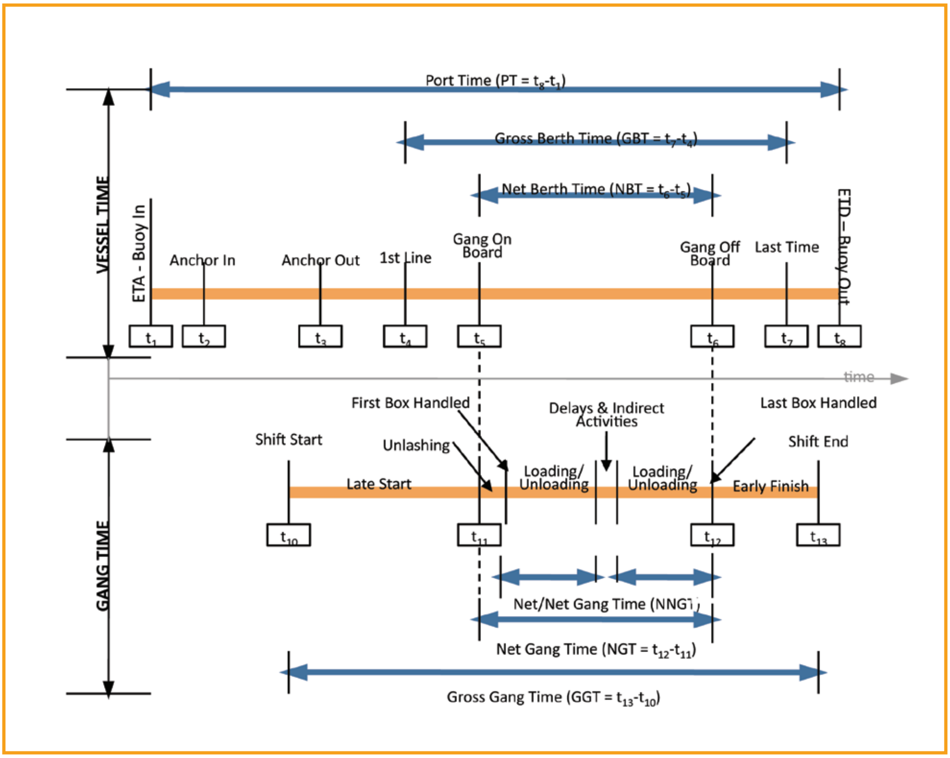
### 4.2.2. Productivity

Productivity shows the amount of cargo handled per unit of resource and per unit of time.

Apart from the infrastructure, superstructure and human resources of the terminal, also the vessel and the overland modes of transport – road or rail – are important resources for the calculation of productivity indicators.

The unit of time is also segmented according to the sequence of the operation to improve control, planning and productivity. In this sense, in the case of the ship-to-shore subsystem for example, the times identified in Figure 34 are defined.

**Figure 34: Time accounting system for berth operations**




Source: Ashar (1997)

Table 10 includes various productivity indicators with the respective units of output, resource and units of time, while Table 11 provides an example of the main connections between some of the most common objectives of a port terminal and several productivity indicators.

Table 10. Examples of productivity indicators

| Productivity | Output | Resource | Unit of Time |
|---|---|---|---|
| Gross prod. in port | Movements | Vessel/port | Hours at port |
| Gross prod. of berth | Movements | Vessel/berth | Berthing hours |
| Net prod. of berth | Movements | Vessel | Net hours |
| Gross prod. of crane | Movements | Crane | Gross hours |
| Net prod. of crane | Movements | Crane | Net hours |
| Net-net prod. of crane | Movements | Crane | Net hours/net |

Source: Monfort (2000)

Table 11. Main relation between productivity indicators and objectives

| Productivity Indicator | Improvement in crane productivity | Quality control of service to shipping lines | Berth and equipment scheduling |
|---|---|---|---|
| Gross prod. at port | | xxxxxxxxxxx | |
| Gross prod. of berth | | xxxxxxxxxxx | xxxxxxxxxxx |
| Net prod. of berth | | xxxxxxxxxxx | xxxxxxxxxxx |
| Gross prod. of crane | xxxxxxxxxxx | | xxxxxxxxxxx |
| Net prod. of crane | xxxxxxxxxxx | | |
| Net-net prod. of crane | xxxxxxxxxxx | | |

Source: Monfort (2000)

Chapter 5 provides numerical references of productivity scores (UNCTAD, 1998; Kent and Ashar, 2010).

### 4.2.3. Utilisation

The utilization of the resources of a port terminal as a measure of operating performance refers to the proportion of time a resource is in use in regard to total time available for use over a given period. That is why utilisation is always dimensionless (normally a percentage).

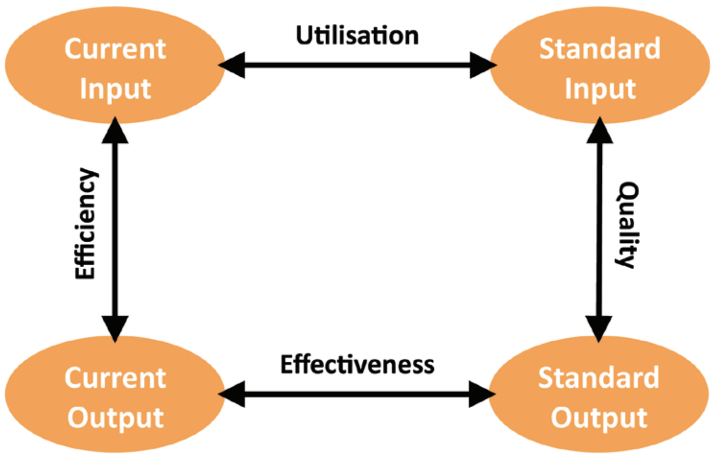
Out of all the infrastructure utilisation indicators that exist, it is worth highlighting that linked to the berthing facility itself, better known as the berth occupancy. This indicator records different values depending on whether it is calculated using continuous or discrete berthing operations. In the first case, the indicator reflects the proportion of time that berths are occupied, regardless of the size of the vessels moored there, whereas in the second case it identifies the proportion of time that the metres of berth are occupied, which depends directly on the length of vessels.

## 4.3. Efficiency

In colloquial language, and even in technical documents, the terms efficiency, efficacy, effectiveness and productivity are often used as synonyms. In all cases, either implicitly or explicitly, there is an underlying valuation of a production process or a process whereby resources (inputs) are transformed into goods or results (outputs) and a reference objective.

Bichou (2007) provides an illustration of (but does not explain in detail) the matrix in Figure 35, in the context of the taxonomy of terms related to measuring port performance commented in the introduction to this chapter, which is different to that considered by Brooks and Pallis (2007).

Figure 35: Basic matrix of performance measurement dimensions




Source: Bichou, 2007

In the field of knowledge on port performance, the use of the academic concept of port efficiency (González and Trujillo, 2006), which is presented below, has become stronger since the mid 1990s.

The utilisation of ratios that express the coefficient between a result (output) and a resource (input) –alternative definition of productivity– has been, and in many cases remains the usual procedure for valuing performance –"efficiency"– in the utilisation of a resource, acting as a basis for planning the necessary resources.

However, the scholarly definition of efficiency, aimed at achieving a better interpretation of reality, which is always complex, considers multiple inputs and outputs (Medal and Sala, 2011):

$$\textit{Efficiency} = \frac{\textit{Weighted sum of outputs}}{\textit{Weighted sum of inputs}} \tag{1}$$

The techniques used to calculate efficiency, particularly Data Envelopment Analysis (DEA), is based on linear programming in order to assess the efficiency of a set of units – terminals – in such a way that the result is the relative efficiency of each unit in regard to the rest. This efficiency can be considered in technical and economic terms.

It must be noted just how difficult it can be for a terminal to study its efficiency, provided that it requires information about the activity of other similar terminals. For this reason, instead of analysing efficiency in relation to other terminals, most of terminals do so in relation to themselves, but over different periods of time. This is called intra-centre efficiency (Wang *et al.*, 2005), as opposed to inter-centre efficiency.

While the techniques referred to above can be useful to analyse how to optimise some resources and results, the characteristics of efficiency analysis described, particularly the fact that it includes a valuation in relative terms, restrict their applicability when the objective of the study or desired result is the estimation of terminal capacity.

## 4.4. Capacity

The capacity of a port terminal can be defined as the maximum traffic it can handle in a given scenario. As the conditions in which this threshold can be calculated are different, there are various concepts of capacity.

Nevertheless, the process involved in determining capacity forces us to build a necessarily simplified model of the workings of a terminal, to imagine extreme conditions to subject the model to them and to calculate the traffic indicator for that scenario.

As a result, a variety of extreme conditions have appeared over time for the calculation of capacity, including the following:

- Those linked to the economic optimisation of facilities;
- Those established by facility saturation; and
- Those referring to the minimum acceptable quality of service perceived by clients, as an increase in traffic results in clients perceiving a decrease in terminal service quality.

Capacity calculation is an important terminal planning tool, as it does not only establish a terminal's limits, but also different scenarios to see how the terminal would respond in those situations.

The next section includes the perspective of measuring the level of service based on estimating the perception of quality, a basic element in the calculation of capacity discussed in Chapter 5.

## 4.5. Level of Service

The concept of Level of Service (LoS) was developed to provide a measure of the quality perceived by system clients and users. It also helps to introduce an extreme scenario, which is part of calculating port capacity.

The clients and users of a port terminal are shipping lines (vessel), transport companies (road and rail) and freight forwarders (cargo).

Generally speaking, shipping lines, the main clients of a terminal, perceive the quality of the service provided in two ways, both expressible in economic terms. The first is the cost of the call, that is, the total amount of charges or tariffs that shipping lines must pay every time their vessels call at a port. While this aspect is very important, it is not one of the objectives of this handbook. The second is related to the duration of the call at port (the less time the better).

The problem arises when it comes to choosing an indicator to measure the level of satisfaction in regard to call duration. One of the main variables is undoubtedly the amount of cargo to be handled. Indeed, the indicator most frequently used by shipping lines is the amount of cargo handled per unit of time at port. As a result, the ratio below is a very important indicator of the level of service offered to shipping lines:

$$\frac{T_P}{Q} \tag{2}$$

Where:
$T_P$: Vessel time at port (call duration)
$Q$: Amount of cargo to be handled in a call at port

Furthermore, call duration at port has two very different components:

$$T_P = T_w + T_s \tag{3}$$

Where:
$T_w$: Waiting time (anchorage), that is, due to port congestion the vessel must wait for a berth; and,
$T_s$: Service time, that is, the time in which the vessel is not anchored since the moment it start the maneuver at port

After introducing the two port time components, the indicator is expressed as follows:

$$\frac{T_P}{Q} = \frac{T_s}{Q}\left(1 + \frac{T_w}{T_s}\right) \tag{4}$$

Ascertaining the capacity of a terminal implies learning the limits that shipping lines can accept in terms of waiting time in regard to service time, a relationship that is expressed by the **relative waiting time** ratio **ε**:

$$\varepsilon = \frac{T_w}{T_s} \tag{5}$$

which expresses **service quality associated to the relative waiting time.**

Similarly, the first term in the formula above ($T_s/Q$) is the opposite to vessel productivity at berth:

$$P = \frac{Q}{T_s} \tag{6}$$

Where:

*P*: Vessel productivity at berth (which is mainly influenced by the number and specifications of the cranes, operator skill, connections to other subsystems and information management, among other factors).

Therefore, expression (4) now reads:

$$\frac{T_P}{Q} = \frac{1}{P}(1 + \varepsilon) \tag{7}$$

In order to minimise the ratio $T_p/Q$ (indicator of shipping line satisfaction with port call time) will entail minimising the above expression. That formula has two factors, one basic factor that is governed by berth productivity *P* and a second factor that extends the previous factor and which represents the effect of terminal congestion and which can be estimated by the aforementioned relative waiting time ε.

As a summary of the above, it is evident that the indicator of level of service offered to shipping lines (a measure of client satisfaction) is a function of two key indicators: on the one hand, vessel productivity at berth *P* and, on the other hand, relative waiting time ε.

The approach is similar in the case of transport companies (road or rail), albeit simpler in that, particularly where trucks are concerned, there are much few operations (receipt/

delivery of 1 or 2 containers at the most) and total operating time, the sum of waiting time and managing entrance and exit through the terminal land gates, should reflect such a small number of movements.

The amount of time that cargo stays in a terminal can also be an indication of quality in the case of freight forwarders (importers and exporters). However, the time cargo spends in a terminal is not generally a consequence of how a terminal is run, but rather to external factors including the desire of freight forwarders themselves to use the terminal as a warehouse to regulate their freight. Other external factors that can affect the length of stay include warehousing charges and the efficiency of customs and inspection authorities.

Finally, it is worth mentioning that the concept of LoS is used in many other activities when attempting to measure user satisfaction. In order to represent LoS, a small set of levels is frequently established, sometimes using letters and others numbers. One example that is worth highlighting is that included in the Highway Capacity Manual (TRB, 2000), in which LoS is represented by five letters from A (the best) to E (the worst), whereby the difference between D and E, by definition, corresponds to infrastructure capacity.

In the case of port terminals, unlike road capacity, no complete model of LoS has been made available to date. Ballis (2003) contributes a similar preliminary exercise for the case of intermodal terminals (Table 12).

Chapter 5 delves into the study of performance indicators and levels of service for container terminals (see Table 17 and Table 18). Finally a Level of Service proposal is suggested considering a range of relative waiting time values and different annual average productivities of vessel at berth (*P*) (see Tables 22, 23 y 24)

**Table 12. LoS proposal for intermodal terminals**

| Proposed Level of Service Standards for the Intermodal terminals | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| **Waiting time of users in the system** (includes waiting time in the queue and service time) | | | | | | SYSTEM BREAKDOWN |
| Waiting time for the 95% of the trucks (minutes) | Up to 19 | 20 – 30 | 31 – 40 | 41 – 60 | 61 – 120 | |
| The waiting time of the ships must be according to the shipping line and port norms while the trains should follow their timetable, (the deviations are addressed by the reliability standard). | | | | | | |
| **Reliability** | Maritime Terminals | | | | | |
| Incidents of vessel delay in departure | up to 2% | (3 – 5) % | (6 – 15) % | (16 – 30) % | (31 – 60) % | |
| Duration of delay (minutes) | up to 30 | 31 - 45 | 46 - 60 | 61 - 90 | 91 - 180 | |
| | Rail Terminals | | | | | |
| Incidents of train delay in departure | up to 2% | (3 – 5) % | (6 – 10) % | (11 – 20) % | (21 – 40) % | |
| Duration of delay (minutes) | up to 10 | 11 - 20 | 21 - 30 | 31 - 40 | 41 - 60 | |

Source: Ballis, 2003

*If your facts are wrong but your logic is perfect, then your conclusions are inevitably false*

**Christie-Davies, engineer**

05

# Measuring port terminal capacity

## 5.1. Methods of measurement

The methods used to determine the capacity of a port terminal have developed from simple formulas based on average productivity scores used as ratios (empirical methods) to more complex formulas (analytical methods), an initial stage of which is based on the queuing theory (Rodriguez, 1977). The latter have led to simulation methodologies in which it is decisive to learn how the terminal as a whole will respond to increasing traffic demand and other current and future scenarios to be analysed.

**Empirical methods** obtain capacity by applying productivity levels to the terminal that stem from benchmarking other similar facilities in terms of size and type and which provide a satisfactory level of service. These methods are very useful when it comes to planning new terminals and designing port management plans (Schreuder, 2005), as the data required to apply other methods are often not available.

**Analytical methods** use concepts and mathematical formulas to describe the processes of the subsystem under analysis. They are frequently used for planning ship-to-shore subsystems (Rodriguez, 1977; UNCTAD, 1984; Agerschou, 2004; Dragovic *et al.*, 2006; among others authors).

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As mentioned in the previous chapter, in order to estimate the berth capacity of a terminal, it is necessary to ascertain the limits that shipping lines will accept as regards the relationship between waiting time and service time, known as relative waiting time. The ship-to-shore subsystem or berthing facility is normally run as a single continuous line, which is therefore far from the simplification of the queuing theory, which requires considering it a group of equivalent berths that serve identical ships. Quays are usually, in the simplest (and most common) case, more or less uniformly aligned (there could be multiple alignments or different drafts that would complicate the study remarkably) and serve vessels of different sizes and with different service needs. Simulation is considered the only way of obtaining more detailed knowledge, which at the same time requires studying many aspects that the simplification of analytical methods concealed.

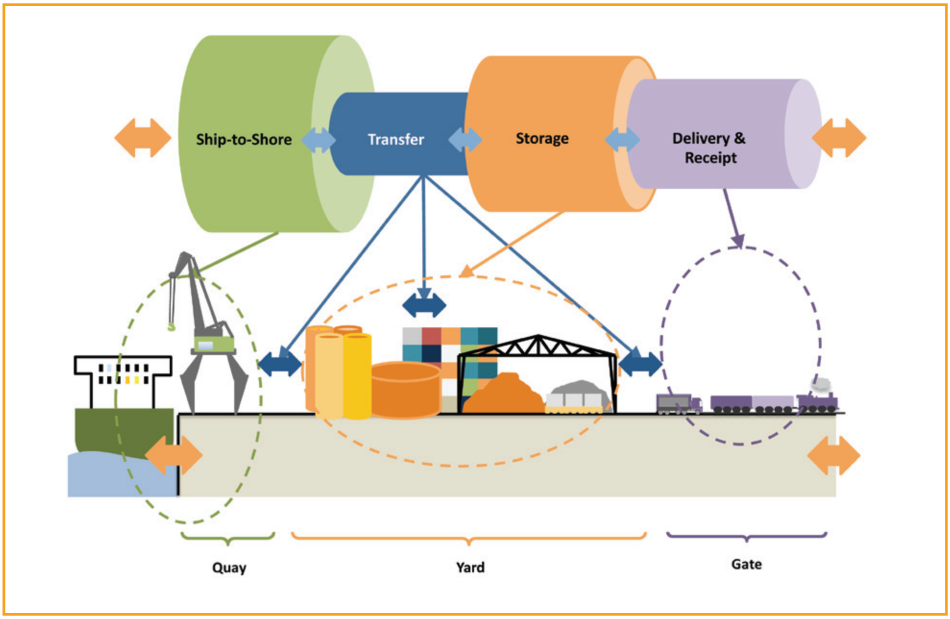
There are two types of simulation, deterministic (one shot) and statistical (or stochastic). In CTs the second one is the most used, due to the complexity of them. **Simulation methods** aim to reproduce the response of terminals to a series of situations using computer programs. In the simulation, the system is divided into various subsystems that can be described mathematically and then combined to obtain a model of the system as a whole in order to assess the different scenarios considered. Simulation methods have two advantages over analytical models. On the one hand, they consider a higher level of detail and, on the other hand, they avoid the oversimplification of analytical models. The drawback is the enormous amount of data required to perform them.

The level of detail employed in the components and behaviour of a simulation model (or models) will be determined by its intended use. There normally needs to be a compromise between the complexity of the model (level of detail) and its purpose (objectives). In port container terminal management, there are different strategic, tactical and operational aspects that have different time frames and detail requirements in simulation models (Henesey, 2006). Therefore, one can define as many levels of abstraction as desired or as required (Sanz *et al.*, 2010). In this sense, if a model is divided into several increasingly complex levels, level 1 would include the least complex and therefore most abstract group of simulations and the last would include the most complex or least abstract. Finally, it is important to mention that the more complex and detailed a simulation model is, the greater the computation requirements, which can restrict the utility of the model if it is unable to provide an answer in satisfactory time.

## 5.2. Analytical calculation by subsystem: hypothesis

In an internal systemic conception of a port terminal (Chapter 2), capacity will be the lowest of the respective capacities of the subsystems it comprises (the minimum of the maximum) (Figure 36): the ship-to-shore subsystem (berthing facility), transfer subsystem, storage subsystem and overland receipt and delivery subsystem. This is evidently a simplified analytical view, as the subsystems interact naturally (see Section 3.2). As a result, the approach will require a series of working hypotheses to be proposed in order to isolate each subsystem and calculate their individual capacity.

Figure 36. Port terminal capacity by subsystems




Source: Fundación Valenciaport based on Henesey (2006)

From a planning perspective, neither the transfer subsystem nor the receipt and delivery subsystem should restrict capacity. Therefore, the working hypothesis is that they are equipped with sufficient equipment not to cause bottlenecks in the terminal system.

The transfer subsystem is in charge of the internal movement of cargo between the rest of subsystems. This analysis assumes that there are as many transfer vehicles as those required to do the job, so they do not delay the activity of ship-to-shore cranes (or ship cranes, where applicable) or yard equipment and, as a result, cannot be considered to restrict the capacity of the terminal.

In the case of the receipt and delivery subsystem, a distinction must be made between the entrance of external trucks or railcars into the terminal and the receipt and delivery operation itself. In the case of external road transport, entrance flows depend on the number of gates, their opening times and the time required to enter or leave (this is particularly important, especially in terminals with a large traffic volume of containers O/D). The terminal operator is assumed to gauge the number of gates according to the influx of external trucks (which can vary throughout the day). Under no circumstances must terminal entrance or exit limit the capacity of the receipt and delivery subsystem, which as indicated, should be duly endowed with the corresponding resources. In the case of rail transport, the terminal is assumed to have sufficient rail platforms to attend to the inflow and outflow of cargo on this mode of transport. However, what could limit the capacity of the receipt and delivery subsystem is the size of the gangs, which are often shared by operations in other subsystems. In the case of bulk terminals where cargo receipt and delivery operations are performed using pipelines or other special facilities, the latter will be of the correct size so that the subsystem does not constitute a restriction in terminal capacity either.

When analysing the capacity of the ship-to-shore subsystem, two different operations must be distinguished: berthing itself (depending mainly on the number of berths and the berth occupancy ratio) and vessel loading and unloading productivity (which primarily depends on the number of cranes, the transfer vehicle assigned and how productive they both are). In the analysis presented in this chapter, it is assumed the terminal has the necessary equipment to cater for the traffic and that their level of productivity is satisfactory. Therefore, ship-to-shore capacity is related to berth capacity through the productivity of the vessel at berth (see Section 5.3.1).

The storage subsystem regulates the different rates of maritime and overland transport (road and rail). Calculating the capacity of this subsystem is more difficult than one would expect, depending on: the space used for storage, operational height of stacks – related to the equipment employed, traffic and the TOS – and cargo dwell time. Some authors (Kent and Ashar, 2010) also dismiss the calculation of storage capacity, arguing for example that cargo dwell time is a decisive factor in the capacity of the subsystem - focusing on berth capacity as a limitation of capacity, as that time can be "managed" by implementing tariffs and logistical measures. The analysis of storage capacity is maintained in this manual due to its utility in the planning and enhancement of terminal management, as the foregoing storage time management measures are often not easy to implement.

The next section describes the methodology employed to calculate the berth and storage capacity of port facilities, due to both subsystems having the greatest impacts on the overall capacity of the terminal, as mentioned previously. Furthermore, specific references to port container terminals are provided in both.

## 5.3. Berth capacity

The methodology presented in this manual for the calculation of berth capacity is twofold: it combines analytical calculation with a simulation of the subsystem under study.

### 5.3.1. Definition

The main aspects to be taken into account when calculating berth capacity at a port terminal or facility are:

- The forecasts of the amount of cargo to be handled (demand) according to freight format (liquid bulk, dry bulk, container, beak bulk or non containerized cargo, Ro-Ro).
- Statistical inter arrival time distribution of vessels and their characteristics (length and draft).
- Description of quay berth alignments (length and draft).
- Statistical service time distribution.
- Number of quay cranes.

- Quay cranes productivity (Tonnes/hour; TEU/hour or containers/hour; units/ hour).
- Quality of service associated to relative waiting time considered acceptable.
- The time the terminal is operational per year.

Annual berth capacity is equal to the product of the number of berths, by the berth occupancy ratio, operational hours per year and average vessel productivity per hour while the vessel is at berth:

$$C_B = n \times \Phi \times t_{year} \times P$$

Where:

$C_B$: Capacity of the quay or terminal per year (Tonnes, containers or TEU, units per year).
$n$: Number of berths.
$\Phi$: Acceptable berth occupancy ratio. This depends on the number of berths, relative waiting time (ratio between waiting time and service time: $T_w/T_s$), and the definition of arrivals and service times.
$t_{year}$: Hours the terminal is operational per year. This depends on the number of days the port operates and working conditions (shifts per day, hours per shift, holidays, etc.) and weather conditions.
$P$: Annual average productivity of vessel at berth. It is the ratio between the annual volume of handled goods and the aggregate of the estimated annual gross times during which vessel is at berth (gross berth times). This factor depends on the number and operational productivity of equipment. It also depends on other parameters such as the skills of operators or the connection with the other subsystems involved, etc.

The **number of berths (*n*)** does not have to be a whole number, although figures are often rounded down to the nearest whole number in the calculation that is detailed below, in order to ensure that the result in terms of capacity is on the safe side. The number of berths depends on the length of the berthing facility, the length of a standard vessel that will berth at the terminal (see Appendix 1, Section 3 on the modelling of the berth) and the safe distance (berthing gap or distance between vessels at berth), or ratio of separation, $K_{separation}$.

The bibliography suggests different methods to calculate *n*:

$$n = \frac{\textit{length of berthing facility}}{\textit{length of standard vessel} \times (100\% + K_{separation})}$$

The specialised literature is yet to agree on the definition of a standard vessel. In this sense, while some authors (González-Herrero *et al.*, 2006) propose using extreme vessels, the length of which is exceeded by 15% of arrivals, other authors suggest average values, such as average length (Rodriguez, 1977), or the weighted average of the distribution of lengths by their respective service times (service time distribution). If the necessary information is not available (length and service time distributions), length can be estimated according to the type of vessels expected to berth at the terminal, such as panamax or post-panamax container carriers (see Table 13), to their position in regard to maritime transport routes, to the draft of the port, etc.

As mentioned, the length of a standard vessel must be increased. There are several ways of calculating that safe distance (berthing gap), such as 10% of the length of the vessel spread between the bow and the stern ($K_{separation}$=10%), or a fixed value (for example, 20 metres). The ROM makes a proposal considering several quay layouts (see Appendix 2).

Table 13. Berth capacity per berth type ("Chile case" analysis)

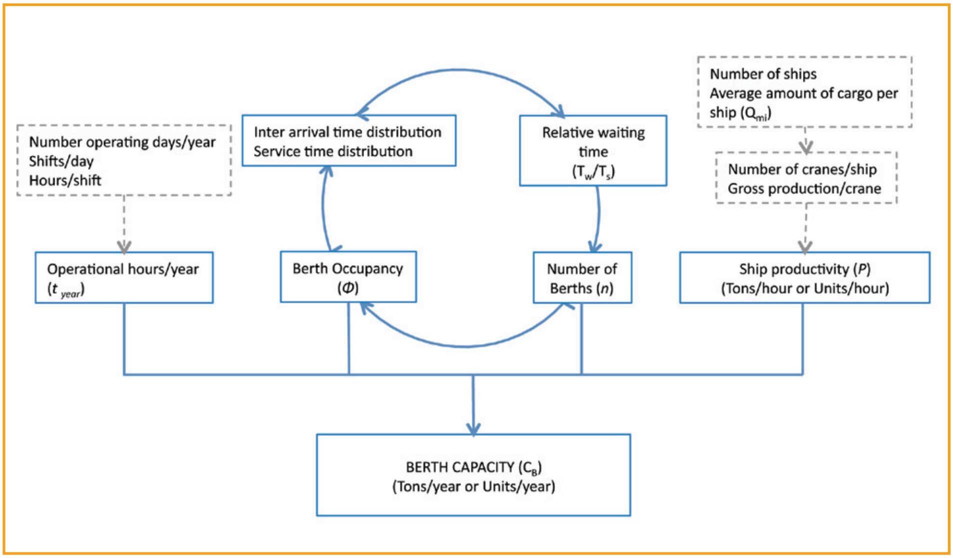
| Year | Type of Berth | Berth length (m) | Depth alongside (m) | Berths per terminal | Design ship | Berth Capacity (TEU) | Berth-m Capacity (TEU/m) |
|---|---|---|---|---|---|---|---|
| **2009** | **Sub Panamax** | 250 | 12 | 3 | 3,000 | 350,000 | 1,400 |
| **2012** | **Panamax** | 280 | 14 | 3 | 4,500 | 450,000 | 1,607 |
| **2012** | **Panamax** | 280 | 14 | 4 | 4,500 | 495,000 | 1,768 |
| **2014** | **Post Panamax I** | 300 | 15 | 3 | 5,700 | 500,000 | 1,667 |
| **2014** | **Post Panamax I** | 300 | 15 | 4 | 5,700 | 550,000 | 1,833 |
| **2017** | **Post Panamax II** | 350 | 16 | 4 | 8,000 | 700,000 | 2,000 |
| **2025** | **Post Panamax III** | 400 | 16 – 18 | 4 | 12,000 | 1,000,000 | 2,500 |
| **2009** | **Multipurpose** | 150 | 10 – 11 | 2 | 1,000 | 100,000 | 667 |

Source: Ashar (2009)

The **acceptable berth occupancy ratio** ($\Phi$) is the result of considering vessel inter arrival time distribution, quay service time distribution and number of berths on the one hand, and on the other hand the quality of service associated to relative waiting time. The berth occupancy ratio can be calculated using the Queuing Theory or by means of simulation models.

Figure 2 presents a diagram of the key aspects that must be taken into account when calculating berth capacity, together with the relationship between them.

**Figure 37. Berth capacity of port terminals**




**Source: Fundación Valenciaport**

## 5.3.2. Recommendations regarding berth capacity

### 5.3.2.1. Vessel arrivals and service times distribution systems by type of terminal

In order to conduct a detailed analysis of berth capacity using analytical methods, it is necessary to ascertain the distributions of vessel inter arrival time and service time at the terminal. These methods treat the quhay or the terminal as a queue system endowed with n service points (in this case, n would refer to berths), whereby distribution depends on vessel inter arrival time probabilities ($f_1$), and another distribution that depends on service time probabilities ($f_2$). The queue system is defined by those distributions (inter arrival time and service time) and the number of berths: $f_1/f_2/n$. Distribution functions can be exponential (M – also called Poisson, Markovian or random), Erlang of order K ($E_k$), constant (D), hyper-exponential (H), or of any other type (G).

When information regarding the quay or the terminal is lacking in terms of inter arrival time and service time distribution, researchers are recommended to use the following queue systems depending on the type of terminal (UNCTAD, 1984; MOPT, 1992; Arnau, 2000; Thoresen, 2003; Agerschou, 2004; González-Herrero *et al.*, 2006; OPPE, 2006; Aguilar and Obrer-Marco, 2008):

- In the case of **bulk terminals**:
    - **Common-user terminal: $M/E_2/n$** (mixed arrivals/ Erlang 2 ($E_2$) service times and *n* berths).
    - **Dedicated terminal: $E_K/E_K/n$** (arrivals and service times according to an Erlang of order K distribution for *n* berths).

- In the case of **multipurpose terminals**, depending on the type of cargo and its distribution, the queue system could be one of the following:
    - **M/M/*n*** (distribution of random inter arrival times/ random service times/n berths) or
    - **$E_2/E_2/n$** (inter arrival times and service times according to an Erlang distribution of order K=2 for *n* berths).

- In the case of container terminals:
  - **Common-user terminals: M/$E_K$/*n*** (distribution of random inter arrival times/ service times according to an Erlang distribution of order K / n berths). Recent empirical studies show that public container terminals employ a random distribution type for vessel inter arrival time (M), while service times are better suited to an Erlang distribution of K=4 ($E_4$) or higher (the more regular service times are, the higher the value of K should be)– M/$E_4$/*n*.

  - **Terminal with tightly scheduled calls: $E_K$/$E_K$/*n*,** less random inter arrival time distribution (as could be the case with dedicated terminals). Regarding the arrival time distribution in the case of dedicated terminals, some authors identify these arrivals as random ones (Kou el at., 2006; Aguilar and Obrer-Marco, 2008) whereas others authors consider them as regular arrivals such as Erlang of order 2 (Agerschou, 2004).

**5.3.2.2. Definition of berth occupancy ratio**

The berth occupancy ratio can be calculated using the Queuing Theory or by means of simulation models. The literature specific to this issue (UNCTAD, 1984; MOPT, 1992; Thoresen, 2003; Agerschou, 2004; González-Herrero *et al.*, 2006; OPPE, 2006, among others) makes various recommendations – some more rigorous than others – to define the acceptable berth occupancy ratio or acceptable relative waiting time for port terminals.

It is important to highlight that the acceptable berth occupancy ratio is linked to a number of berths, which result in a certain quality of service associated to relative waiting time ($T_w/T_s$) depending on the queue system that most suits the terminal, that is, vessel inter arrival time distribution or service time distribution. In other words, depending on the type of queue system (M/M/*n*, M/$E_K$/*n* or $E_K$/$E_K$/*n*) and the number of berths, different acceptable berth occupancy ratios are obtained for the same relative waiting time. However, some of the bibliographical references on this topic fail to mention the type of queue system (for each type of terminal) and also quality of service on many occasions or can even avoid mentioning the dependence between $\Phi$ and the number of berths.

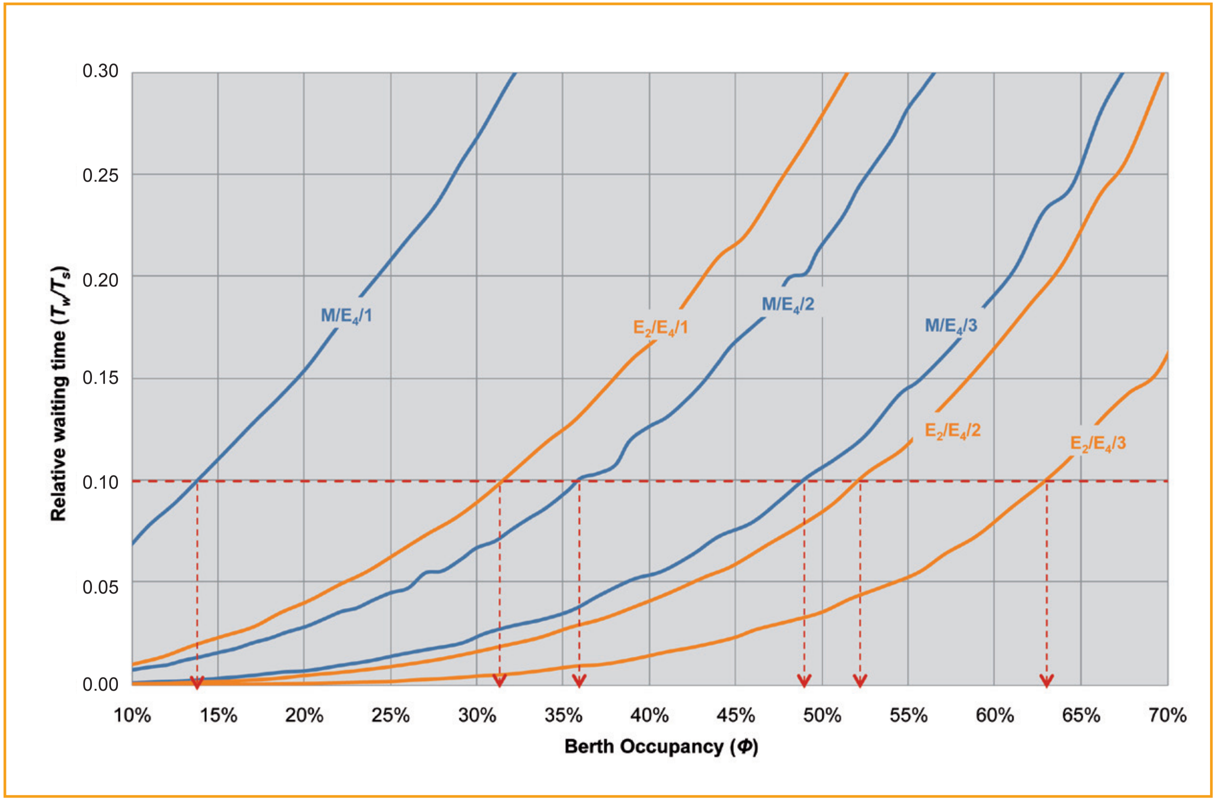
Therefore, as displayed in Graph 1, for a relative waiting time of 0.10, that is, waiting time represents 10% of service time, in a terminal with an M/$E_4$/*n* queue system, the acceptable berth occupancy ratio would be in the vicinity of 14% for a single berth and would rise to 36% and 49% for two and three berths, respectively. However, in a dedicated terminal with an $E_2/E_4/n$ system, the berth occupancy ratios for the same relative waiting time are approximately 31%, 53% and 69% for 1, 2 and 3 berths respectively (Table 14). It is important to mention that a terminal, regardless of how many berths it has, will never be able to reach 100% occupancy, as this would imply "infinite" average waiting time for vessels queuing.

**Table 14. Example of the influence of the type of queue system and the number of berths on the berth occupancy ratio for a given level of quality of service associated to the relative waiting time**

| $\Phi$ (for $T_w/T_s$ = 0.10) | *n*=1 | *n*=2 | *n*=3 |
|---|---|---|---|
| $M/E_4/n$ | 14% | 36% | 49% |
| $E_2/E_4/n$ | 31% | 53% | 63% |

**Source: Fundación Valenciaport based on data from Agerschou (2004) and Aguilar and Obrer-Marco (2008)**

Graph 1. Relative waiting time ($T_w/T_s$) and berth occupancy ratio ($\Phi$) according to queue system (M/$E_4$/*n* and $E_2$/$E_4$/*n*) for 1, 2 and 3 berths



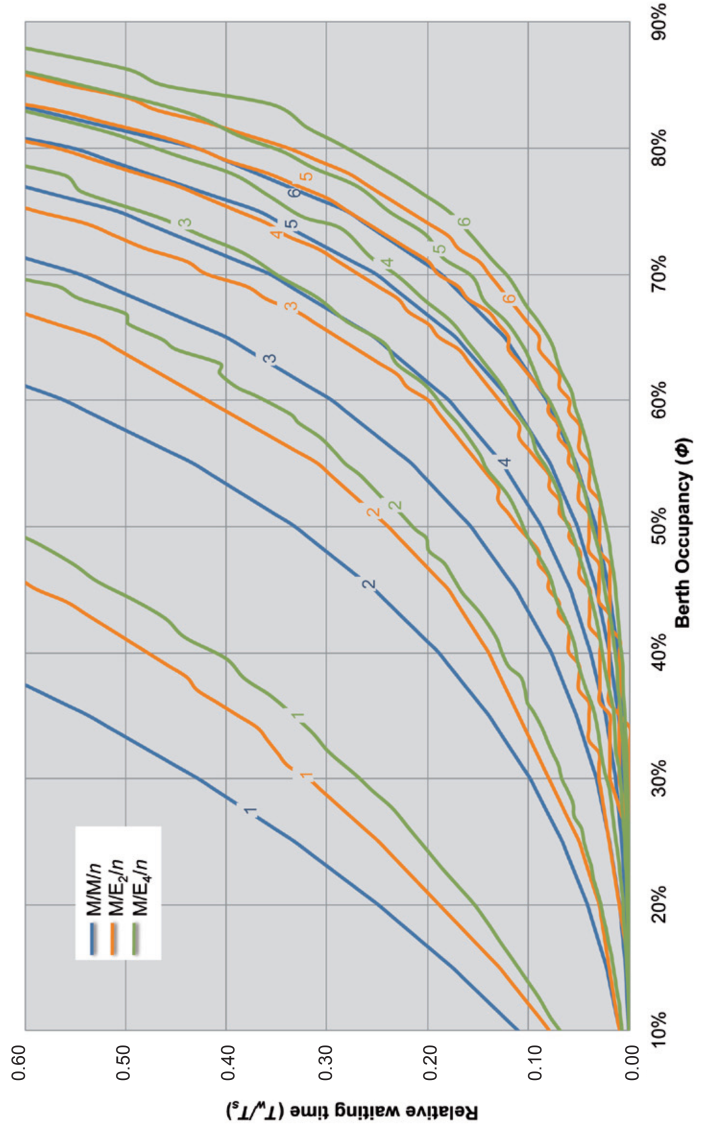

Source: Fundación Valenciaport based on data from Agerschou (2004) and Aguilar and Obrer-Marco (2008)

According to Agerschou (2004), some economic viability studies indicate that waiting time should not represent more than 10% of service time in the case of container terminals. Meanwhile, Thoresen (2003) mentions that the $T_w/T_s$ ratio should be between 5% and 20% depending on the type of terminal, and the quay berth occupancy ratio also depends on the type of quay, the size of vessels, transfer machines, environmental conditions, etc. As indicated by the ROM 2.1 (González-Herrero, *et al.* 2006), multipurpose terminals are recommended a value of $T_w/T_s = 0.25$ and bulk terminals a value of $T_w/T_s = 0.50$. However, in the case of the latter, depending on the type of bulk terminal (a dedicated terminal, for example), a lower value of $T_w/T_s$ might have to be considered (enhancing relative waiting time).

Moving on, when it comes to deciding the quality of service to offer in facilities, it is worth remembering that one of the references to take into account is the value of the quality offered by competing facilities.

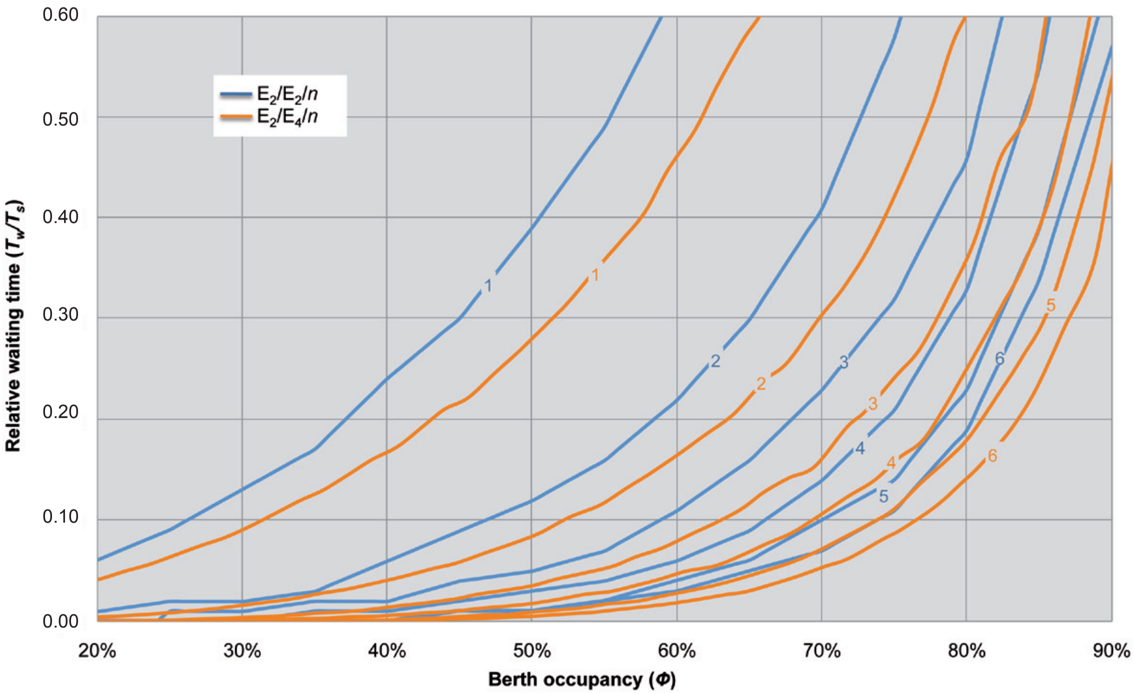
According to the foregoing bibliographical review and using the berth simulation performed by Aguilar and Obrer-Marco (2008), it has been possible to draw the curves of the M/M/*n*, M/$E_2$/*n* and M/$E_4$/*n* queue systems, represented in Graph 2, and the $E_2$/$E_2$/*n* and $E_2$/$E_4$/*n* queue systems, displayed in Graph 3.

Graph 2. Relationships between berth occupancy ratio ($\Phi$) and relative waiting time for M/M/*n*, M/$E_2$/*n* and M/$E_4$/*n* queue system and 1 to 6 berths




Source: Fundación Valenciaport based on data from UNCTAD (1984), Agerschou (2004) and Aguilar and Obrer-Marco (2008)

Graph 3. Relationships between berth occupancy ratio ($\Phi$) and relative waiting time for $E_2/E_2/n$ and $E_2/E_4/n$ queue system and 1 to 6 berths




Source: Fundación Valenciaport based on data from UNCTAD (1984), Agerschou (2004) and Aguilar and Obrer-Marco (2008)

Table 15 and Table 16 summarise the recommended acceptable berth occupancy ratios according to the number of berths (from 1 to 6) and vessel inter arrival time and service time distribution queue systems for a given relative waiting time. It is observed, as is logical, that higher berth occupancy ratios are reached, the lower the quality of service, that is, the higher the value of $T_w/T_s$.

**Table 15. Recommended acceptable berth occupancy ratio ($\Phi$) according to the number of berths and the queue system for multipurpose terminals ($T_w/T_s$=0.25) and bulk terminals ($T_w/T_s$ =0.50)**

| Number of berths ($n$) | Acceptable berth occupancy ratio $\Phi$ (%) | | | |
|---|---|---|---|---|
| | Multipurpose terminals $T_w/T_s$ = 0.25 | | Bulk terminals $T_w/T_s$ = 0.50 | |
| | M/M/$n$ | $E_2/E_2/n$ | $M/E_2/n$ | $E_2/E_2/n$ |
| 1 | 20 | 41 | 41 | 55 |
| 2 | 45 | 62 | 64 | 73 |
| 3 | 57 | 71 | 73 | 81 |
| 4 | 65 | 77 | 78 | 84 |
| 5 | 70 | 80 | 82 | 87 |
| 6 or more | 73 | 82 | 84 | 89 |

Source: Fundación Valenciaport based on data from UNCTAD (1984), Agerschou (2004) and Aguilar and Obrer-Marco (2008)

Table 16. Recommended acceptable berth occupancy ratio (Ø) according to the number of berths and the queue system for container terminals ($T_w/T_s$=0.05, $T_w/T_s$=0.10 and $T_w/T_s$=0.20)

| Number of berths ($n$) | Acceptable berth occupancy ratio $\Phi$ (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $T_w/T_s$ = 0.05 | | | $T_w/T_s$ = 0.10 | | | $T_w/T_s$ = 0.20 | | |
| | $M/E_2/n$ | $M/E_4/n$ | $E_2/E_4/n$ | $M/E_2/n$ | $M/E_4/n$ | $E_2/E_4/n$ | $M/E_2/n$ | $M/E_4/n$ | $E_2/E_4/n$ |
| 1 | < 5 | 7 | 22 | 12 | 14 | 31 | 21 | 24 | 43 |
| 2 | 25 | 27 | 43 | 33 | 36 | 53 | 47 | 49 | 63 |
| 3 | 38 | 39 | 53 | 49 | 49 | 63 | 60 | 61 | 72 |
| 4 | 47 | 47 | 61 | 56 | 57 | 70 | 66 | 68 | 78 |
| 5 | 53 | 54 | 66 | 62 | 63 | 73 | 71 | 73 | 81 |
| 6 or more | 57 | 58 | 69 | 66 | 67 | 77 | 74 | 76 | 84 |

Source: Fundación Valenciaport based on data from UNCTAD (1984), Agerschou (2004) and Aguilar and Obrer-Marco (2008)

These recommended acceptable berth occupancy ratios according to the type of quay or terminal and the berth capacity formula mentioned previously make it possible to calculate the annual capacity of any terminal or facility.

#### 5.3.2.3. Recommendations on productivity and level of service: evolution

While references to productivity scores are relatively abundant in the literature on this subject, there are very few in relation to regulating levels of service. Both categories of indicators, productivity and level of service, are available, for example:

- In the literature that deals with the clauses in concession contracts, due to addressing the need to guarantee the quality of the services provided by the operator (UNCTAD, 1998; Kent and Ashar, 2010);
- In comparative analyses of ports (Marconsult, 2000; Productivity Commission, 2003; Doerr and Sanchez, 2006; OSC, 2007; Drewry, 2009, etc.);
- When estimating the capacity of ports by geographical region or the capacity of operators (Marconsult, 2000; OSC, 2006; Drewry, 2009, etc.).

UNCTAD (1998), for example, contributes with a series of performance indicators to be included in concession contracts in the case of container terminals (Table 17). While the scores are now out of date, it is interesting to consider the reflection on the need for improvement, in different time frames, throughout the duration of the contract.

**Table 17. Examples of performance indicator scores for a container terminal contract**

| Indicator | First 2 years | 3 - 8 years | >9 years |
|---|---|---|---|
| Minimum annual throughput | 350,000 TEU | 400,000 TEU | 500,000 TEU |
| | 300,000 moves | 360,000 moves | 420,000 moves |
| Gross output in moves per vessel per 24 hours at berth | 500 | 750 | 1,000 |
| Number of TEU per metre of quay per year | 300 | 400 | 500 |
| Maximum allowable berth occupancy (%) | 45 | 45 | 50 |
| Average turnaround time per vessel call (in hours) ($T_p$) | 24 | 20 | 18 |

Source: UNCTAD (1998)

Kent and Ashar (2010) contribute another set of productivity indicators and their scores (Table 18) and incorporate two new aspects:

- Scores for the indicators of receipt and delivery operations; and,
- The category of level of service, both for the ship-to-shore subsystem and also for receipt and delivery.

**Table 18. Recommendations on productivity and level of service**

| | | | Level of service | | |
|---|---|---|---|---|---|
| **Indicator** | **Additional sub-division** | **Unit** | **Optimal** | **Acceptable** | **Unacceptable** |
| | | **Productivity** | | | |
| Net productivity of vessel at berth (net time at berth) | >1,000 moves/call | moves/hour | >80 | 60-80 | <60 |
| | 500-1,000 moves/call | moves/hour | >50 | 35-50 | <35 |
| | <500 moves/call | moves/hour | >25 | 20-25 | <20 |
| Net crane productivity (net time) | STS | moves/hour | >30 | 25-30 | <25 |
| | Mobile crane | moves/hour | >25 | 20-25 | <20 |
| | Vessel | moves/hour | >15 | 10-15 | <10 |
| Berth Throughput Productivity | Measured annually | TEU/Berth-m | >1,250 | 750-1,250 | <750 |
| | | **Relative waiting time** | | | |
| Ship Delay | Containers | hour | <2 | 2-4 | >4 |
| | Bulk | hour | <4 | 4-12 | >12 |
| Truck Delay (receipt and delivery) | Containers | hour | <0.5 | 0.5-1 | >1 |
| | Bulk | hour | <2 | 2-4 | >4 |
| Truck Turn Time (receipt and delivery) | Containers | hour | <0.5 | 0.5-1 | >1 |
| | Bulk | hour | <2 | 1-2 | >2 |

**NOTE: The nomenclature is the one used in the Manual; values come from the original table.**
**Source: Fundación Valenciaport adapted from Kent and Ashar (2010)**

### 5.3.2.4. Specific reference to container terminals

Bearing in mind the foregoing considerations and the study of Drewry (2002 and 2010), which proposes a value for berth capacity at container terminals according to the type of traffic and the size of the terminal itself (see Table 19), we now delve deeper, as regards the methodology, into the estimation of annual berth capacity per metre by proposing a series of ranges of values depending on the type of traffic, vessel productivity at berth and the number of berths (see Table 20).

Table 19. Container terminal berth capacity according to terminal size and type of traffic

| Berth capacity (TEU per metre of quay p.a.) | | | |
|---|---|---|---|
| Mixed arrival schedule, competition encouraged, free-market tariff, gateway port | 1,300 | 1,600 | 1,700 |
| Mixed arrival schedule, regulated tariff, high berth occupancy, common user facility, gateway port | 1,000 | 1,200 | 1,500 |
| Tightly scheduled ship arrivals, low priority given to competition policy, high transhipment activity | 800 | 1,000 | 1,200 |
| SCENARIO | SIZE OF PORT TERMINAL (quayline) | | |
| | Small > 250 m < 500 m | Medium > 500 m < 1,000 m | Large > 1,000 m |

Source: Drewry (2002 and 2010)

The range of values (Table 20) were calculated for terminals with 300 metre berths and three different waiting times that represent 5%, 10% and 20% of service time. The value of 10% (0.1) is highlighted in bold type as a maximum value recommended by Agerschou (2004), which falls within the range considered by Thoresen (2003) of between 5% and 20%.

**Table 20. Annual capacity per metre of berth according to type of traffic, vessel productivity at berth and number of berths (berths of 300 metres in length)**

| System and traffic profile | Annual average productivity of vessel at berth (*P*) (Cont./h) | **BERTH CAPACITY – CONTAINER TERMINAL** (containers / metre of berth and year) Length of each berth = 300 m; $t_{year}$ = 8,640 h Relative waiting time: $T_w/T_s$ = 0.05 – **0.10** – 0.20 | | | | | |
|---|---|---|---|---|---|---|---|
| $E_2/E_4/n$ Tightly scheduled calls | 80 | 505 - **710** - 990 | 990 - **1,220** - 1,450 | 1,220 - **1,450** - 1,655 | 1,405 - **1,610** - 1,795 | 1,520 - **1,680** - 1,865 | 1,590 - **1,770** - 1,930 |
| | 70 | 440 - **625** - 865 | 865 - **1,065** - 1,270 | 1,065 - **1,270** - 1,450 | 1,230 - **1,410** - 1,570 | 1,330 - **1,470** - 1,630 | 1,390 - **1,550** - 1,690 |
| | 60 | 380 - **535** - 740 | 740 - **915** - 1,085 | 915 - **1,085** - 1,240 | 1,050 - **1,210** - 1,345 | 1,140 - **1,260** - 1,400 | 1,190 - **1,330** - 1,450 |
| | 50 | 315 - **445** - 615 | 615 - **760** - 905 | 760 - **905** - 1,035 | 875 - **1,005** - 1,120 | 950 - **1,050** - 1,165 | 990 - **1,105** - 1,210 |
| $M/E_4/n$ Random inter arrivals times | 70 | 140 - **280** - 480 | 540 - **725** - 985 | 785 - **985** - 1,230 | 945 - **1,145** - 1,370 | 1,085 - **1,270** - 1,470 | 1,165 - **1,350** - 1,530 |
| | 60 | 120 - **240** - 415 | 465 - **620** - 845 | 670 - **845** - 1,050 | 810 - **985** - 1,175 | 930 - **1,085** - 1,260 | 1,000 - **1,155** - 1,310 |
| | 50 | 100 - **200** - 345 | 385 - **515** - 705 | 560 - **705** - 875 | 675 - **820** - 975 | 775 - **905** - 1,050 | 835 - **965** - 1,090 |
| | 40 | 80 - **160** - 275 | 310 - **415** - 560 | 445 - **560** - 700 | 540 - **655** - 780 | 620 - **725** - 840 | 665 - **770** - 875 |
| Number of berths (*n*) | | 1 | 2 | 3 | 4 | 5 | 6 |

**Source: Fundación Valenciaport**

In accordance with Section 5.3.2.1 regarding traffic profiles, the distribution of arrival times to common-user terminals is a random function (M), whereas the function corresponding to dedicated terminals is a distribution between the case of random inter arrivals times (M) and terminal with tightly scheduled calls ($E_2$).

The Appendix 3 provides a table similar to the previous one but considering the cases of 250 metres berth and 350 metres berth. Graphs are also included.

**Annual average productivity of vessel** at berth, *P*, stems from the ratio between annual output (expressed in container movements) and the aggregate of the gross berth times. Annual output or traffic involves origin/destination container moves by land and transhipment moves (loading and unloading).

*P* depends on the average number of cranes used, their productivity and idle time. For example, a vessel average productivity at berth of 50 cont./h is the result of operating with 2 cranes at 25 cont./h (including idle time) or with an average of 2.5 cranes at 20 cont./h. It must be underlined that productivity is gross (calculated considering idle time when vessel is at berth) and must not be confused with net productivity, which is calculated on the sum of net times at berth (see Figure 34, Chapter 4) and consequently it results higher because the output (traffic) is divided by a lower sum of times.

The annual average productivity of vessel at berth depends on the average call size moves (containers) in such a way that the higher the call size moves are, the higher the productivity that can be achieved or required is. Table 21 by Stenvert and Penfold (2004) illustrates the relation between the call size and the vessel productivity at berth. It only remains to add that the growth potential of the average call size moves in the medium and long term allows it to improve the productivity. Therefore, *P* is a dynamic variable itself. Appendix 4 delves into the concept of annual average productivity of vessel at berth.

**Table 21. Relation between call size and performance**

| Vessel size (TEU) | Call size (moves) | Vessel productivity at berth (moves/h) | Crane productivity (moves/h) | Average number of cranes |
|---|---|---|---|---|
| 4,400 | 1,067 | 44 | 22 | 2 |
| 5,200 | 1,261 | 53 | 22 | 2.4 |
| 6,200 | 1,503 | 63 | 22 | 2.8 |
| 6,200 | 2,104 | 88 | 26 | 3.4 |
| 8,800 | 2,987 | 124 | 30 | 4.2 |

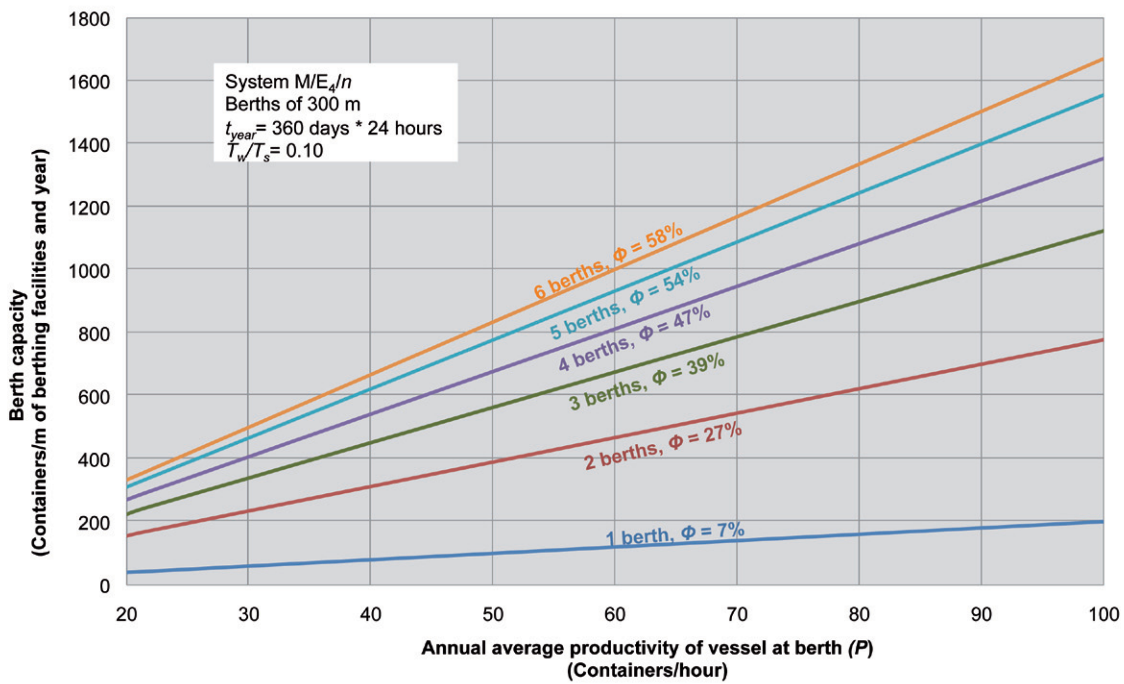
**Source: Stenvert and Penfold (2004)**

Graph 6 and Graph 7 portray annual capacity in containers per metre of berthing facility, according to the productivity of the vessel berthed and the number of berths (each berth is 300 metres long), 0.10 relative waiting time and terminals with $M/E_4/n$ and $E_2/E_4/n$ queue systems, respectively.

In the calculation operational time per year ($t_{year}$) is considered to be 24 hours and 360 days.

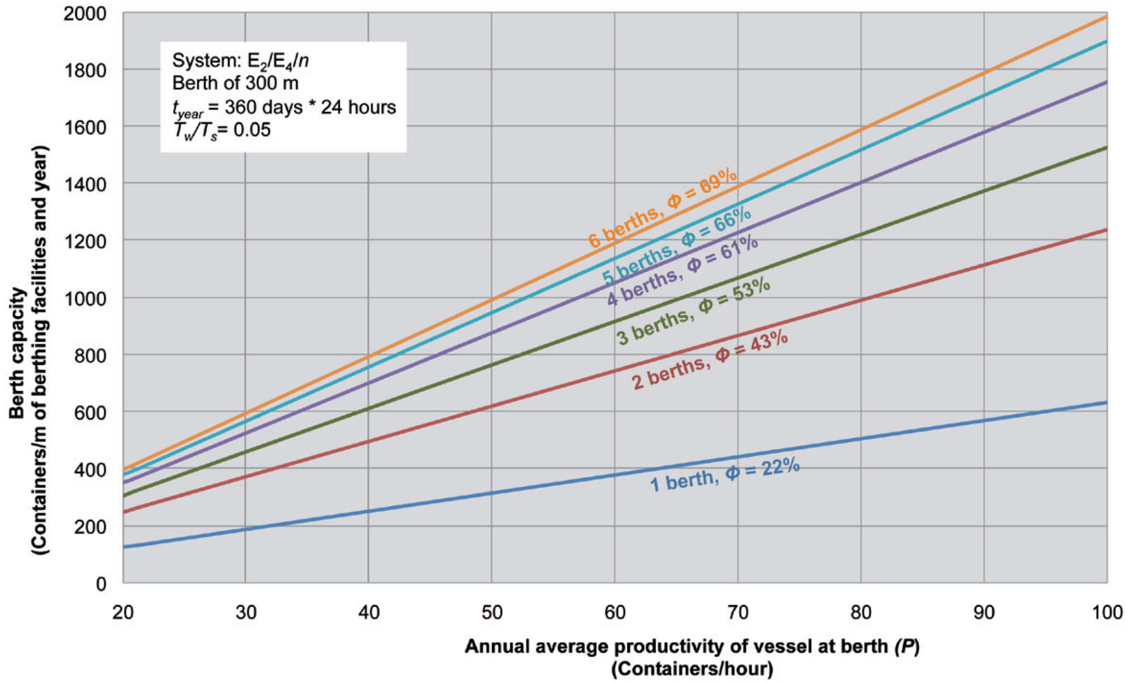
Graph 4 and Graph 5 are nearly the same but the relative waiting time is considered to be 0.05. Graph 8 and Graph 9 depict the annual capacity for a relative waiting time of 0.20.

Graph 4. Annual berth capacity for M/E$_4$/*n* queue system and relative waiting time of 0.05 with berths of 300 metres in length



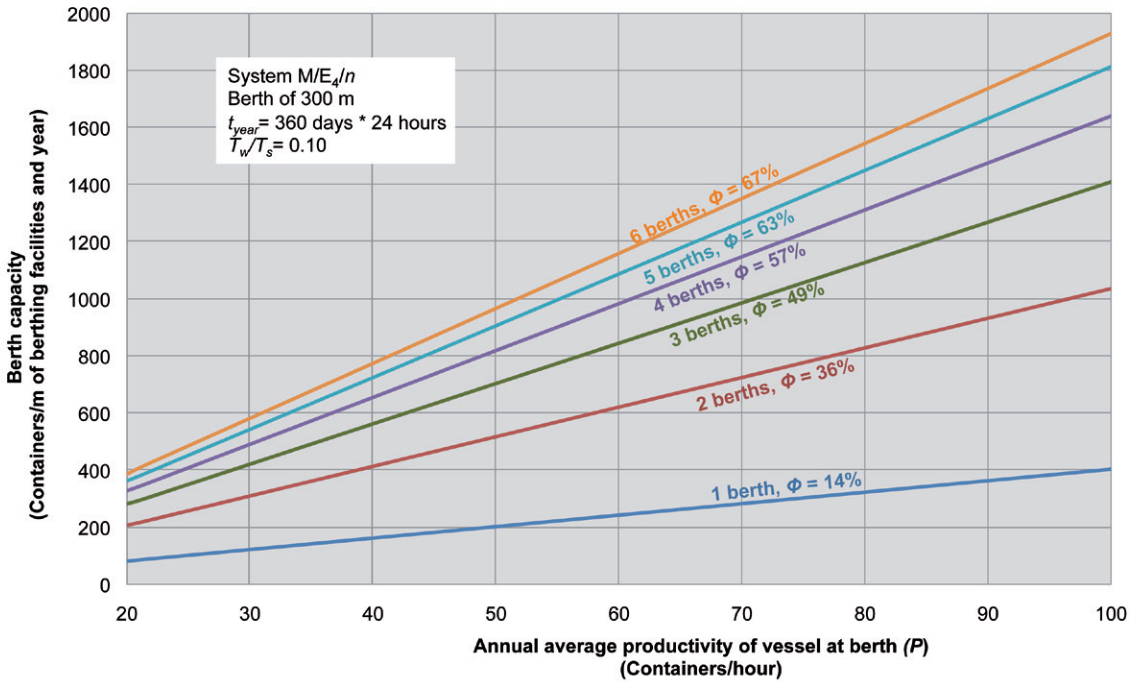

Source: Fundación Valenciaport

Graph 5. Annual berth capacity for $E_2/E_4/n$ queue system and relative waiting time of 0.05 with berths of 300 metres in length



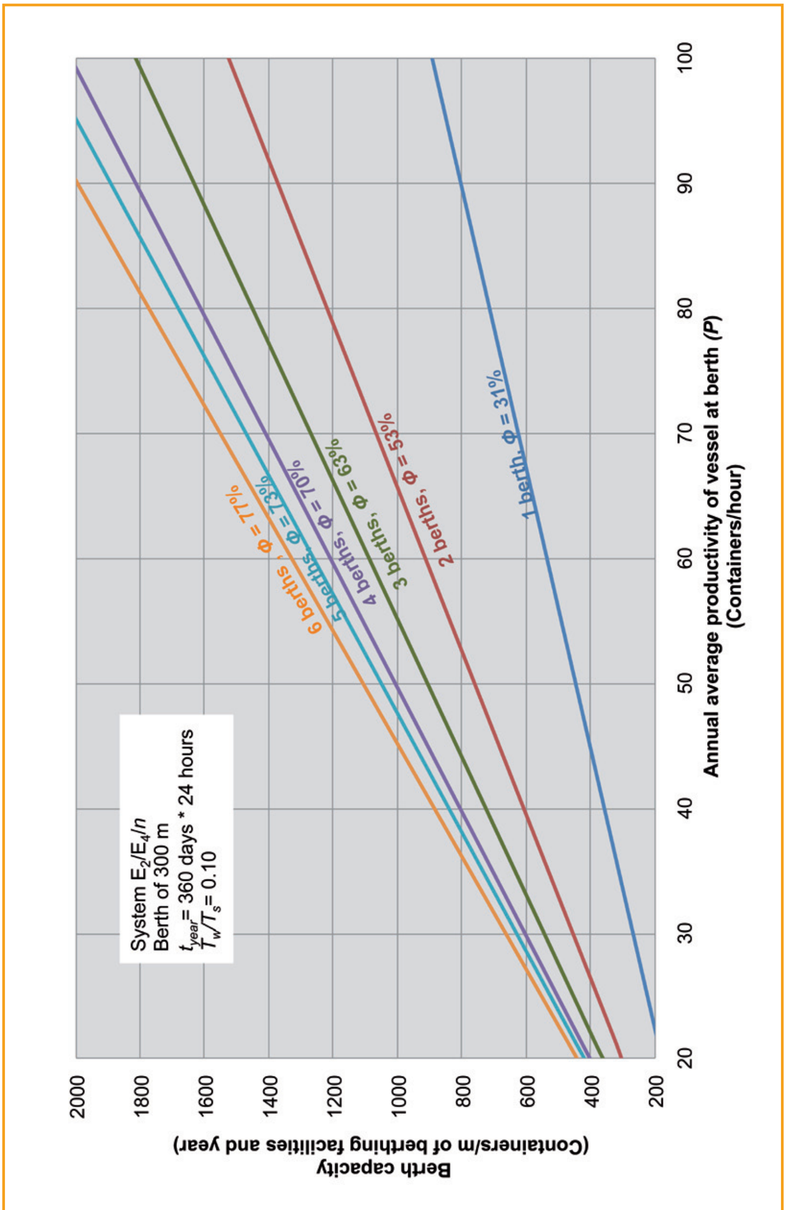

Source: Fundación Valenciaport

Graph 6. Annual berth capacity for M/$E_4$/*n* queue system and relative waiting time of 0.10 with berths of 300 metres in length



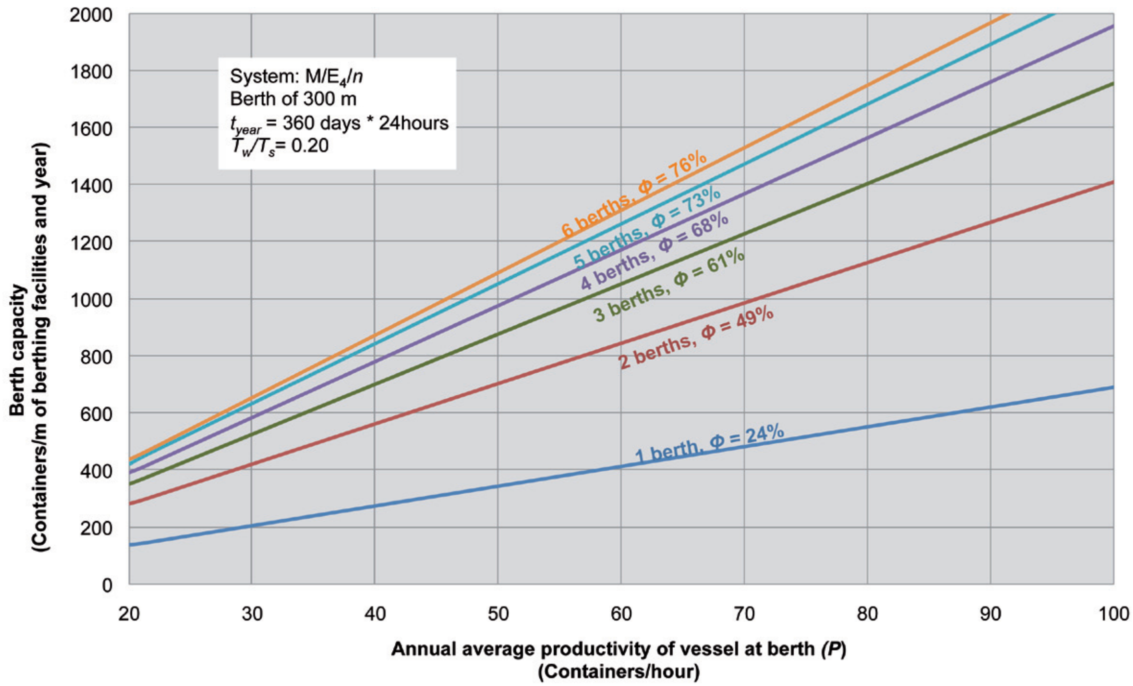

Source: Fundación Valenciaport

Graph 7. Annual berth capacity for $E_2/E_4/n$ queue system and relative waiting time of 0.10 with berths of 300 metres in length



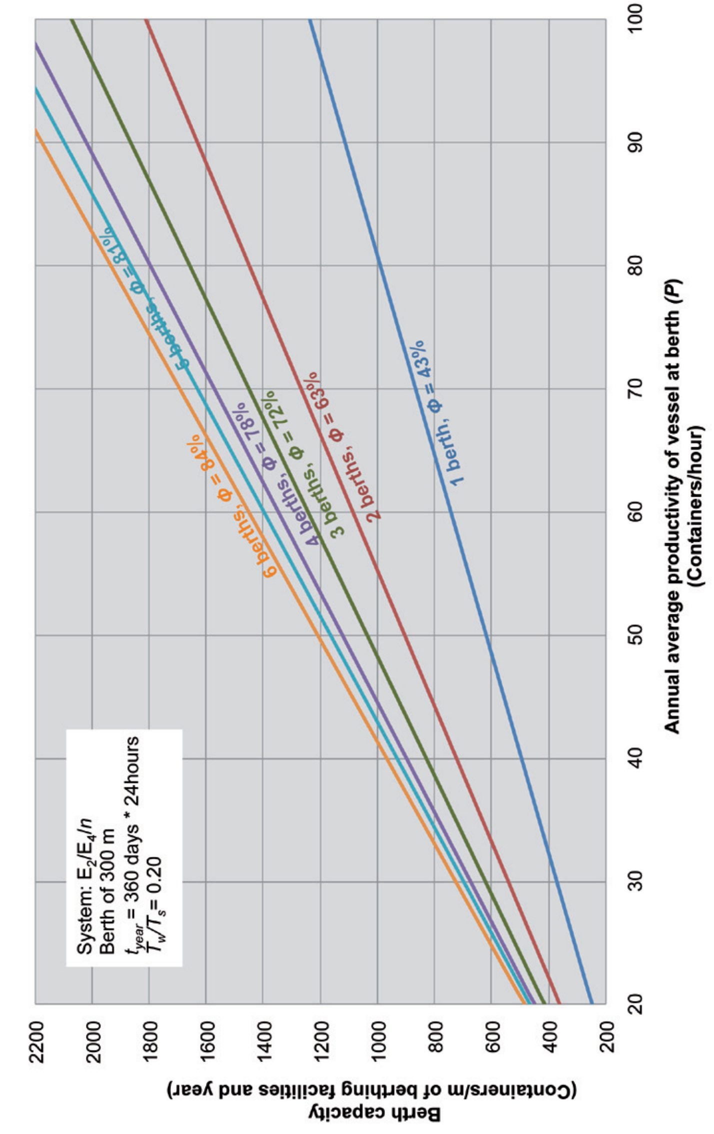

Source: Fundación Valenciaport

Graph 8. Annual berth capacity for $M/E_4/n$ queue system and relative waiting time of 0.20 with berths of 300 metres in length




Source: Fundación Valenciaport

Graph 9. Annual berth capacity for $E_2/E_4$ /*n* queue system and relative waiting time of 0.20 with berths of 300 metres in length




Source: Fundación Valenciaport

It must be said that the capacity scores per metre of berth and those referring to vessel productivity at berth, displayed in both Table 20 and also the graphs above, are expressed in terms of containers/hour. Therefore, in order to determine berth capacity in TEU/hour, a TEU/container conversion factor needs to be applied. Assuming 50% of containers are 40', the factor would be 1.5. However, the percentage of 40' containers in some ports is higher, which implies a higher ratio.

According to Graph 6 and Table 20, a terminal using an $M/E_4/n$ ($T_w/T_s$=0.10) queue system with 3 berths has 36% more capacity, per berth, than a terminal with 2 berths. Furthermore, terminals with 4, 5 and 6 berths have 58%, 75% and 86% more capacity respectively, per berth, than a terminal with 2 berths. That is, **the number of berths has a non proportional impact on terminal capacity**.

On the other hand, when the relative waiting time ($T_w/T_s$) of a terminal with 3 or more berths decreases by 100% (from 0.10 to 0.20, i.e., vessel waiting time doubles while service time remains the same), capacity increases by less than 25%.

**5.3.2.5. Proposal of levels of service**

In order to provide a different approach regarding the current bibliography, Table 22 suggests the following rates of Levels of service at the **berthing facilities or ship-to-shore subsystem**. They are associated to the perception of quality by the shipping companies in terms of the relative waiting time ratio ($T_w/T_s$) and the annual average productivity of vessel at berth (*P*).

Table 22. Level of service proposal for the ship to shore subsystem or berthing facilities

| Level of service | Relative waiting time | LEVELS OF SERVICE | | | |
|---|---|---|---|---|---|
| D | > 0.20 | - | - | - | - |
| C | 0.10 - 0.20 | - | CC | BC | AC |
| B | 0.05 - 0.10 | - | CB | BB | AB |
| A | up to 0.05 | - | CA | BA | AA |
| | | < 35 | 35-50 | 50-65 | > 65 |
| | | Annual average productivity of vessel at berth (*P*) (cont./h) | | | |
| | | D | C | B | A |
| | | Level of service | | | |

Source: Fundación Valenciaport

The proposal includes 9 levels of service (AA, AB,..., CC) and it is related to the dimension of the berth capacity (expressed in containers per metre of berthing facility and year) through graphics that depicts the link between the aforementioned capacity and the annual average productivity of vessel at berth (*P*) for different levels of relative waiting time, so you can graphed in such dimensions.

Tables 23 and 24 display the levels of service taking into account both dimensions and also in terms of berth capacity (in containers and TEU per metre of berthing facility respectively) in the $M/E_4/2$ case. It must be noted that the acceptable minimum level (CC) that has been admitted for the annual average productivity of vessel at berth (*P*) is 35 moves/hour (inland O/D and transhipment). In the case of a relative waiting time of 0.2, the result is a berth capacity of 494 containers per metre and year. It is equivalent to 741 TEU considering the ratio 1.5 TEU/cont. Graph 10 portrays the foregoing case including additional levels of service in the case of 3 berths.

Table 23. Level of service for $M/E_4/2$ case and berth of 300 m (Berth capacity in containers/metre)

| Level of service | Relative waiting time | LEVELS OF SERVICE (System $M/E_4/2$) Berth of 300 m Berth capacity (cont./m) | | | |
|---|---|---|---|---|---|
| D | > 0.20 | - | - | - | - |
| C | 0.10 – 0.20 | - | 494-706 | 706-917 | > 917 |
| B | 0.05 – 0.10 | - | 363-518 | 518-674 | > 674 |
| A | up to 0.05 | - | 272-389 | 389-505 | > 505 |
| | | < 35 | 35-50 | 50-65 | > 65 |
| | | Annual average productivity of vessel at berth (*P*) (cont./h) | | | |
| | | D | C | B | A |
| | | Level of service | | | |

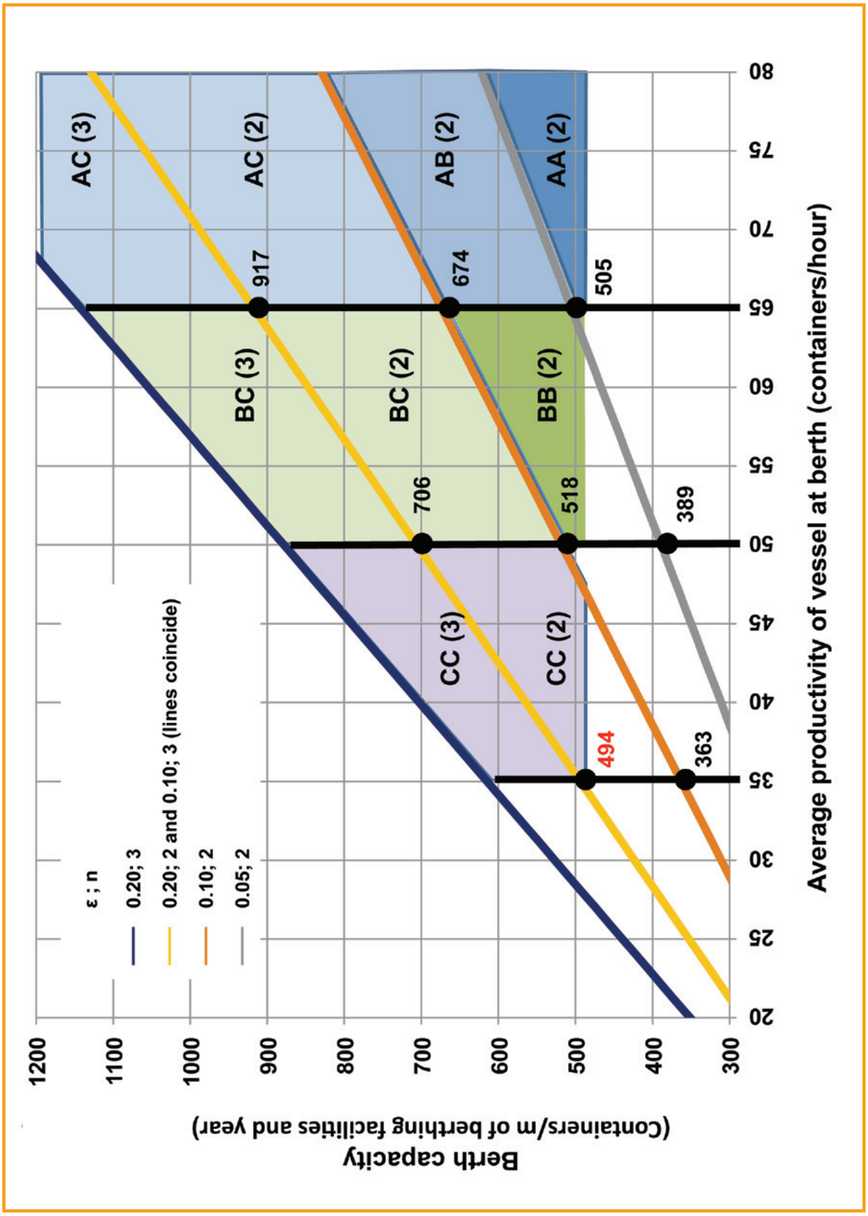
Source: Fundación Valenciaport

Table 24. Level of service for $M/E_4/2$ case and berth of 300 m (Berth capacity in TEU/metre)

| Level of service | Relative waiting time | LEVELS OF SERVICE (System $M/E_4/2$) Berth of 300 m Berth capacity (TEU/m) | | | |
|---|---|---|---|---|---|
| D | > 0.20 | - | - | - | - |
| C | 0.10 - 0.20 | - | 741-1,058 | 1,058-1,376 | > 1,376 |
| B | 0.05 - 0.10 | - | 544-778 | 778-1.011 | > 1,011 |
| A | up to 0.05 | - | 408-583 | 583-758 | > 758 |
| | | < 35 | 35-50 | 50-65 | > 65 |
| | | Annual average productivity of vessel at berth (*P*) (cont./h) | | | |
| | | D | C | B | A |
| | | Level of service | | | |

Source: Fundación Valenciaport

Graph 10. Level of service for M/E$_4$/*n* case for *n*=2 and *n*=3 and berth of 300 m




Source: Fundación Valenciaport

## 5.4. Storage capacity

This section studies how to calculate the storage capacity or yard area capacity of port terminals from a planning and management perspective. In this sense, two aspects can be considered:

- The area required to cater for a given amount of traffic; and,
- The maximum amount of traffic that can be catered for by a given area.

Yard area capacity or the storage subsystem capacity depends on the following factors:

- Cargo format;
- Area density and storage system productivity;
- Stack height;
- Cargo dwell time in the terminal (turnover);
- Seasonal variations (peaks and slumps) in traffic;
- Terminal floor plant shape and size; and
- Yard management (particularly, the level of TOS development).

### 5.4.1. Definition

The generic formula for capacity by area is (ROM 2.1 – González-Herrero *et al.,* 2006):

$$C_{Y_i} = \frac{A_i \times h_i \times 365 \times g_o \times \alpha_o}{T_{dw} \times s_i}$$

Where,

$C_{Yi}$: Annual storage capacity according to type of traffic i (tonnes, containers or TEU, units per year). Transhipment traffics are counted only once.

$A_i$: Storage area according to type of traffic i (in $m^2$ or ha).

$h_i$: Stack factor, defined as the coefficient between average stack height and maximum stack height, according to type of traffic i. Increasing this factor assumes a greater number of removals of the goods or of the stored transport elements.

$g_o$: Occupancy factor, or peak factor, which makes it possible to consider a non uniform distribution of cargo arrivals and departures throughout the year, together with acceptable frequency of area saturation. In the absence of other data, a normal value of 0.80 can be taken.

$\alpha_o$: Net storage coefficient, defined as the percentage of storage area and auxiliary services devoted to storing cargo, including internal roads, in regard to the total.

$T_{dw}$: Average cargo transit time or dwell time in the storage area (in days). This factor is highly variable, depending on the type of traffic, on whether the port area is used as a temporary warehouse in the short term or as a strategic reserve, and on the local conditions of the site.

$s_i$: Gross unit area required (in $m^2$ or ha) per type of traffic *i* per tonne, container, TEU or unit, considering both the net area for stacks and also the internal roads therein. This parameter depends on the type of cargo or transfer vehicle, the operation and handling equipment used in the storage area, the layout and o rganisation of the area, together with area density and maximum stack height. In the absence of other data, the following values can be taken as a reference:

- Ro-Ro traffic: 20 $m^2$/Ut in the case of cars and 120 $m^2$/Ut for trucks and chassis.
- Break bulk non containerized and dry bulk: this value can be obtained from the stack layout and the normal maximum storage heights included in the ROM 0.2-90 (MFOM and OPPE, 1990) – see Appendix 3.
- Containers: consider the calculations and specifications that appear in the next section.

## 5.4.2. Specific reference to container terminals

This section makes a specific reference to calculating storage capacity for container terminals. First, some of the concepts used are defined; next, the formula for the calculation of the storage capacity of container terminals is presented, together with the factors that affect it and, finally, some recommendations are included regarding the area capacity of such terminals.

### 5.4.2.1. Concepts

Some of the concepts used in this section are defined below in order to establish the grounds for calculating capacity:

**Terminal area ($A_T$)** ($m^2$ or ha): Total area of the terminal delimited by fences.

**Storage area or yard ($A_Y$)** ($m^2$ or ha): Terminal area used to store containers. It includes the area used for storage infrastructure, that is, the aisles between blocks of containers (working, intersecting and turning aisles), equipment rails, etc.

**Ground slot** (units): Number of ground TEU slots available at the terminal at a terminal. The area one TEU occupies is considered to be 15 $m^2$.

**Slot**: Any possible location for a container in the yard taking into account yard layout (3D).

**Net storage area ($A_{YN}$)** ($m^2$ or ha): Terminal area used strictly for storing containers, that is considering only the area that is occupied by ground slots, without counting the space occupied by storage infrastructure.

$$A_{YN} = \#\ \textit{ground slot} \times 15\ m^2$$

**Terminal area density ($D_T$)** (Ground slots/ha): Number of slots per area in the terminal:

$$D_T = \#\ \textit{ground slot} / A_T$$

**Storage area density ($D_Y$)** (Ground slots/ha): Number of slots per storage yard area:

$$D_Y = \#\ \textit{ground slot} / A_Y$$

**Dwell time ($T_{dw}$)** (days): Average dwell time of containers in the terminal storage yard.

**Average number of turnovers per year**: $365/T_{dw}$

**Static storage capacity ($C_S$):** The capacity per area of the container terminal taking into account only area density (Ground slots/ha) and average operational stacking height. It is the maximum number of containers that can be stored in the yard per hectare, considering the layout of the yard and an appropriate operational.

**Annual yard capacity ($C_Y$):** Terminal yard capacity considering the (annual) turnover of containers, together with area density and average stacking height.

### 5.4.2.2. Definition

In the specific case of container terminals, the generic formula for area capacity is:

$$C_Y = \#\,ground\_slot \times h \times \frac{365}{T_{dw}}$$

Where,

$C_Y$: Terminal annual yard capacity (TEU/year)
$h$: Average operational height of stacks
$T_{dw}$: Average dwell time of containers in the storage area (in days)
$365/T_{dw}$: Average number of turnovers per year

Finally, expressed in terms of the maximum stack height and of the operational factor (*K*):

$$C_Y = \#\,ground\_slot \times H \times \frac{365}{T_{dw}} \times K$$

Where,

$C_Y$: Terminal annual yard capacity (TEU/year)
$H$: Maximum height of stacks or nominal height of equipment
$T_{dw}$: Average dwell time of containers in the storage area (in days)
$K$: Operational factor
$365/T_{dw}$: Average number of turnovers per year

$K$ is the operational factor for the storage system used and which reduces maximum height. This is necessary to work in operating conditions and not have to reposition too many containers (unproductive movements). The higher the stack is, the more containers will have to be moved to reach one in particular. This factor normally ranges from 0.55 to 0.70 (Wieschemann and Rijsenbrij, 2004).

Both the height and dwell time of containers can take different values for different types of traffic. For example:

- Empty containers are stacked higher and dwell longer;
- Import and export containers are stacked the same height but dwell for different amounts of time;
- Import containers are stacked lower;
- Different dwell times depending on the service.

The formula above is simplified by not differentiating the average operational heights and dwell times of specific types of containers (full/empty; import-export/transhipments, reefers, etc.). This formula can take into account the characteristics of the traffic distinguishing as many categories as data available or that the terminal simulates. By way of example, the formula for considering the differences between empty and full container traffic would be as follows:

$$C_Y = \#\, ground\_slot \times 365 \times \left(\%\,\text{full} \times \frac{H_F \times K_F}{T_F} + \%\,\text{empty} \times \frac{H_E \times K_E}{T_E}\right)$$

Where,

% full: percentage of full containers
$H_F$: Maximum stack height of full containers
$K_F$: Operational factor for full containers
$T_F$: Average dwell time of full containers
% empty: percentage of empty containers
$H_E$: Maximum stack height of empty containers
$K_E$: Operational factor for empty containers
$T_E$: Average dwell time of empty containers

The previous formula provides a different result when comparing to the annual berth capacity. This is due to the fact that transhipment containers are included twice. In order to obtain the value of annual storage capacity equivalent to the annual berth capacity it is necessary to consitder the expression as follows:

$$C_{Y\,eq\,B} = K_{YTS} \times C_Y$$

Where,

$C_{Y\,eq\,B}$: Annual storage capacity equivalent to annual berth capacity
$K_{YTS}$: Container yard capacity vs. container berth capacity transformation coefficient, and the formula to calculate this coefficient is proposed is:

$$K_{YTS} = \frac{200}{2 \times \%O/D + \%TS}$$

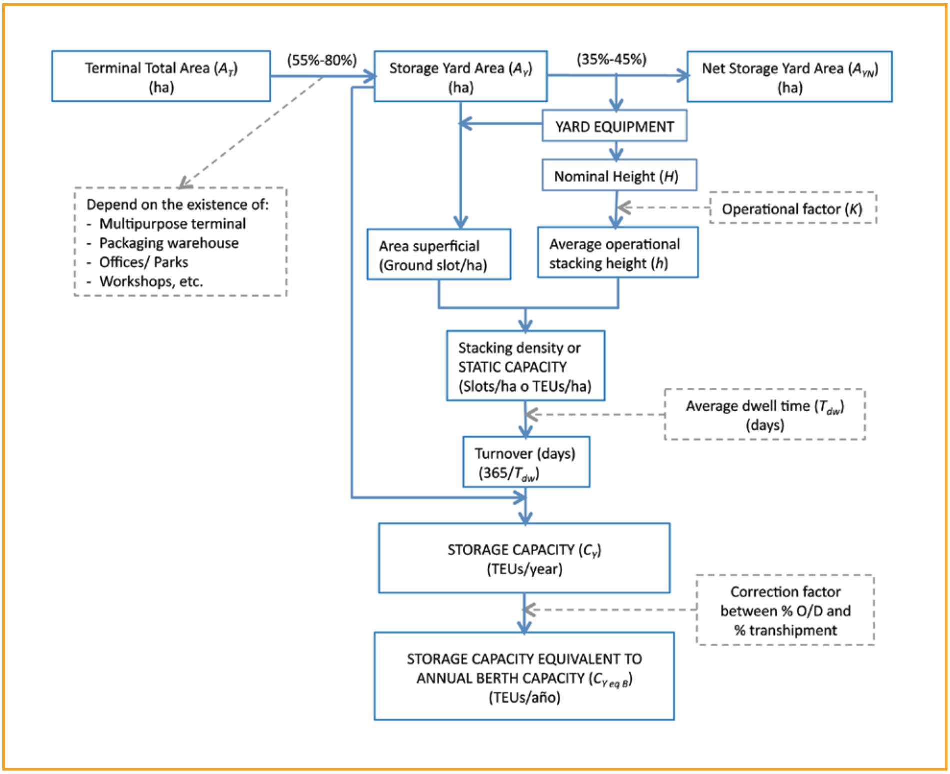
Where,

$\%O/D$: percentage of inland origin and destiny traffic (local cargo) over total traffic
$\%TS$: percentage of transhipment traffic over total traffic

Likewise, for instance, if transhipment traffic is null, then $K_{YTS}$ is 1, but if it is 100%, then $K_{YTS}$ is 2, and if transhipment traffic is 50%, $K_{YTS}$ is 1.33.

Figure 38 is a diagram of the key elements that must be considered when calculating the storage capacity of container terminals, together with the relationship between them.

Figure 38. Container terminal storage capacity




Source: Fundación Valenciaport

### 5.4.2.3. Factors that influence storage capacity

The main factors that influence capacity are:

- **Area density** (ground slots per hectare of the yard);
- **Operational average stacking height**; and,
- Container **dwell time** in the terminal.

**Area density: ground slots per area**

The total area of a port terminal includes the storage area, the area for ship-to-shore operations, offices, equipment warehouses and workshops, parking areas and others that may or may not exist depending on the type of terminal, such as a Container Freight Station (CFS), a container repair workshop, a multimodal terminal (see Figure 22 in Chapter 2), etc. As defined previously and according to some authors, the storage area (marked in orange in the same figure) is the part of the terminal used to store containers that, as mentioned, includes the roads and aisles between blocks (Germanischer Lloyd Certification, 2008; Wieschemann and Rijsenbrij, 2004; Kuznetsov, 2008).

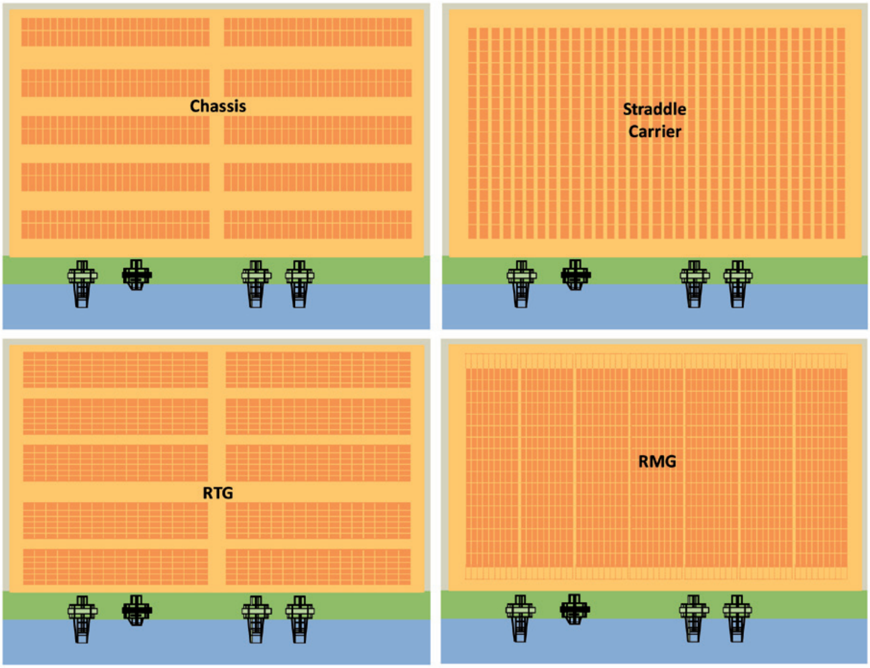
Area density stems from the ratio between the number of ground slots and the storage area. Area density in the case of each storage system (chassis, reachstackers, straddle carriers, RTGs, RMGs, etc.), measured in ground slots/m2 or ground slots/ha, depends on the distribution of ground slots, aisles and roads, the geometry of the terminal yard (see examples in Figure 39) and yard management. Area density, if expressed as a percentage of the utilization of the stacking area, then is a measure of use of such resource.

Generally, when managing the yard, different areas are assigned for different traffics, like import, export, transhipment and empty containers; for reefers; for rail loading and unloading and for special containers (dangerous goods, oversized containers, etc.). Following safety criteria, dangerous cargo can be spread around the terminal or stored in a special area for that type of cargo, also depending on the nature of the cargo.

Apart from the above management criteria, terminals can take into account other factors as many as they consider convenient to improve the organisation of the yard. For example, large terminals can reserve space in each of the foregoing areas for important clients (depending on the services – lines – and ports of destination, etc.).

In general, the aforementioned conditions derived from the distribution of the yard will reduce area density and, therefore, the capacity of the terminal storage subsystem.

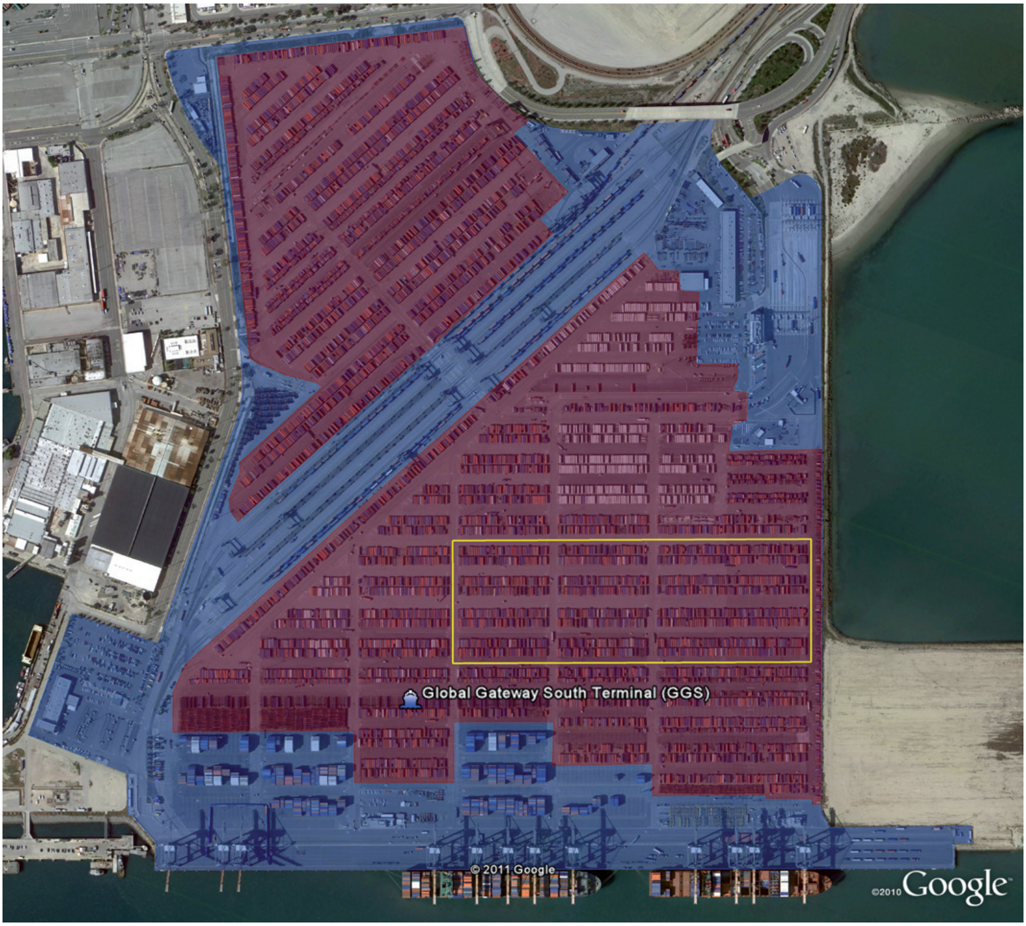
Figure 39. Yard layouts according to type of terminal




Source: Fundación Valenciaport

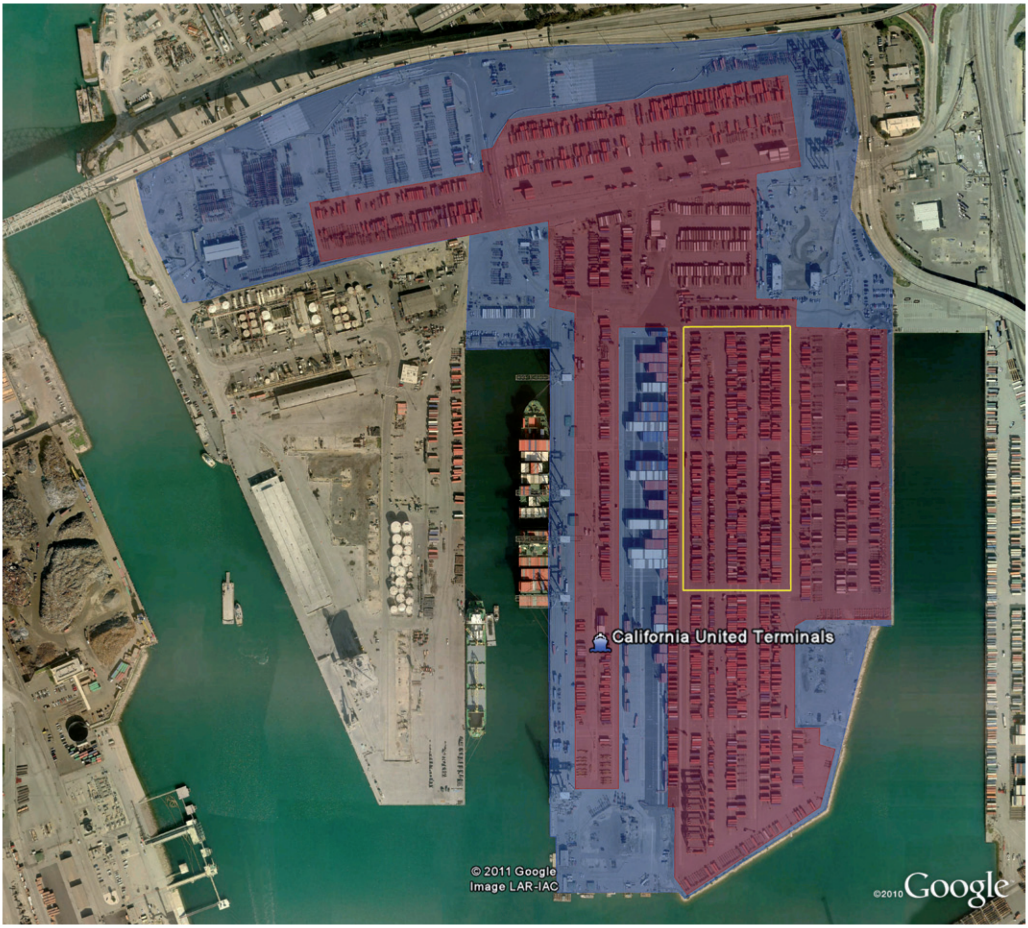
Next, area density (ground slots/ha) has been calculated for several container terminals at international level. Below are the aerial photographs of these facilities with their respective total areas (in blue) and storage areas reserved for the yard equipment the terminal uses (in red), see Figure 40. Using these photographs as a basis, together with the data provided by the terminals themselves (and, otherwise, the data found on their web pages), the area density of their storage yards has been calculated, taking into account the yard equipment used in each case.

Figure 40. Chassis yard at Global Gateway South (Port of Los Angeles – USA)




Source: © 2011 Google

Figure 41. Chassis yard at California United Terminals (Port of Los Angeles – USA)

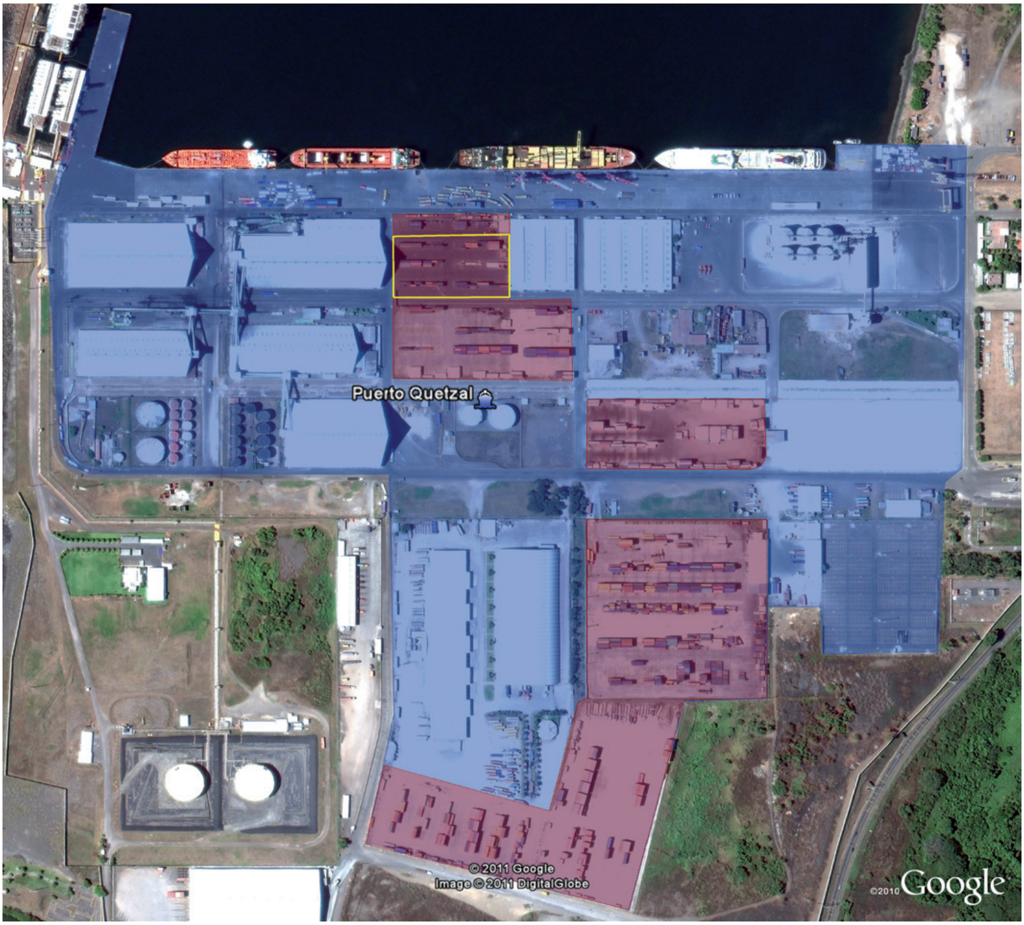



Source: © 2011 Google. Image LAR-IAC

Figure 42. Reachstackers yard at Terminal P. Castellon (Port of Castellón – Spain)


Source: © 2011 Google. © 2011

Figure 43. Reachstackers yard at Puerto Quetzal (Puerto Quetzal – Guatemala)

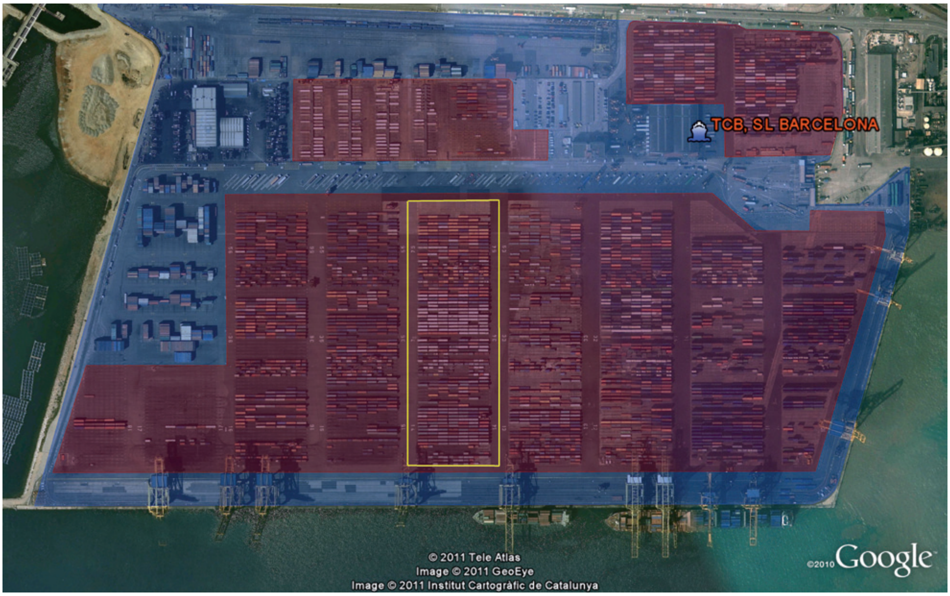



Source: © 2011 Google. Image © 2011 DigitalGlobe

Figure 44. Reachstackers yard at San Antonio Terminal Internacional (Port of San Antonio – Chile)


Source: © 2011 Google. Image © 2011 GeoEye. © Inav/Geosistemas SRL

Figure 45. Straddle carriers yard at TCB, S.L. (Port of Barcelona – Spain)




Source: © 2011 Google. © 2011 Tele Atlas. Image © 2011 GeoEye. Image © 2011 Institut Cartogràfic de Catalunya

Figure 46. Straddle carriers yard at Eurogate Container Terminal (Port of Hamburg – Germany)


Source: © 2011 Google. Image © 2011 AeroWest

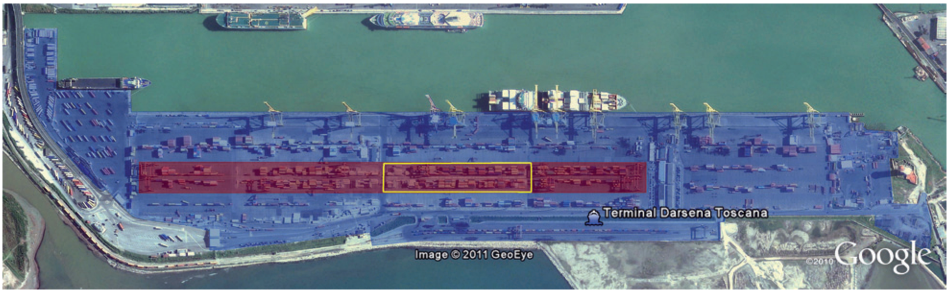
Figure 47. RTGs (6+1) yard at Noatum Container Terminal Valencia (Port of Valencia – Spain)


Source: © 2011 Google. © 2011 Tele Atlas

Figure 48. RTGs (6+1) yard at MSC Terminal Valencia (Port of Valencia – Spain)

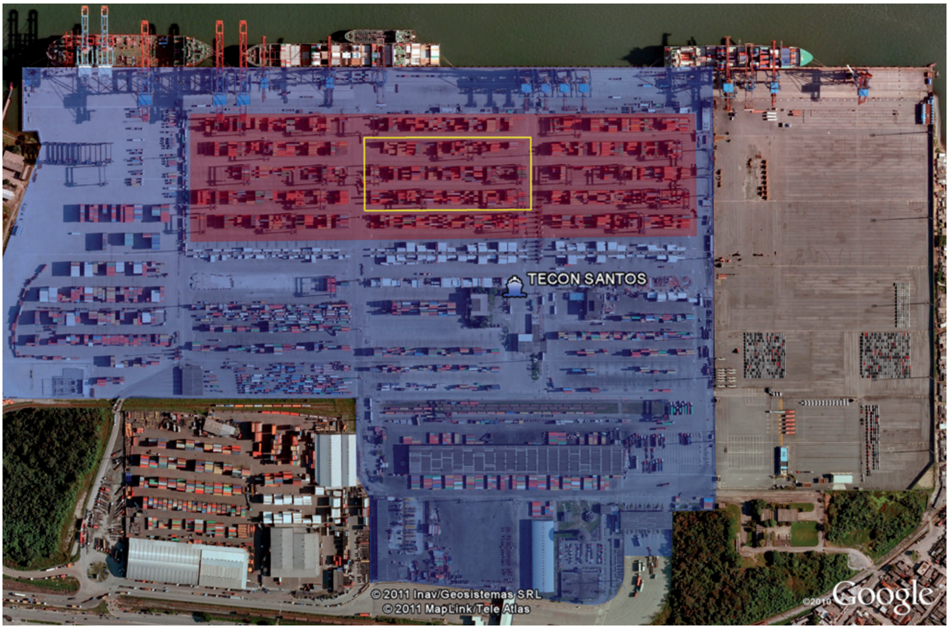

Source: © 2011 Google. © 2011 DigitalGlobe © 2011 Tele Atlas

Figure 49. RTGs (6+1) yard at Terminal Darsena Toscana (Port of Livorno – Italy)




Source: © 2011 Google. © 2011 GeoEye

Figure 50. RTGs (7+1) yard at TECON Santos (Port of Santos – Brazil)

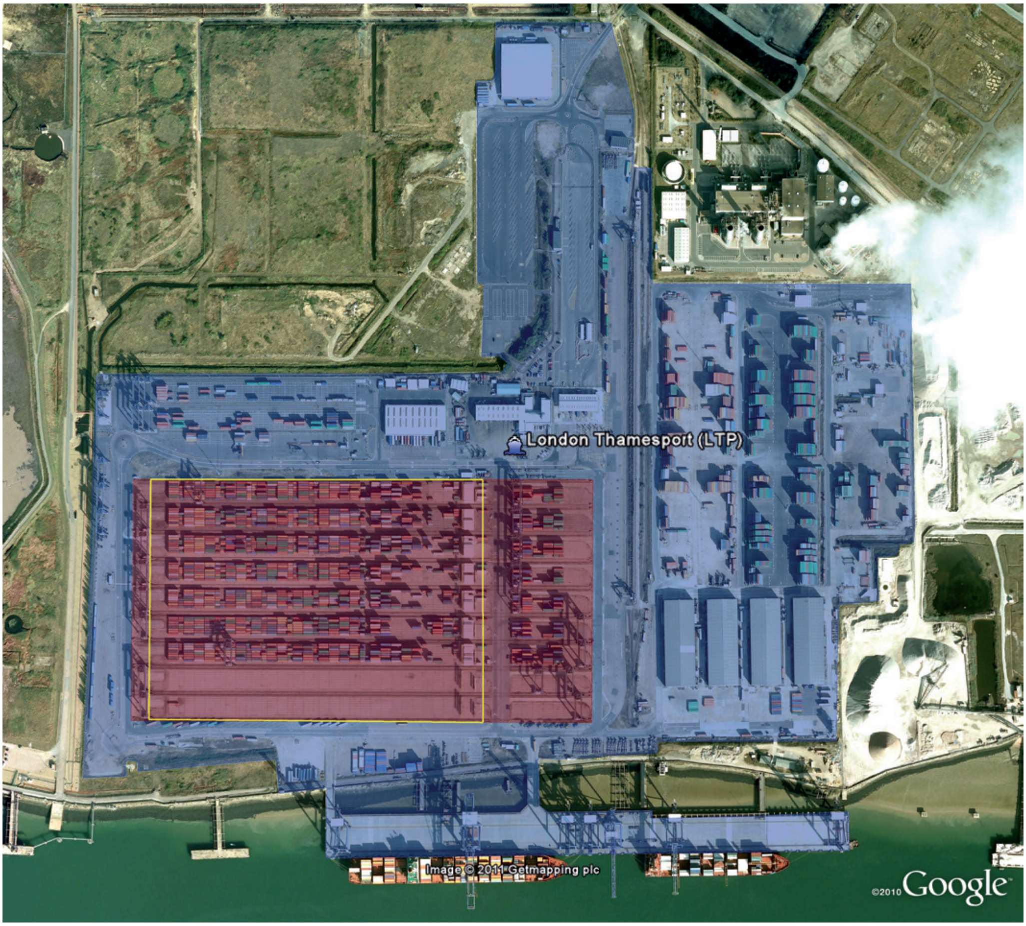



Source: © 2011 Google. © Inav/Geosistemas SRL© 2011 MapLink/Tele Atlas

**Figure 51. RTGs (8+1) yard at Brani Terminal (Port of Singapore – Singapore)**

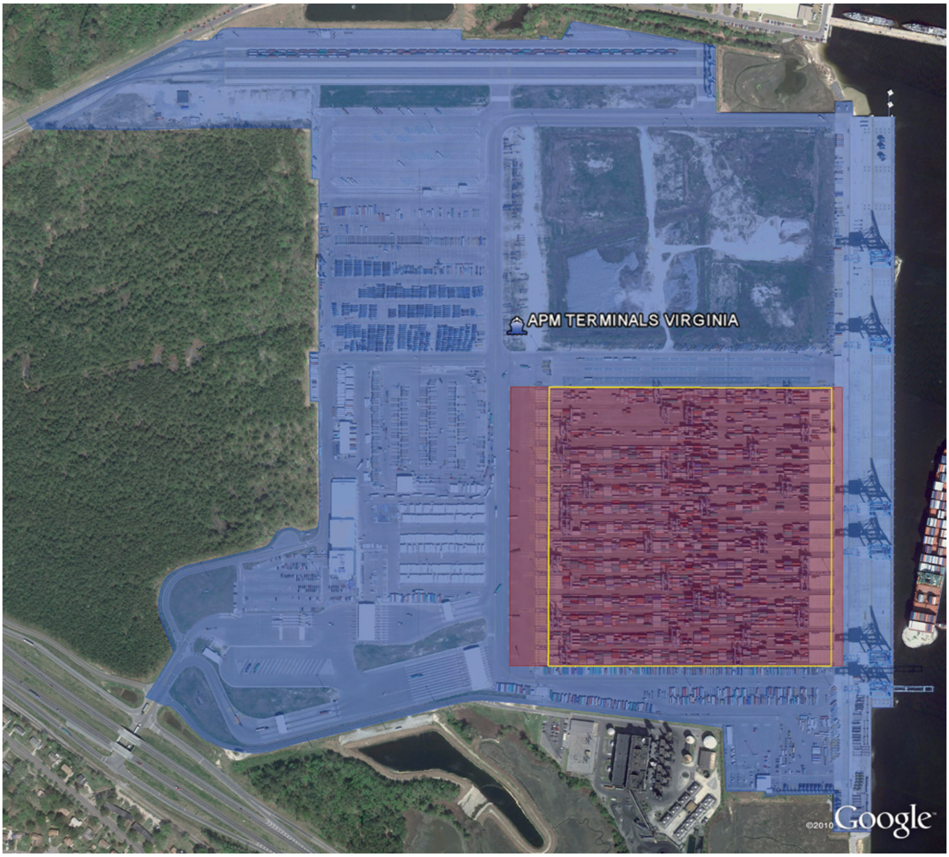

**Source: © 2011 Google. Image © 2011 DigitalGlobe**

Figure 52. RMGs (9) yard at London Thamesport (London Thamesport – United Kingdom)




Source: © 2011 Google. Image © 2011 Getmapping plc

**Figure 53. RMGs (8) yard at APM Terminals Virginia (Port of Norfolk – USA)**




Source: © 2011 Google

Figure 54. RMGs (9) yard at Antwerp Gateway Terminal – DP World (Port of Antwerp – Belgium)


Source: © 2011 Google. © 2011 DigitalGlobe

Table 25 summarises the area and terminal and storage density of each of the facilities presented from Figure 40 to Figure 54.

Table 25. Summary of productivity indicators per area in certain international container terminals

| Terminal | Equipment | Terminal Area ($A_T$) (ha) | Storage Area ($A_Y$) (ha) | Ground slots in Reference Area | Reference Area (ha) | Terminal Area Density ($D_T$) (Ground slots/ha) |
|---|---|---|---|---|---|---|
| Global Gateway South Terminal, Los Angeles (USA) | Chassis | 119.0 | 71.0 | 2,640 | 10.3 | 257 |
| California United Terminals, Long Beach (USA) | Chassis | 60.1 | 32.6 | 1,224 | 5.0 | 247 |
| Terminal P. Castellón, Castellón (Spain) | RS | 11.9 | 6.4 | 280 | 1.4 | 201 |
| San Antonio Terminal Internacional, San Antonio (Chile) | RS | 31.8 | 16.4 | 480 | 1.7 | 276 |
| Puerto Quetzal (Guatemala) | RS | 59.0 | 13.6 | 216 | 0.9 | 229 |
| TCB Barcelona, Barcelona (Spain) | SC | 56.7 | 35.0 | 1,078 | 3.7 | 291 |
| Medcenter Container Terminal, Gioia Tauro (Italy) | SC | 132.0 | 70.2 | 960 | 2.9 | 328 |
| Marvalsa, Valencia (Spain) | RTG (6+1) | 125.0 | 78.3 | 3,420 | 13.4 | 256 |
| MSC Terminal Valencia, Valencia (Spain) | RTG (6+1) | 32.6 | 20.2 | 2,700 | 10.1 | 268 |
| Terminal Darsena Toscana, Livorno (Italy) | RTG (6+1) | 42.1 | 6.3 | 528 | 1.7 | 305 |
| TECON Santos, Santos (Brazil) | RTG (7+1) | 59.7 | 12.7 | 735 | 2.4 | 301 |
| Brani Terminal Singapur (Singapore) | RTG (8+1) | 71.0 | 50.1 | 3,520 | 10.2 | 344 |
| London Thamesport (United Kingdom) | RMG (9) | 63.0 | 16.9 | 4,536 | 12.2 | 372 |
| APM Terminals Virginia, Norfolk (USA) | RMG (8) | 113.3 | 23.8 | 7,200 | 20.2 | 357 |
| Antwerp Gateway Terminal – DP World, Antwerp (Belgium) | RMG (9) | 126.6 | 8.8 | 2,214 | 6.5 | 342 |

**NOTE *: The data referring to California United Terminals (CUT) are based on the aerial photograph from Google taken on 28th July, 2008, as the CUT have since changed their yard equipment from chassis to RTGs.**
**NOTE **: The $A_Y$ of all the terminals in this table only considers the area reserved for the yard equipment in each terminal.**

**Source: Google, interview to the terminals and Fundación Valenciaport**

Table 26 displays the storage yard area density recommended by some authors and the real data from the terminals chosen, by type of equipment deployed.

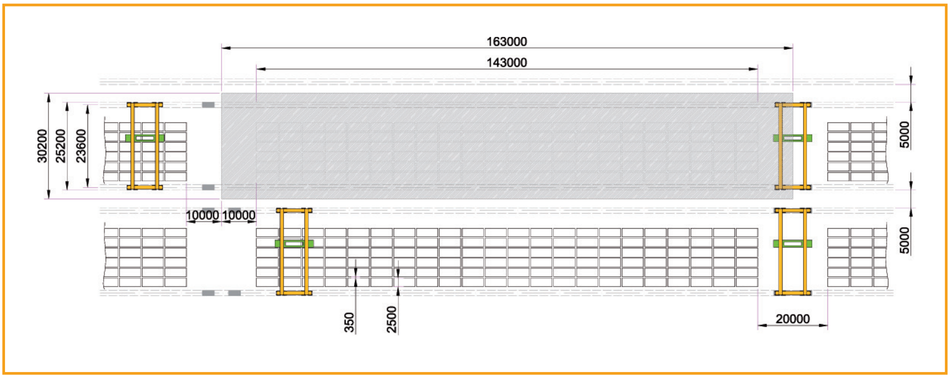
Table 26. Area density according to author and storage equipment

| Author | Area density (ground slots/hectare of yard) | | | | |
|---|---|---|---|---|---|
| | Frontloader | Reachstacker | SC | RTG | RMG |
| Wieschmann (2004) | – | 258 | 265 | 286 | 384 |
| Kuznetsov (2008) | 130 | 200 | 270 | 330 | |
| OPPE (2006) | 238 | – | 278 | 385 | |
| International terminals* | – | 201 – 276 | 283 – 291 | 261 – 372 | |

NOTE: (*) Elaborated by Fundación Valenciaport
Source: Fundación Valenciaport based on several sources

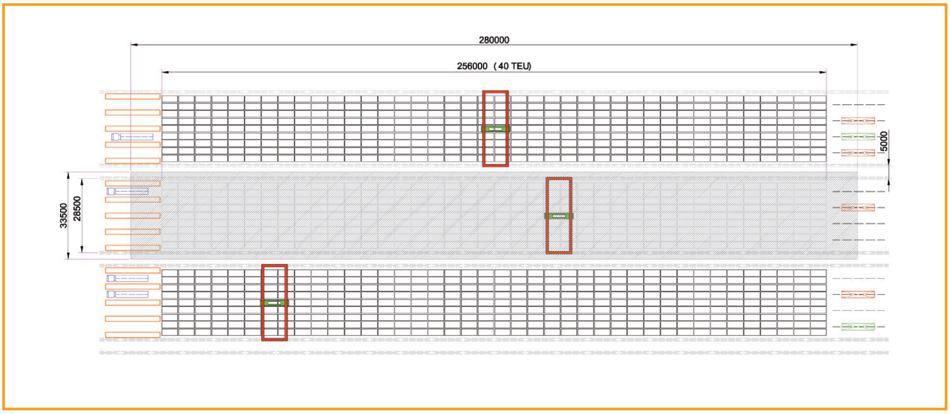
Figure 55 and Figure 56 display examples of the layout of the storage area for RTG and RMG handling systems respectively. In those figures, we can distinguish the area considered the storage area (grey rectangles), which includes part of the area devoted to infrastructure (rails for superstructure, aisles or roads for horizontal transport).

Figure 55. Example of yard layout with RTG (6-wide, 1 over 4)




Source: Wieschemann and Rijsenbrij (2004)

Figure 56. Example of yard layout with RMG (9-wide, 1 over 4)




Source: Wieschemann and Rijsenbrij (2004)

Wieschemann and Rijsenbrij (2004) used these layouts to calculate the area density of these storage systems (Table 27). Below we show how the number of ground slots per hectare is calculated for RTG and RMG systems (presented in the first column of the same table):

- **RTG (6-wide, 1 over 4)**
  Number of TEU = 6 (wide) x 22 (long) = 132 TEU
  Storage yard area = 163 m x 30.2 m = 4,923 $m^2$ = 0.4923 ha
  Area density = 132 TEU / 0.4923 ha = 268 ground slots

- **RMG (9-wide, 1 over 4)**
  Number of TEU = 9 (wide) x 40 (long) = 360 TEU
  Storage yard area= 280 m x 33.5 m = 9,380 $m^2$ = 0.938 ha
  Area density = 360 TEU / 0.938 ha = 384 ground slots

Table 27 provide preliminary values of storage density, measured in TEU/ha, considering the layout and maximum stack height of each system (RS, SC, RTG, RMG, etc.), the operational factor and the peak factor (Wieschemann and Rijsenbrij, 2004).

**Table 27. Storage static capacity of the container yard according to type of equipment**

| | # ground slots / hectare (TEU/ha) | Max. stacking height | Absolute max. stack capacity (TEU/ha) | Typical average operational filling rate (%) | Recommended maximun filling rate in peaks (%) | Average stack capacity (TEU/ha) | Peak stack capacity (TEU/ha) | "Ball park" figure (TEU/ha) |
|---|---|---|---|---|---|---|---|---|
| Reach Stacker, block 3 wide / 3 high | 258 | 3 | 774 | 55 | 85 | 426 | 658 | **425** |
| Straddle Carrier 3 high (1 over 3) Spacing 4,1 m between containers | 265 | 3 | 795 | 60 | 80 | 477 | 636 | **475** |
| RTG 6-wide (1 over 4) | 268 | 4 | 1,072 | 60 | 75 | 643 | 804 | **650** |
| RTG 7-wide (1 over 5) | 286 | 5 | 1,430 | 55 | 75 | 787 | 1,073 | **800** |
| RMG 9-wide (1 over 4) Transfer at the end of the module | 384 | 4 | 1,536 | 70 | 85 | 1,075 | 1,306 | **1,075** |
| RMG 12-wide (1 over 6) Transfer parallel to the module | 291 | 6 | 1,746 | 60 | 85 | 1,048 | 1,484 | **1,050** |
| WSG 18-wide (1 over 5) + Buffers alongside 3-wide / 3-high | 337 | 5 | 1,685 | 65 | 85 | 1,095 | 1,432 | **1,095** |
| OBC 9-wide or MT 10-wide (1 over 4) Transfer at the end of the module | 432 | 4 | 1,728 | 70 | 85 | 1,210 | 1,469 | **1,200** |
| MT-stacker (8-deep / 7-high) | 375 | 7 | 2,625 | 65 | 90 | 1,706 | 2,363 | **1,700** |

**NOTE 1: Recommended storage occupancy ratios depend on the stacking strategy and required manoeuvrability.**
**NOTE 2: Usual average operational storage occupancy is determined by the past experience of many terminals.**
**NOTE 3: The nomenclature is the one used in the Manual; values come from the original table.**
**Source: Fundación Valenciaport based on Wieschemann and Rijsenbrij (2004)**

Kuznetsov (2008) provides another reference regarding yard area density by storage system (see Table 28), which is also calculated taking the aisles and roads between blocks into account (together with those which encircle them). The author calculates the storage area necessary for different types of systems to draw 1,000 ground slots organised in 40 rows with 25 TEU in each. Assuming that each row is 150 metres long (25 x 6 m) and 2.5 m wide and that the aisle around the stacks for horizontal transport is 15 m wide, 2.34 ha are required to store those slots. Each system needs different spaces between blocks, depending on how stacks are organised and equipment used, which will lead to different storage areas and densities, as detailed below:

- Area of 1,000 slots + outside aisle = 2.34 ha (regardless of the system)

- **Frontloader (FL)**
  Blocks of two rows of containers and 19 aisles each 15 metres wide between blocks.
  Internal aisle area = 19 x 15 m x 180 m = 5.13 ha
  Storage area = 2.34 ha + 5.13 ha= 7.47 ha
  Area density = 134 ground slots/ha

- **Reachstacker**
  Blocks of 4 rows of containers and 9 aisles each 15 metres wide between blocks.
  Internal aisle area = 9 x 15 m x 180 m = 2.43 ha
  Storage area = 2.34 ha + 2.43 ha= 4.77 ha
  Area density = 210 ground slots/ha

- **Straddle carrier**
  40 rows of containers and 39 aisles each 2 metres wide between rows.
  Internal aisle area = 39 x 2 m x 180 m = 1.404 ha
  Storage area = 2.34 ha + 1.404 ha= 3.744 ha
  Area density = 267 ground slots/ha

- **Yard cranes (RTG/RMG)**
  5 blocks of 8 rows of containers and 4 aisles each 10 metres wide between blocks.
  Internal aisle area = 4 x 10 m x 180 m = 0.72 ha
  Storage area = 2.34 ha + 0.72 ha= 3.06 ha
  Area density = 327 ground slots/ha

Table 28. Area density according to yard equipment

| Storage System | FL 2-wide | RS 4- wide | SC | RTG/RMG 8- wide |
|---|---|---|---|---|
| Gap between stacks (Internal aisle) | 15 m | 15 m | 2 m | 10 m |
| Aisle around the stacks | 15 m | 15 m | 15 m | 15 m |
| $m^2$/ ground slot | 75 | 50 | 37 | 30 |
| Ground slots/ha or TEU/ha | 130 | 200 | 270 | 330 |

Source: Kuznetsov (2008) and Fundación Valenciaport

Apart from the references presented in this manual, it is worth mentioning other bibliographical sources regarding this topic, such as: UNCTAD (1984); Alderton (1999); Thoresen (2003), Henesey (2006), González-Herrero *et al.* (2006), OPPE (2006); etc.

As can be appreciated, storage yard area densities can vary noticeably depending on the author and the type of terminal. When using a reference to gauge the dimensions or calculate the capacity of a container yard, researchers must take into account which areas have been included in the estimation by the indicator consulted. The most operational and recommendable when it comes to ascertaining the dimensions of a container yard and calculating its area density and capacity, is to consider several layout alternatives, that is, various plans with the slot layouts for each of the plans to be compared and also different handling systems in order to choose the most suitable.

### Operational average stacking height: static storage capacity

The static storage capacity is the result of multiplying the area density of the yard by the average stacking height. Its units are TEU/ha.

Wieschemann and Rijsenbrij (Table 27) provide values of static storage capacity considering the type of yard equipment. It is calculated from the area density, the maximum stacking height and an operational factor that varies from 0.55 to 0.70. The product of these two last terms is h (operational average stacking height).

The mentioned Table 27 shows an estimate peak value of the storage capacity obtained from the maximum stacking height and employing a peak factor that varies from 0.75 to 0.90.

Table 29 summarises the values of static storage capacity (considering an average stacking height) and peak storage capacity used by different authors. Due to the fact that capacities are the result of multiplying the area density (ground slot/yard ha) by the stacking height in average and peak terms respectively, estimated by each author, values vary depending on this fact.

**Table 29. Stacking density -incorporating stack height- according to author and type of handling equipment**

| | | Forklift (3+1) RS (3+1) | SC (3+1) | RTG (6; 4+1) | RTG (7; 5+1) | RMG (9; 4+1) | RMG (12; 6+1) |
|---|---|---|---|---|---|---|---|
| Gilman (1982) | Operational | 315 | 465 | 675 | | | |
| | Peak | | | | | | |
| UNCTAD (1985) | Operational | | 500 | | | | |
| | Peak | | | 667 | 1,000 | | |
| Rodríguez (1985) | Operational | 288-360 | 411-514 | | 800 | | |
| | Peak | 540 | 771 | | 1,500 | | |
| Thorensen (2003) | Operational | 417 | | | | | |
| | Peak | | 625 | 1,000 | 1,428 | 1,250 | |
| Henesey (2004) | Operational | | 500 | | | | |
| | Peak | | | 833 | | 1,250 | |
| Wieschemann and Rijsenbrij (2004) | Operational | 425 | 475 | 650 | 800 | 1,075 | 1,050 |
| | Peak | 658 | 636 | 804 | 1,073 | 1,306 | 1,484 |
| González-Herrero *et al.* (2006) | Operational | 417 | | | | | |
| | Peak | | 625 | 1,000 | | 1,250 | |
| Saanen (2007) | Operational | | | | | | |
| | Peak | 540 | 675 | 800 | 1,000 | 1,300 | 1,500 |
| Koch (2008) | Operational | | | | 861 | | |
| | Peak | | | | | | |
| **FV (2011)** | Operational | 360-470 | 480-595 | 625-720 | 800-855 | 955-1,205 | |
| | Peak | | | | | | |

**Source: Fundación Valenciaport based on several sources**

### Dwell time

Finally, dwell time is analysed, which is a "dynamic" factor. Every terminal has static capacity, which refers to the maximum number of slots per hectare and depends on the yard equipment the terminal utilises. By also considering the average number of annual turnovers, which depends on the average container dwell time in the yard, annual capacity is obtained. Therefore, average container dwell time is inversely proportional to capacity. In this sense, for example, if average dwell time is reduced from 11 to 10 days, annual yard capacity increases by 10%.

Dwell time in port is normally somewhat less in the case of export containers than for import containers. According to a study conducted in a selection of European ports (Dekker, 2005), dwell times range from 4 to 7 days depending on the port, the type of container (import or export) and the mode of transport the container uses to enter or leave the port.

Dwell times in Spain are generally higher than those reported in the aforementioned study. According to the interviews performed with a selection of Spanish container terminal operators, average dwell time per type of container is as follows:

- Full export container: 5 – 9 days.
- Empty export container: 12 – 14 days.
- Full import container: 8 – 10 days.
- Empty import container: 15 – 20 days.
- Full transhipment container: 4 – 7 days.
- Empty transhipment container: 20 days.

### 5.4.2.4. Recommendations on storage capacity in container terminals

On the basis of the literature and real cases studied, some recommendations are made regarding the area density, average stack height and static capacity of a terminal, depending on storage equipment, as displayed in Table 30.

$$C_Y = \#\,ground\_slot \times h \times \frac{365}{T_{dw}}$$

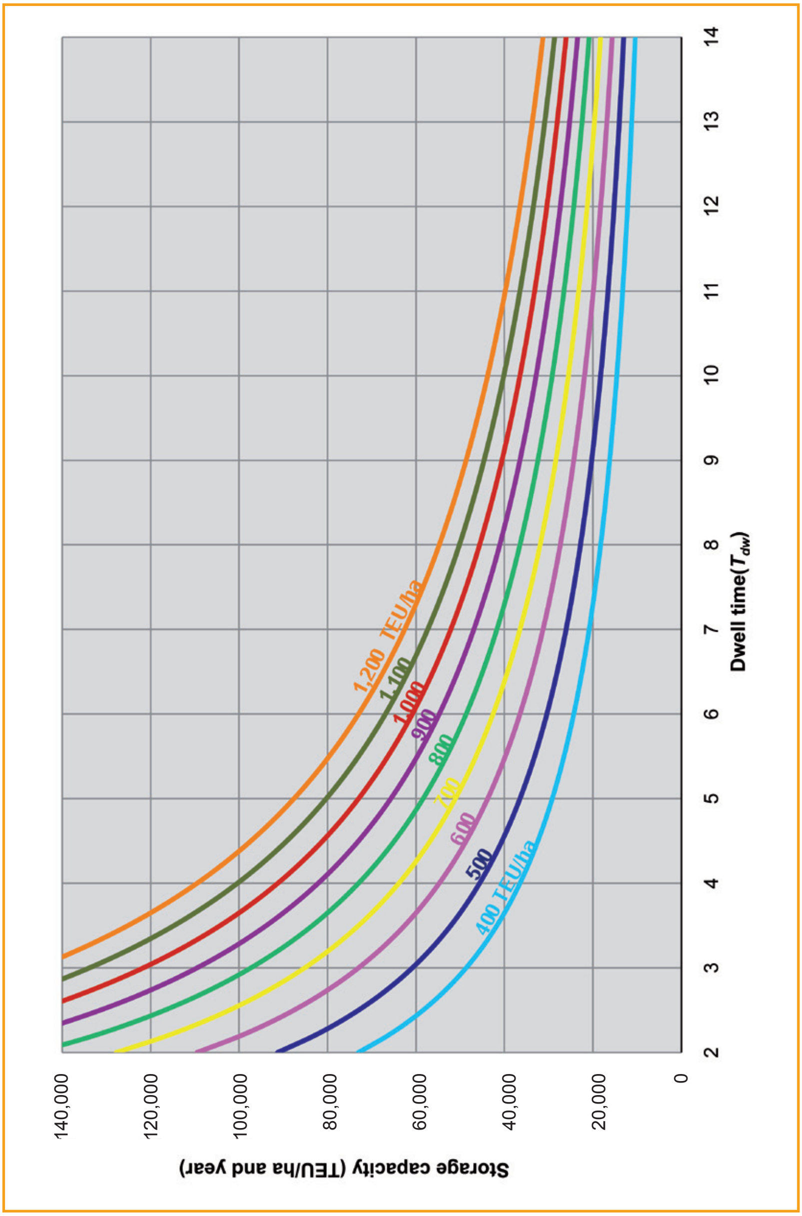
Table 30. Area density, operational average stacking height and static capacity of container terminals according to type of equipment

| Equipment (wide; nominal stacking height) | Area density (ground slots ha) | Operational average stacking height ($h$) | System density or static capacity ($C_S$) (TEU/ha) |
|---|---|---|---|
| Chassis | 150 - 250 | 1.00 | 150 - 250 |
| Forklift ( –; 3) | 130 - 190 | 1.80 | 235 - 345 |
| Reachstacker ( –; 3) | 200 – 260 | 1.80 | 360 - 470 |
| SC (–; 3+1) | 265 – 290 | 1.80 | 480 - 525 |
| RTG (6; 4+1) | 260 – 300 | 2.40 | 625 - 720 |
| RTG (7; 5+1) | 290 - 310 | 2.75 | 800 - 855 |
| RTG (8; 5+1) | 300 - 350 | 2.75 | 825 – 965 |
| RMG (9; 4+1) | 340 - 430 | 2.80 | 955 – 1,205 |

Source: Fundación Valenciaport

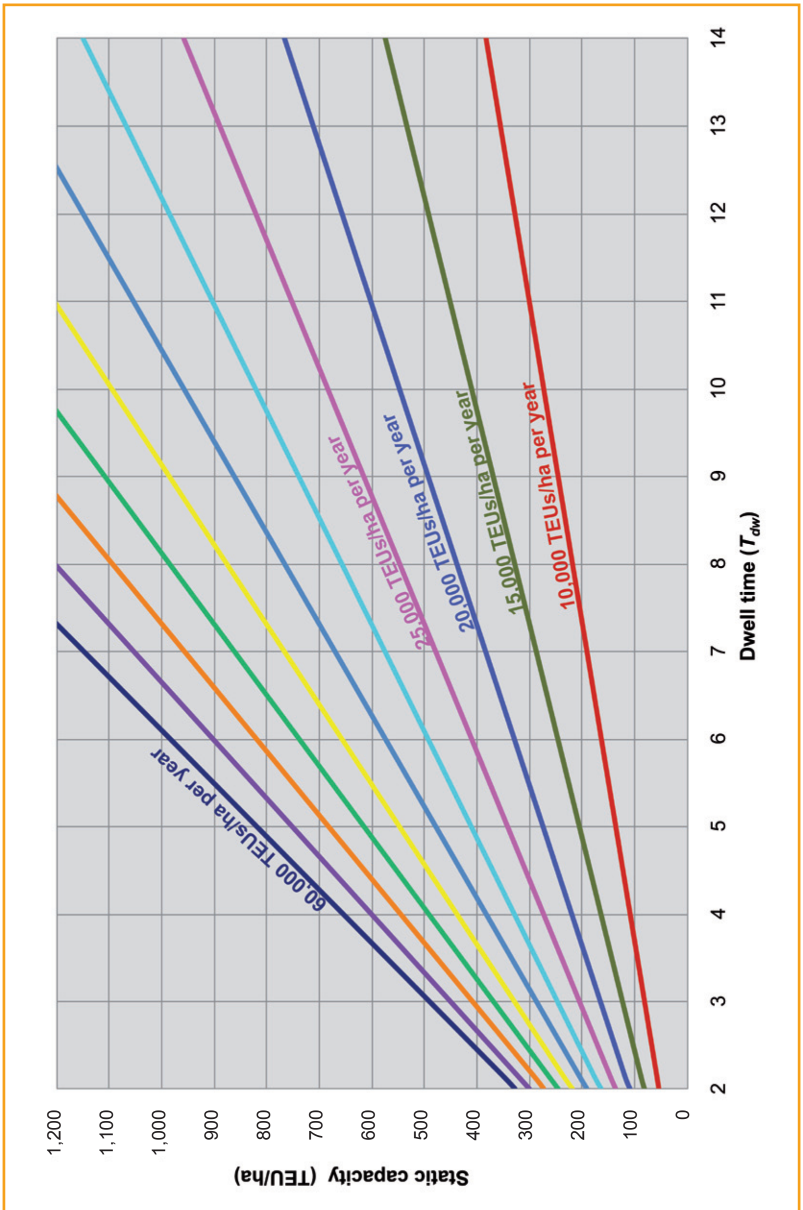
After obtaining the static capacity of the terminal storage yard, annual capacity will vary depending on the dwell time of containers there, as represented in Graph 11 and Graph 12.

Graph 11. Annual Storage capacity (TEU/ha per year) according area density and dwell-time




Source: Fundación Valenciaport

Graph 12. Storage static capacity of the yard equipment as the result of annual capacity requirements and dwell-time




Source: Fundación Valenciaport

For example, in the case of a terminal that employs a handling system with a static capacity of 400 TEU/ha (RS) and average dwell time of 5 days, annual capacity will be slightly more than 29,000 TEU/ha year (Graph 10). Therefore, if the terminal yard measures 20 hectares, storage capacity will be 580,000 TEU per year.

In the case of planning a terminal with a maximum capacity of 60,000 TEU/ha per year and average container dwell time of 5 days, a handling system with a capacity of at least 800 TEU per yard hectare should be employed, that is, a RTG.

*Longum iter est per praecepta, breve et efficax per exempla.*

**Séneca, philosopher**

06

# Examples of capacity calculations

This chapter presents a practical exercise on how to calculate the capacity of a hypothetical port container terminal for each of the scenarios considered here. In order to perform the calculation, the theoretical considerations discussed in previous chapters are used.

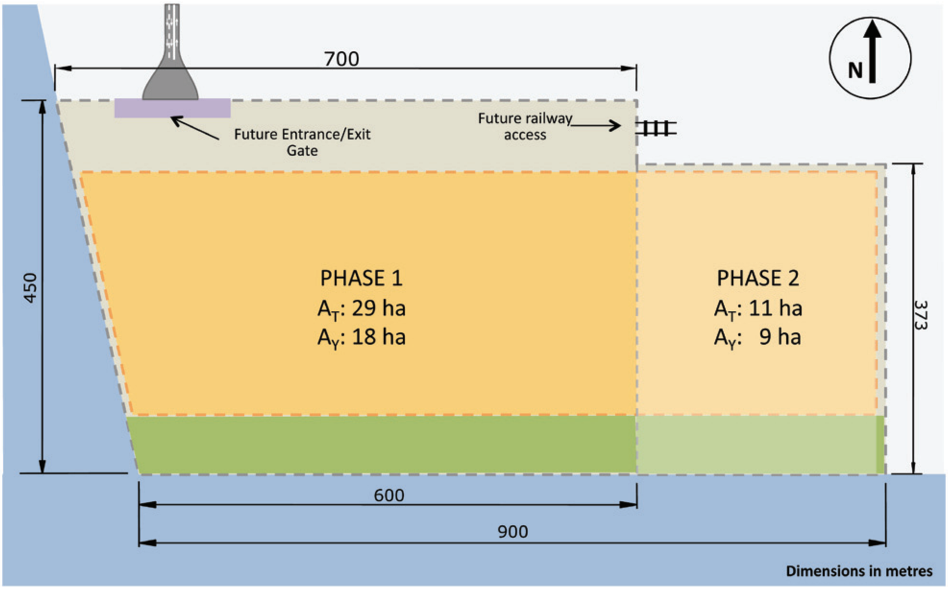
## 6.1. Scenario and source data for the new port container terminals

The Green Valley Port Authority (GVPA) is going to finance the civil engineering work required for a container terminal to be constructed at the port. The construction of the terminal will be carried out in two phases: in Phase I, the terminal will have a 600-metre long quay and an 18-hectare storage yard. In Phase II, the quay will be enlarged by 300 metres to 900 metres and the yard by 9 hectares to 27 hectares (see Figure 57). After Phase I has been completed, the facility, following an international tender, will be leased out to a private stevedoring company, which will run it as a Common-user Terminal (CUT) for a period of 20 years. At the same time, a large shipping line has contacted the GVPA requesting a tender to run a Dedicated Container Terminal (DT) also for 20 years. The second terminal will be constructed by the shipping line itself and will have the same physical specifications and phases as the first one. Both terminals are compatible, both in strategic terms

06

(GVPA Strategic Plan) and spatially (Port Master Plan). The respective second phases of the projects will begin depending on the Level of Service to be provided.

**Figure 57. Model of Container Terminal (CUT and DT) – Green Valley Port**




**Source: Fundación Valenciaport**

Table 31 displays the data of the Container Terminals on the Southern Dock at Green Valley Port.

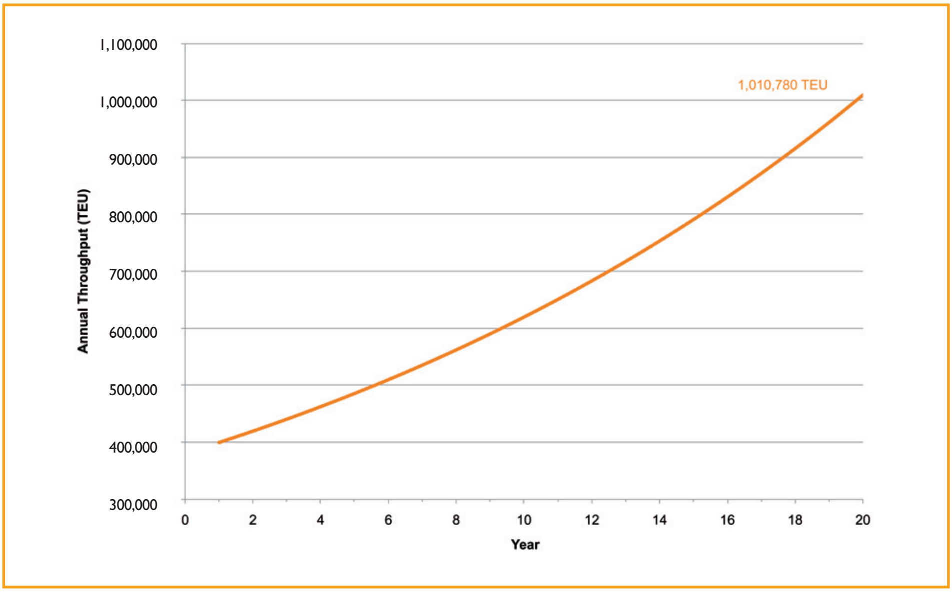
Table 31. Operative and geometric data of reference Container Terminal (CUT and DT) of the Container Terminals on the Southern Dock at Green Valley Port

| | Phase I | Phase II |
|---|---|---|
| Length of quay (metres) | 600 | 900 |
| Terminal area (hectares) | 29 | 40 |
| Stacking area (hectares) | 18 | 27 |
| Length of a standard vessel (metres) | 270 | 270 |
| Days the terminal is operational per year (days) | 360 | |
| Hours the terminal is operational per day (h) | 24 | |
| Draught (metres) | 16 | |
| Tidal range (metres) | 0.3 | |
| Rate TEU/Container | 1.5 | |

Source: Fundación Valenciaport

Throughput is forecast to amount to 400,000 TEU in the first year the terminals are operative and this figure is expected to grow by an annual 5% until 2020. Graph 13 shows the traffic trend for both container terminals on the Southern Dock throughout the concession. Transhipment is estimated to account for 15% of throughput for the CUT and 75% for the DT.

**Graph 13. Throughput forecast for model of Container Terminal (CUT and DT) – Green Valley Port**




Source: Fundación Valenciaport

Average container dwell time in the yard ($T_{dw}$) during the concession is 6 days, while the service provision conditions demanded by the GVPA vary throughout the concession and depend on whether the terminal is common-user (CUT) or dedicated (DT).

In the case of the CUT, the minimum levels of service (LoS) demanded by the GVPA in the concession contract regarding relative waiting time and berthed ship productivity (*P*) are:

- Level of service associated to relative waiting time: C ($T_w/T_s$ between 0.10 and 0.20)
- Level of service associated to berthed ship productivity (*P*): C (between 35 and 50 cont./h)
    - *P* must be at least 40 cont./hour for the first 10 years of the concession
    - *P* must be at least 10% higher than initially between year 10 and year 15
    - *P* must be at least 20% higher than initially between year 15 and year 20

And in the case of the DT, the shipping line itself has offered the following:

- Level of service associated to relative waiting time: B ($T_w/T_s$ between 0.05 and 0.10)
- Level of service associated to berthed ship productivity (*P*): A (>65 cont./h)
  - *P* must be at least 65 cont./hour for the first 10 years of the concession
  - *P* must be at least 70 cont./hour between year 10 and year 15
  - *P* must be at least 75 cont./hour between year 15 and year 20

Questions to be answered:

1. What is the berth capacity (LoS C) of the **Common-user Terminal** throughout the concession as a whole and when will Phase II be necessary, taking into account the traffic forecasts provided?

2. What is the berth capacity (LoS B) of the **Dedicated Terminal** throughout the concession as a whole and when will Phase II be necessary, taking into account the traffic forecasts provided?

3. If average container dwell time is expected to be 6 days, what yard equipment is the most suitable, strictly in terms of capacity, for each terminal: RTGs or straddle carriers (SCs)? How would yard equipment capacity vary, depending on dwell time?

4. Taking into account the answers to the above questions, and only in regard to the most suitable yard equipment in each case, what would the capacity of each Container Terminal be and when should Phase II of the terminal start up operations, both for the CUT and the DT?

## 6.2. Calculation of berth capacity

Answer to Question 1

In the first place, we calculate the number of berths at the future Common-User Container Terminal on the Southern Dock. Taking into account that the standard ship is 270 metres long and considering a safety allowance of an additional 10% of the length of the ship (ship separation coefficient), there will be 2 berths in the first phase and 3 in the second:

Phase I: $n = 600 / (270x1.1) = 2$ *berths*

Phase II: $n = 900 / (270x1.1) = 3$ *berths*

According to the foregoing scenario, berthed ship productivity for the first 10 years of the concession must be at least 40 containers/hour. Similarly, in order to fulfil the contract, *P* must be at least 10% higher than that ratio from years 10 to 15 and at least 20% higher from years 15 to 20. Using these conditions as a basis, we obtain the levels of productivity that can be observed in Table 32 below.

**Table 32. Minimum vessel productivity over the period of the concession in a common-user terminal's concession**

| Period | Minimum annual average productivity of vessel at berth (*P*) (container/hour) |
|---|---|
| 0-10 years | 40 |
| 10-15 years | 44 |
| 15-20 years | 48 |

**Source: Fundación Valenciaport**

Following the recommendations made in Section 5.3.2.1 for common-user terminals, an $M/E_4/n$ queue system is applied, that is, with random inter arrival distribution (M), service times in accordance with Erlang 4 ($E_4$) and n berths.

Furthermore, Table 22 assigns service quality limits associated to ε ($T_w/T_s$) of 0.10 to 0.20 to a level of service C (as indicated above). According to those limits, when calculating berth capacity we must ensure that relative waiting time is less than 0.20 at all times. In fact, it is that limit which determines when Phase II should be carried out.

Once the variable *P* is known for each period along with the number of berths in each phase of the project, Table 20 in Section 5.3.2.4 allows us to ascertain annual berth capacity for a service quality of 5%, 10% and 20% for certain ship productivity levels, depending on the type of queue system. It is important to remember that the table was calculated for certain parameters, such as 300-metre long berths and 8,640 annual operating hours (360 operating days/year x 24 hours/day), which coincide with the data considered in this exercise. Any Container Terminal whose physical specifications or operating data differ from the above, would require capacity ($C_B$) to be calculated using the formula (see Section 5.3.1) that in this exercise is used for the levels of productivity that have not been included in the aforementioned table.

Berth capacity for a productivity level of 40 containers/hour is considered directly in Table 20. In the case of the levels of productivity between years 10 and 15 ($P_{10\text{-}15}$= 44 containers/hour) and years 15 and 20 ($P_{15\text{-}20}$= 48 containers/hour), capacity is obtained using the formula mentioned previously in Section 5.3.1 $(C_B = n \times \ \times t_{year} \times P)$ , using Table 16 (or Graph 2) to ascertain the acceptable occupancy factor ($\Phi$) that corresponds to the level of service quality required, or also by interpolating capacity values, as *P* is directly proportional to capacity.

Finally, by applying a TEU/container ratio of 1.5 (figure already specified in Table 31), we obtain the berth capacity results. Table 33 and 34 show them separately according to the method employed to calculate them.

**Table 33. Berth capacity in a CUT on the Southern Dock for a productivity of 40 containers/hour**

| Berth capacity in a CUT ($M/E_4/n$) on the Southern Dock – Phase I and Phase II | | | | |
|---|---|---|---|---|
| $t_{year}$: Hours the terminal is operational per year: 8,640 (360 days x 24 hours/day) | | | | |
| *P*: Annual average productivity of vessel at berth: 40 container/ hour | | | | |
| TEU/container ratio =1.5 | | | | |
| | $T_w/T_s$=0.10 | | $T_w/T_s$=0.20 | |
| | Phase I | Phase II | Phase I | Phase II |
| *n*: Number of berths | 2 | 3 | 2 | 3 |
| Length of quay (m) | 600 | 900 | 600 | 900 |
| Annual capacity per metre of berth (cont./m-berth and year) | 415 | 560 | 560 | 700 |
| $C_{1P50}$: System $M/E_4/n$ (cont./year) | 249,000 | 504,000 | 336,000 | 630,000 |
| **$C_{2P50}$: System $M/E_4/n$ (TEU/year)** | **373,500** | **756,000** | **504,000** | **945,000** |

**Source: Fundación Valenciaport**

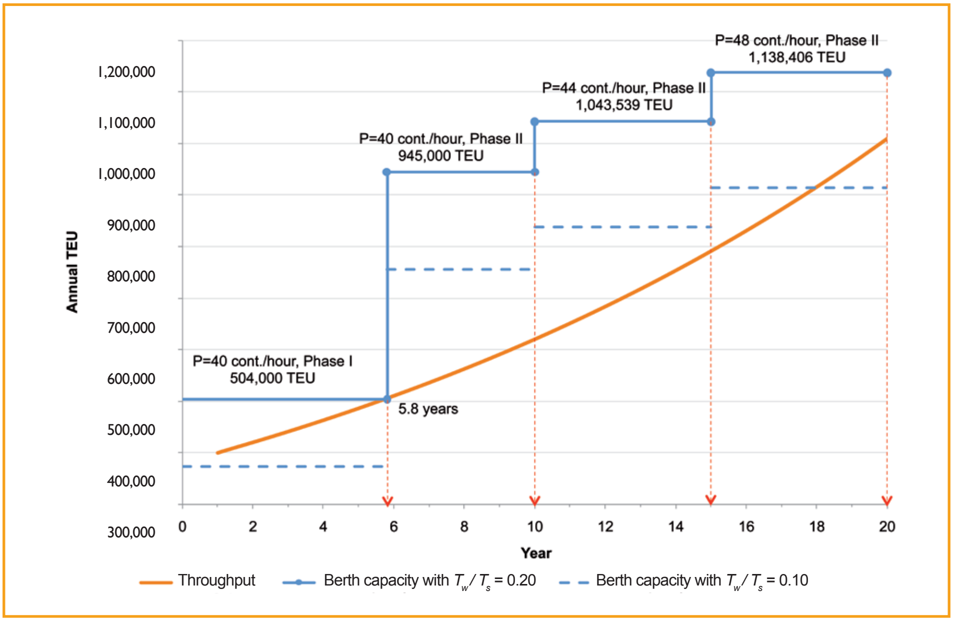
**Table 34. Berth capacity in a CUT on the Southern Dock for productivities of 44 and 48 containers/hour**

| Berth capacity in a CUT ($M/E_4/n$) on the Southern Dock – Phase I and Phase II | | | | | |
|---|---|---|---|---|---|
| $t_{year}$: Hours the terminal is operational per year: 8,640 (360 days x 24 hours/day) | | | | | |
| TEU/container ratio =1.5 | | | | | |
| | | $T_w/T_s$=0.10 | | $T_w/T_s$=0.20 | |
| | | Phase I | Phase II | Phase I | Phase II |
| *n*: Number of berths | | 2 | 3 | 2 | 3 |
| $\Phi_1$: Containers – System $M/E_4/n$ | | 0.36 | 0.49 | 0.49 | 0.61 |
| P=44 cont./hour | $C_{1P44}$: System $M/E_4/n$ (cont./year) | 273,715 | 558,835 | 372,557 | 695,693 |
| | **$C_{2P44}$: System $M/E_4/n$ (TEU/year)** | **410,573** | **838,253** | **558,835** | **1,043,539** |
| P=48 cont./hour | $C_{1P48}$: System $M/E_4/n$ (cont./year) | 298,598 | 609,638 | 406,426 | 758,938 |
| | **$C_{2P48}$: System $M/E_4/n$ (TEU/year)** | **447,898** | **914,458** | **609,638** | **1,138,406** |

**Source: Fundación Valenciaport**

Graph 14 determines when Phase II should be undertaken, depending on the capacity calculated for a service quality associated to the relative waiting time of $T_w/T_s$ = 0.20.

**Graph 14. Comparison of berth capacity in the CUT with the throughput forecast**




**Source: Fundación Valenciaport**

According to the blue line, which represents the capacity of the CUT for a service quality associated to ε of 0.20, Phase II is necessary after 5.8 years of the concession. Once this phase is complete, the CUT, bearing in mind the subsequent increases in P imposed by the contract, will have sufficient capacity to cope with the traffic forecast for the rest of the concession (1,138,496 TEU over the last five years of concession).

Furthermore, the dotted blue line in the same graph represents the berth capacity for a service quality associated to ε of 0.10, the lower bound of service level C. Service quality associated to $T_W/T_S$ is observed to remain between 0.10 and 0.20 over the first

5.8 years of the concession, but as traffic grows, ship average waiting time will increase until it reaches the upper bound of 20% of average service time. When Phase II begins operations and practically until year 18 of the concession, relative waiting time offered will be even lower than 0.10, so ships will queue for less time than corresponds for a LoS C and service quality will therefore be perceived as better.

On the other hand, it is striking, as observed in Table 33 and Table 34, that for all three levels of productivity considered, if service quality relating to ε decreases by 100%, that is, from 0.10 to 0.20, berth capacity only increases by 35.7% on average in Phase I ($n$ = 2) and by 24.7% in Phase II ($n$ = 3).

In contrast, increasing the number of berths by only 50% from 2 (Phase I) to 3 (Phase II), average berth capacity increases by 103.6% on average when $T_w/T_s$ = 0.10, and by 87% when $T_w/T_s$ = 0.20.

In summary, it is important to highlight that while capacity increases (decreases) in the same proportion as the increase (or decrease) in berthed ship productivity, proportionality is not maintained when service quality or the number of berths is altered. This is due to the fact that the acceptable quay occupancy factor depends on those two variables.

Answer to Question 2

As in the case of the question addressed above, capacity is calculated with the aid of Table 20 in Section 5.3.2.4 and the capacity formula in Section 5.3.1, on the basis of the recommendations in Section 5.3.2.1, which assign an $E_2/E_4/n$ queue system to a DT whereby arrivals are tightly scheduled. However, in less favourable cases, arrivals are really considered to be random and an $M/E_4/n$ queue system is recommended. In this exercise, berth capacity is calculated for both scenarios.

The source data to be introduced in Table 20 to ascertain annual berth capacity have in this case already been calculated; minimum ship productivity ($P$) was specified in the call for tenders and the number of berths in each phase does not depend on the type of terminal, so is therefore the same as in Question 1, $n$ = 2 for Phase I and $n$ = 3 for Phase II. The table below summarises the ship productivity requirements:

Table 35. Minimum vessel productivity over the period of the concession in a dedicated terminal (DT)

| Period | Minimum annual average productivity of vessel at berth (*P*) (container/hour) |
|---|---|
| 0-10 years | 65 |
| 10-15 years | 70 |
| 15-20 years | 75 |

Source: Fundación Valenciaport

As it was the case with the previous question, for an $E_2/E_4/n$ queue system the berth capacity for one of those levels of productivity (70 containers/hour) can be obtained from Table 20, but for $P_{0\text{-}10}$ = 65 containers/hour and $P_{15\text{-}20}$ = 75 containers/hour are calculated using the capacity formula (Section 5.3.1) and Table 16 in Chapter 5 to obtain $\Phi$. Likewise, in the case of the $M/E_4/n$ queue system, Table 20 only determines berth capacity for $P_{10\text{-}15}$ = 70 containers/hour, so in order to calculate capacity for $P_{0\text{-}10}$ and $P_{15\text{-}20}$ the formula and Table 16 are used.

As indicated in Table 22, a service quality relating to ε ($T_w/T_s$) of between 5% and 10% corresponds to a level of service B, as the scenario indicates. And as in the first question, the DT must ensure that service quality associated to the relative waiting time is always below the upper bound of relative waiting time, in this case 10%. As a result, the capacity for that level of service quality is what determines the need for Phase II and when to execute it.

Table 36 and Table 37 display the berth capacity for the two phases of a DT with an $E_2/E_4/n$ queue system separately, according to the method used to calculate them.

**Table 36. Berth capacity in a DT ($E_2/E_4/n$) on the Southern Dock for a productivity of 70 containers/hour**

| Berth capacity in a DT ($E_2/E_4/n$) on the Southern Dock – Phase I and Phase II | | | | |
|---|---|---|---|---|
| $t_{year}$: Hours the terminal is operational per year: 8,640 (360 days x 24 hours/day) | | | | |
| $P$: Annual average productivity of vessel at berth: 70 container/ hour | | | | |
| TEU/container ratio =1.5 | | | | |
| | $T_w/T_s$=0.05 | | $T_w/T_s$=0.10 | |
| | Phase I | Phase II | Phase I | Phase II |
| *n*: Number of berths | 2 | 3 | 2 | 3 |
| Length of quay (m) | 600 | 900 | 600 | 900 |
| Annual capacity per metre of berth (cont./m-berth and year) | 865 | 1,065 | 1,065 | 1,270 |
| $C_{1P70}$: System $E_2/E_4/n$ (cont./year) | 519,000 | 958,500 | 639,000 | 1,143,000 |
| **$C_{2P70}$: System $E_2/E_4/n$ (TEU/year)** | **778,500** | **1,437,750** | **958,500** | **1,714,500** |

**Source: Fundación Valenciaport**

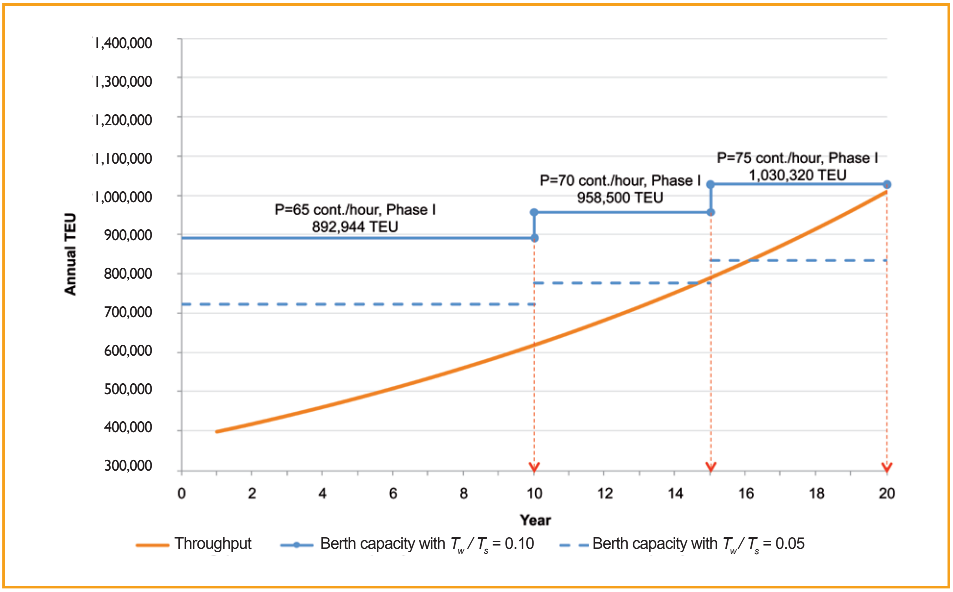
**Table 37. Berth capacity in a DT ($E_2/E_4/n$) on the Southern Dock for productivities of 65 and 75 containers/hour**

| Berth capacity in a DT ($E_2/E_4/n$) on the Southern Dock – Phase I and Phase II | | | | | |
|---|---|---|---|---|---|
| $t_{year}$: Hours the terminal is operational per year: 8,640 (360 days x 24 hours/day) | | | | | |
| TEU/container ratio =1.5 | | | | | |
| | | $T_w/T_s$=0.05 | | $T_w/T_s$=0.10 | |
| | | Phase I | Phase II | Phase I | Phase II |
| ***n***: Number of berths | | 2 | 3 | 2 | 3 |
| $\Phi_1$: Containers – System $E_2/E_4/n$ | | 0.43 | 0.53 | 0.53 | 0.63 |
| P=65 cont./h | $C_{1P65}$: System $E_2/E_4/n$ (cont./year) | 482,976 | 892,944 | 595,296 | 1,061,424 |
| | **$C_{2P65}$: System $E_2/E_4/n$ (TEU/ year)** | **724,464** | **1,339,416** | **892,944** | **1,592,136** |
| P=75 cont./h | $C_{1P75}$: System $E_2/E_4/n$ (cont./ year) | 557,280 | 1,030,320 | 686,880 | 1,224,720 |
| | **$C_{2P75}$: System $E_2/E_4/n$ (TEU/ year)** | **835,920** | **1,545,480** | **1,030,320** | **1,837,080** |

**Source: Fundación Valenciaport**

As can be observed in Graph 15, for an $E_2/E_4/n$ queue system with tightly scheduled arrivals, the DT does not need to execute Phase II because the berth capacity for a service quality associated to ε of 10% is greater than the traffic forecast throughout the entire concession; what is more, service quality is better than 5% for the first 16 years of the concession.

**Graph 15. Comparison of berth capacity in the DT ($E_2/E_4/n$) with the throughput forecast**




**Source: Fundación Valenciaport**

Similarly, Table 38 and Table 39 present the berth capacity for the two phases of the DT with an $M/E_4/n$ queue system.

Table 38. Berth capacity in a DT ($M/E_4/n$) on the Southern Dock for a productivity of 70 containers/hour

| Berth capacity in a DT ($M/E_4/n$) on the Southern Dock – Phase I and Phase II | | | | |
|---|---|---|---|---|
| $t_{year}$: Hours the terminal is operational per year: 8,640 (360 days x 24 hours/day) | | | | |
| *P*: Annual average productivity of vessel at berth: 70 container/ hour | | | | |
| TEU/container ratio =1.5 | | | | |
| | $T_w/T_s$=0.05 | | $T_w/T_s$=0.10 | |
| | Phase I | Phase II | Phase I | Phase II |
| *n*: Number of berths | 2 | 3 | 2 | 3 |
| Length of quay (m) | 600 | 900 | 600 | 900 |
| Annual capacity per metre of berth (cont./m-berth and year) | 540 | 785 | 725 | 985 |
| $C_{1P70}$: System $M/E_4/n$ (cont./year) | 324,000 | 706,500 | 435,000 | 886,500 |
| **$C_{2P70}$: System $M/E_4/n$ (TEU/year)** | **486,000** | **1,059,750** | **652,500** | **1,329,750** |

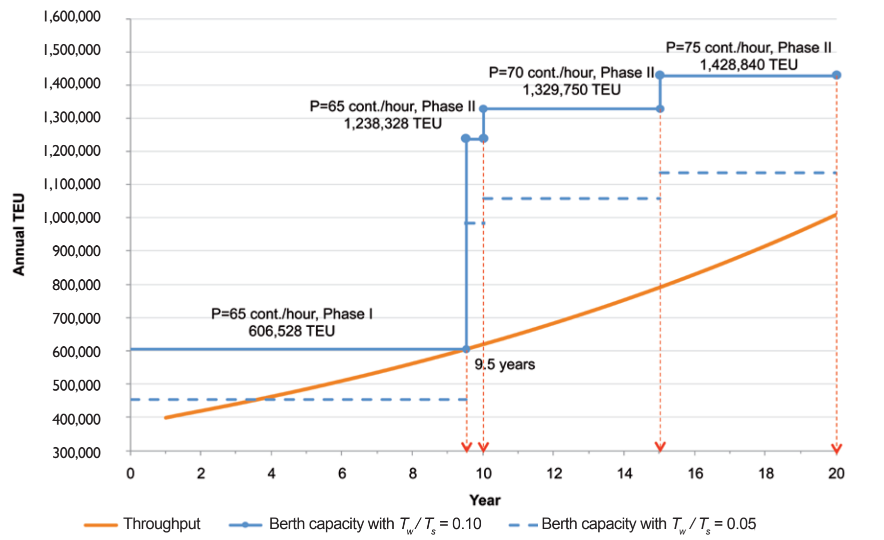
Source: Fundación Valenciaport

Table 39. Berth capacity in a DT ($M/E_4/n$) on the Southern Dock for productivities of 65 and 75 containers/hour

| Berth capacity in a DT ($M/E_4/n$) on the Southern Dock – Phase I and Phase II | | | | | |
|---|---|---|---|---|---|
| $t_{year}$: Hours the terminal is operational per year: 8,640 (360 days x 24 hours/day) | | | | | |
| TEU/container ratio =1.5 | | | | | |
| | | $T_w/T_s$=0.05 | | $T_w/T_s$=0.10 | |
| | | Phase I | Phase II | Phase I | Phase II |
| *n*: Number of berths | | 2 | 3 | 2 | 3 |
| $\Phi_1$: Containers – System $M/E_4/n$ | | 0.27 | 0.39 | 0.36 | 0.49 |
| P=65 cont./h | $C_{1P65}$: System $M/E_4/n$ (cont./year) | 303,264 | 657,072 | 404,352 | 825,552 |
| | **$C_{2P65}$: System $M/E_4/n$ (TEU/year)** | **454,896** | **985,608** | **606,528** | **1,238,328** |
| P=75 cont./h | $C_{1P75}$: System $M/E_4/n$ (cont./year) | 349,920 | 758,160 | 466,560 | 952,560 |
| | **$C_{2P75}$: System $M/E_4/n$ (TEU/year)** | **524,880** | **1,137,240** | **699,840** | **1,428,840** |

Source: Fundación Valenciaport

**Graph 16. Comparison of berth capacity in the DT (M/$E_4$/*n*) with the throughput forecast**



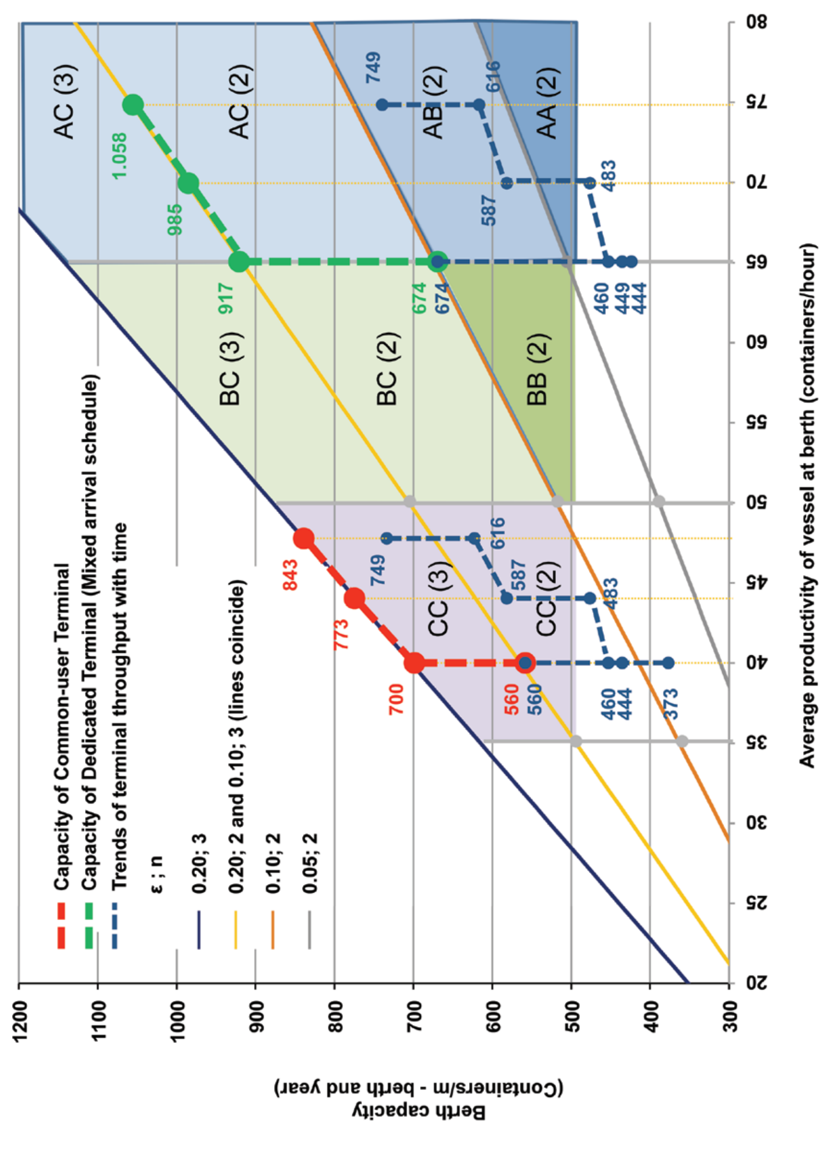

**Source: Fundación Valenciaport**

As can be seen in Graph 16, in order to guarantee at least a LoS B when the DT faces a less favourable scenario in which arrivals are random (M/$E_4$/*n* queue system), for service quality associated to the relative waiting time to be better than or equal to 0.10 (dotted blue line), Phase II is seen to be necessary after 9.5 years of concession. Once Phase II is operating, the DT will have sufficient capacity to deal with the traffic forecast and will even offer a better level of service quality at 0.05.

In summary, if the DT under study has tightly scheduled arrivals ($E_2$/$E_4$/*n*), the services provided can be better organised and, consequently, a higher occupancy factor can be achieved. As a result, for a given level of service quality relating to ε, greater berth capacity is achieved than with a more random queue system (M/$E_4$/*n*).

Graph 17 below represents the berth capacity and traffic trends of both terminals in regard to the levels of service defined in Chapter 5 of this Manual.

Graph 17. Trends of berth capacity of CUT and DT related to waiting service ($M/E_4/n$)




Source: Fundación Valenciaport

## 6.3. Calculation of storage capacity

Answer to Question 3

The answer to this question does not initially depend on whether the terminal is common user or dedicated, as storage capacity depends on the yard equipment employed, as we show below. However, the percentage of terminal throughput accounted for by transhipment does have an impact on this calculation. The share of transhipment is normally greater in a dedicated terminal than in a common-user terminal, as is the case here and as specified in the initial case scenario.

In order to calculate the storage capacity of container terminals, the following formula specified in Section 5.4.2.2 is used:

$$C_Y = \#\,ground\_slot \times h \times \frac{365}{T_{dw}}$$

However, to be able to compare this yard capacity to the forecast for maritime traffic (specified in the initial case scenario) or to berth capacity itself, we must take into account that the percentage of transhipment traffic affects equivalent yard capacity per berth ($C_{Y\,eq\,B}$), since must consider that transhipment containers are counted twice by the ship-to-shore subsystem. As a result, if the average dwell time of containers at the terminal ($T_{dw}$) is 6 days, both for containers or TEU with a land origin/destination (O/D) and also for transhipment (TS), the following formula is applied.

$$C_{Y\,eq\,B} = K_{YTS} \times C_Y$$

where $K_{YTS}$ is:

$$K_{YTS} = \frac{200}{2 \times \%O/D + \%TS}$$

The original case scenario establishes that transhipment accounts for 15% of the traffic of the common-user terminal and 75% of the traffic of the dedicated terminal, so yard capacity is increased by the following coefficients:

CUT: 15% Transhipment Traffic ⟶ $K_{YTS}$= 1.081

DT: 75% Transhipment Traffic ⟶ $K_{YTS}$= 1.600

The rest of the terms in the capacity formula are the number of ground slots that fit in the terminal yard, which depends on area density and average stack height. Both these factors depend at the same time on the type of storage equipment. The most accurate way of proceeding would be, for the equipment chosen, to draw the container ground slots on the ground of the terminal layout itself. However, as stated previously in this Seaport Capacity Manual, there are several studies on this subject that enable us to calculate storage capacity more simply and directly thanks to the values presented in Table 30 (Section 5.4.2.4).

Table 30 shows the ranges of area densities (Ground slots/ha) and static capacity ($C_S$) (TEU/ha – average stack height *h* has already been internalised) according to the storage equipment. Therefore, having defined the size of the terminal yard and using these recommendations, the annual storage capacity for each of the types of equipment that exist varies depending on the time that containers dwell at the terminal.

In accordance with Table 30, static capacity values have been taken for one yard employing RTGs (6-wide with 4+1 stack height) and for another employing straddle carriers (SC with 3+1 stack height) with 650 TEU/ha and 475 TEU/ha, respectively, both values in line with the recommendations.

These data are used to calculate the storage capacity of the two yard systems proposed, both for Phase I and Phase II, as can be observed in Table 40 and Table 41.

**Table 40. Storage capacity in a CUT**

| Storage capacity in a CUT on the Southern Dock – Phase I and Phase II | | | | |
|---|---|---|---|---|
| $T_{dw}$: Average dwell time of containers in the terminal (storage) = 6 days | | | | |
| **Common-user Terminal with 15% Transhipment Traffic, $K_{YTS}$= 1.081** | | | | |
| | SC | | RTG | |
| | Phase I | Phase II | Phase I | Phase II |
| $C_S$: Static storage capacity (TEU/ha) | 475 | 475 | 650 | 650 |
| $A_Y$: Storage area or yard (ha) | 18 | 27 | 18 | 27 |
| $C_Y$: Terminal annual yard capacity (TEU/year) | 520,125 | 780,187 | 711,750 | 1,067,625 |
| **$C_{Y\,eq\,B}$ (TEU/year)** | **562,297** | **843,445** | **769,459** | **1,154,189** |
| Extension year (start Phase II) | 7.9 | | 14.4 | |

**Source: Fundación Valenciaport**

**Table 41. Storage capacity in a DT**

| Storage capacity in a DT on the Southern Dock – Phase I and Phase II | | | | |
|---|---|---|---|---|
| $T_{dw}$: Average dwell time of containers in the terminal (storage) = 6 days | | | | |
| **Dedicated Terminal with 75% Transhipment Traffic, $K_{YTS}$= 1.600** | | | | |
| | SC | | RTG | |
| | Phase I | Phase II | Phase I | Phase II |
| $C_S$: Static storage capacity (TEU/ha) | 475 | 475 | 650 | 650 |
| $A_Y$: Storage area or yard (ha) | 18 | 27 | 18 | 27 |
| $C_Y$: Terminal annual yard capacity (TEU/year) | 520,125 | 780,187 | 711,750 | 1,067,625 |
| **$C_{Y\,eq\,B}$ (TEU/year)** | **832,200** | **1,248,299** | **1,138,800** | **1,708,200** |
| Extension year (start Phase II) | 16.1 | | - | |

**Source: Fundación Valenciaport**

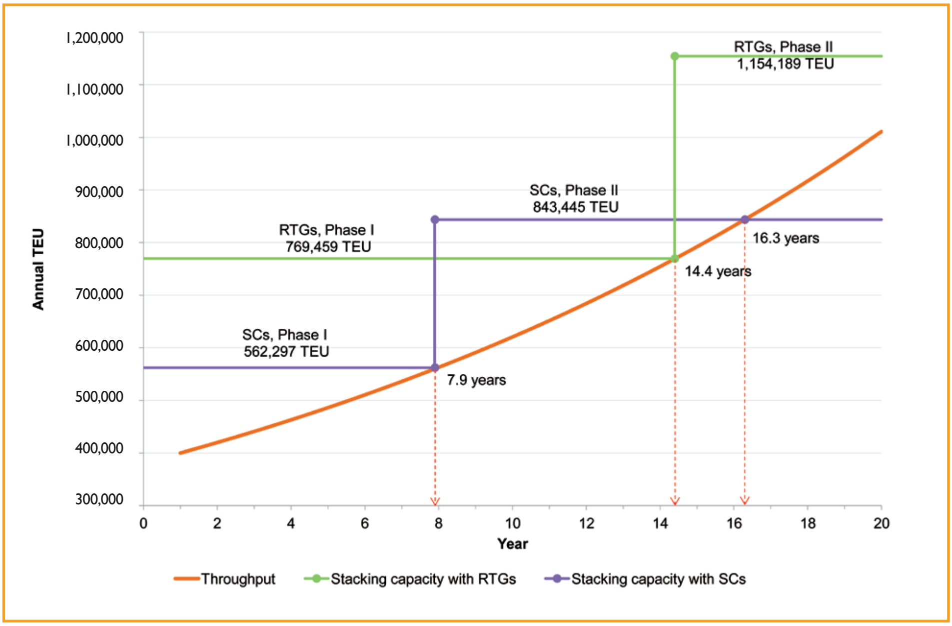
As indicated by the results above, and as appears to be logical on the basis of the static capacity values taken for the calculation, the RTG yard has more capacity than the SC yard.

Graph 18 shows the storage capacity for RTGs and SCs together with the traffic forecasts for the common-user terminal with 15% transhipment, which suggests when the enlargement should be carried out in each case. According to the graph, Phase II would be necessary six and a half years earlier in the case of a yard that employs SCs.

A terminal with an RTG yard in which container dwell time is 6 days will need Phase II to be operating after 14.4 years of the concession to be able to deal with the traffic forecast throughout the concession as a whole.

Should the terminal opt for an SC yard, Phase II would be necessary after 7.9 years and capacity would be insufficient after 16.3 years of the concession. That is to say, a yard with SCs could not cope with the traffic forecast for the last five years of the concession for the common-user terminal. For this reason, RTGs are the only valid yard equipment to deal with the demand for capacity throughout the entire concession.

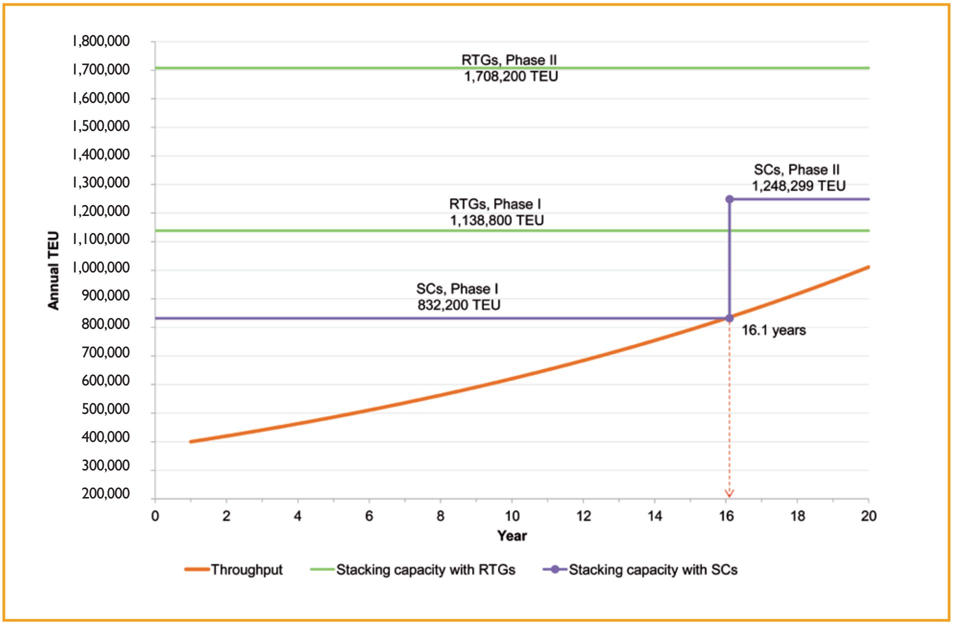
**Graph 18. Comparison of stacking capacity for RTGs and SCs in the CUT (15% of transhipment) with the throughput forecast**




Source: Fundación Valenciaport

As regards the dedicated terminal in which transhipment accounts for 75% of traffic, yard capacity for both types of equipment is much greater than for 15% transhipment, as can be observed in Graph 19.

**Graph 19. Comparison of stacking capacity for RTGs and SCs in the DT (75% of transhipment) with the throughput forecast**




Source: Fundación Valenciaport

In this case, if the yard employed RTGs, it would not be necessary to execute Phase II, as yard capacity would exceed the demand forecast for the entire concession.

In the case of a yard that employs SCs, the enlargement would have to be complete 16.1 years after the beginning of the concession, but on this occasion Phase II would have sufficient capacity to cope with the traffic forecast for the entire concession.

As in the case of the common-user terminal, RTGs initially appear to be the better option for the yard of a dedicated terminal, exclusively in terms of yard capacity, as Phase II would not be necessary. However, if Phase II were required by the DT ship-to-shore subsystem itself, the foregoing conclusion should be backed up by a feasibility study that analyses which of the two types of equipment is the best from an economic and financial perspective.

Likewise, less favourable situations should be considered when deciding which equipment to use, such as traffic growing by more than expected or the percentage of transhipment dropping. For this reason, and in order to avoid a change in demand conditions resulting in the storage subsystem restricting terminal capacity, the yard equipment that yields the most similar storage capacity to berth capacity is recommended.

Another alternative, simpler and more direct way of ascertaining which equipment is the best to cope with the traffic forecast is to use Graph 6 and Graph 7 in the recommendations section of this Manual (5.4.2.4).

On the one hand, Graph 6, on the basis of the static capacity for each of the types of equipment chosen (RTG: 650 TEU/ha and SC: 475 TEU/ha – continuing with the values previously taken from Table 30) and considering $T_{dw}$ = 6 days, provides the annual capacity per hectare for each type of equipment. Multiplying that unit capacity per hectare by the surface area of the yard ($A_Y$) and by the corresponding $K_{YTS}$ (as transhipment exists), we arrive at the conclusion that only the RTG yard is capable of meeting the demands of the traffic forecast (1,000,000 TEU). Table 42 and 43 include these calculations for the CUT and the DT, respectively.

**Table 42. Storage capacity in a CUT – Graph 11**

| Storage capacity in a CUT on the Southern Dock – Phase I and Phase II Graph 11 | | | | |
|---|---|---|---|---|
| $T_{dw}$: Average dwell time of containers in the terminal (storage) = 6 days | | | | |
| Common-user Terminal with 15% Transhipment Traffic, $K_{YTS}$= 1.081 | | | | |
| | SC | | RTG | |
| $C_S$ (TEU/ha) | 475 | | 650 | |
| $C_Y$ (TEU/ha/year) – Graph 11 | 29,000 | | 40,000 | |
| | **Phase I** | **Phase II** | **Phase I** | **Phase II** |
| $A_Y$ (ha) | 18 | 27 | 18 | 27 |
| $C_Y$ (TEU/year) | 522,000 | 783,000 | 720,000 | 1,080,000 |
| **$C_{Y\,eq\,B}$ (TEU/year)** | **564,324** | **846,486** | **778,278** | **1,167,568** |

**Source: Fundación Valenciaport**

**Table 43. Storage capacity in a DT – Graph 11**

| Storage capacity in a DT on the Southern Dock – Phase I and Phase II Graph 11 | | | | |
|---|---|---|---|---|
| $T_{dw}$: Average dwell time of containers in the terminal (storage) = 6 days | | | | |
| Dedicated Terminal with 75% Transhipment Traffic, $K_{YTS}$= 1.600 | | | | |
| | SC | | RTG | |
| $C_S$ (TEU/ha) | 475 | | 650 | |
| $C_Y$ (TEU/ha/year) – Graph 11 | 29,000 | | 40,000 | |
| | **Phase I** | **Phase II** | **Phase I** | **Phase II** |
| $A_Y$ (ha) | 18 | 27 | 18 | 27 |
| $C_Y$ (TEU/year) | 522,000 | 783,000 | 720,000 | 1,080,000 |
| **$C_{Y\,eq\,B}$ (TEU/year)** | **835,200** | **1,252,800** | **1,152,000** | **1,728,000** |

**Source: Fundación Valenciaport**

On the other hand, Graph 7 approaches the problem from the opposite angle by first calculating the need for capacity to later ascertain which yard equipment can fulfil that need. In this sense, once we know the dwell time ($T_{dw}$ = 6 days) and calculating the annual unit capacity requirement per hectare on the basis of the traffic forecast for year 20 of the concession (Traffic in year 20/$A_Y$ = 1M TEU/27 ha = 37,000 TEU/ha approximately) adjusted (divided) by the $K_{YTS}$ of each terminal, we obtain the minimum static capacity (DY) the yard equipment can provide. In the case of the CUT, the figure is slightly more than 560 TEU/ha, while for the DT it is around 380 TEU/ha. Going back to Table 30, we can deduce that RTGs are the only type of equipment that meets the storage needs of the CUT (6-wide and 4+1 stack height). In the case of the DT, as observed in the rest of calculation alternatives, although both types of equipment meet the demand for Phase II, RTGs are the only equipment capable of coping without requiring the enlargement (yard equipment with $D_Y$ > 570 TEU/ha).

It is important to highlight that if any of these pre-established conditions are altered, such as stack height (specified in Table 30), container dwell time in the yard (figure specified in the original case scenario), or the percentage of transhipment, the annual capacity of the system changes and the solution to the problem will therefore be different. Table 44 shows how the storage capacity of the two types of equipment considered varies depending on dwell time, calculated using the formula presented at the beginning of this section and taking into account the transhipment ratio ($K_{YTS}$).

**Table 44. Variation storage capacity of CUT and DT on the Southern Dock depending on dwell time**

| Storage capacity on the Southern Dock – Phase II | | | | |
|---|---|---|---|---|
| $A_Y$: Storage area or yard = 27 ha | | | | |
| $C_S$: Static storage capacity (TEU/ha) | | | SC:<br>RTG: | 475<br>650 |
| Throughput forecast for the year 20 (TEU) | | | 1,010,780 | |
| Dwell time ($T_{dw}$) | Terminal annual yard capacity (TEU) | | | |
| | CUT ($K_{YTS}$ =1.081) | | DT ($K_{YTS}$ =1.600) | |
| | SC | RTG | SC | RTG |
| **2** | **2,530,338** | **3,462,567** | **3,744,900** | **5,124,600** |
| 3 | 1,686,892 | 2,308,378 | 2,496,600 | 3,416,400 |
| **4** | **1,265,169** | **1,731,284** | **1,872,450** | **2,562,301** |
| 5 | 1,012,135 | 1,385,027 | 1,497,960 | 2,049,840 |
| **6** | **843,446** | **1,154,189** | **1,248,300** | **1,708,200** |
| 7 | 722,954 | 989,305 | 1,069,971 | 1,464,171 |
| **8** | **632,584** | **865,642** | **936,225** | **1,281,150** |
| 9 | 562,297 | 769,459 | 832,200 | 1,138,800 |
| **10** | **506,068** | **692,513** | **748,980** | **1,024,920** |

**Source: Fundación Valenciaport**

According to the results in Table 44, the SC system in the common-user terminal with Phase II, which initially lacked sufficient capacity to cope with the traffic forecast for the last five years of the concession, would have sufficient capacity to meet that demand throughout the entire period if average container dwell time were slightly more than 5 days.

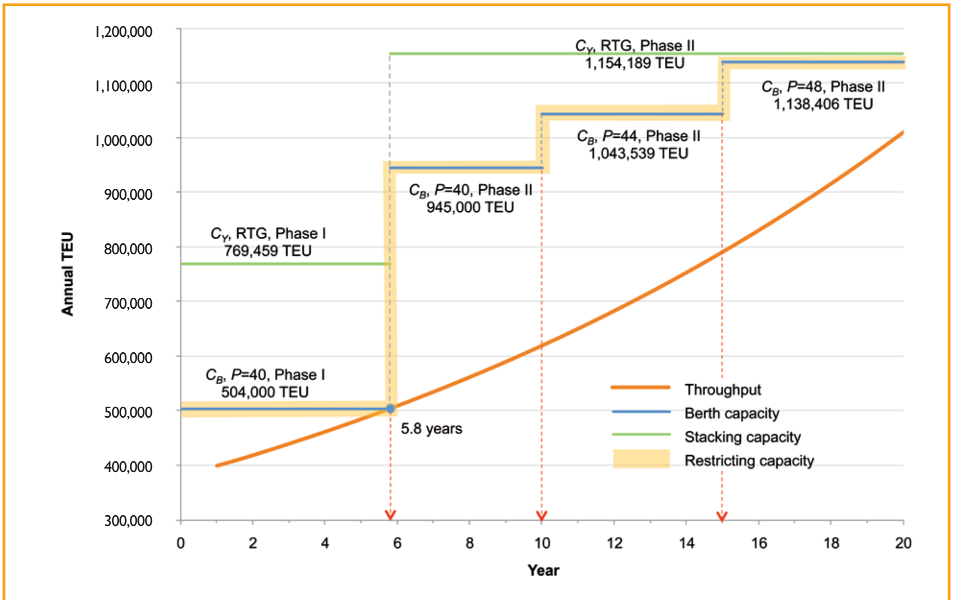
## 6.4. Terminal restricting capacities

<u>Answer to Question 4</u>

According to the results of berth capacity ($C_B$) and storage capacity ($C_Y$ expressed in $C_{Y\ eq\ B}$), obtained in the foregoing questions and taking into account that RTGs are considered the ideal yard machinery both in the case of the CUT and the DT (6-wide; 4+1), the capacity of the future terminals on the Southern Dock at Green Valley Port is, in both cases, the lowest of the capacities of those two subsystems, always assuming the delivery and receipt and transfer subsystems should not restrict the capacity of the terminal.

Graph 20 portrays the restricting capacities by subsystem for the common-user terminal with an RTG yard, for a service quality relating to $T_w/T_s$ of 0.20 (upper bound of relative waiting time for the level of service C), throughout the 20 years of the concession. It is the ship-to-shore subsystem that restricts capacity throughout the entire concession. This subsystem determines that Phase II must be operating 5.8 years after the concession began.

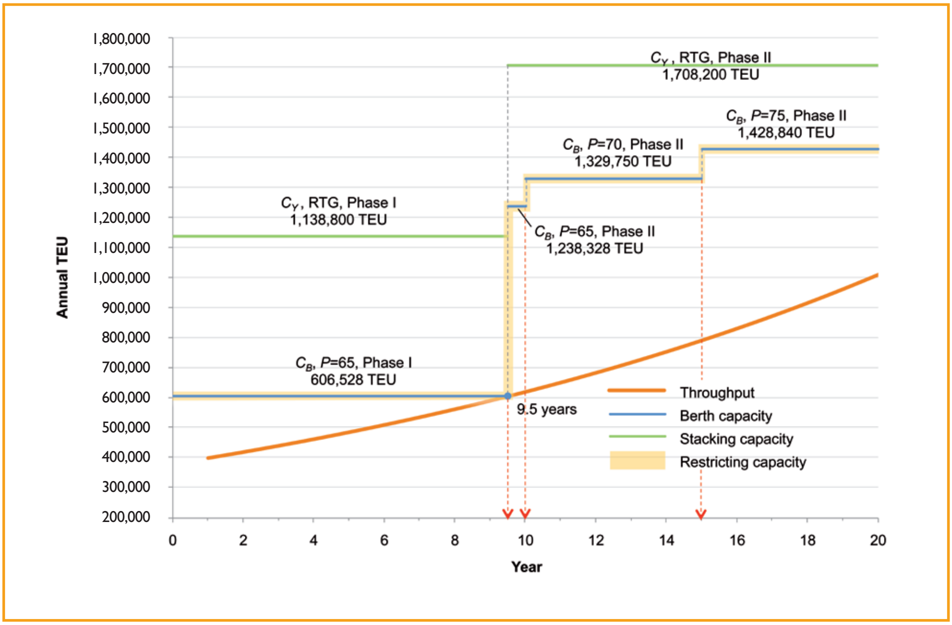
**Graph 20. Restricting capacity in the CUT for $T_w/T_s$=0.20**




Source: Fundación Valenciaport

In the case of the dedicated terminal with an RTG yard, the restricting capacities by subsystem for a service quality of 0.10 (upper bound of relative waiting time for the level of service B) and for an M/E$_4$/$n$ queue system (the worst possible scenario) are shown in Graph 21. We can see that, as in the case of the common-user terminal, it is the ship-to-shore subsystem that determines when Phase II must be executed, in this case after 9.5 years. The same graph also suggests that the ship-to-shore subsystem restricts the capacity of the terminal throughout the entire concession.

**Graph 21. Restricting capacity in the DT (M/$E_4$/*n*) for $T_w/T_s$=0.10**




Source: Fundación Valenciaport

If the DT queue system were in keeping with $E_2$/$E_4$/*n* (tightly scheduled arrivals), according to the calculations presented in Graph 15, Phase I of the ship-to-shore subsystem could cope with the traffic forecast for all 20 years of the concession. If an RTG yard is planned, Phase I also guarantees the necessary storage capacity, so in this case the concessionaire would not need to implement Phase II. Notwithstanding, regardless of whether this figure were reached during the concession, the restricting capacity of the terminal would be 1,030,320 TEU of berth capacity (the lowest of both).

In fact, investments in yard and berth at the Phase II could be done with different timing, this is, berth extension corresponding to Phase II could be ready whilst yard extension can be in different phases, to adjust investments as needed.

*A wise man can learn more from a foolish question than a fool can learn from a wise answer.*

**Bruce Lee, actor**

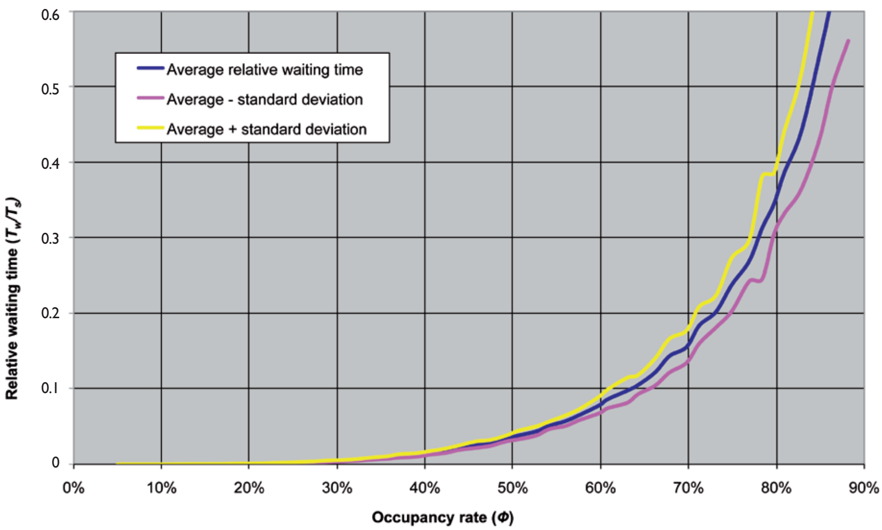
# Appendix 1: Remarks and limitations on the calculation of berth capacity

The following observations can be made in relation to the calculation of berth capacity undertaken in this handbook.

## 1. Natural variability of the berth occupancy ratio

It is worth noting that after defining relative waiting time ($T_w/T_s$), in the case of high berth occupancy ratios, which can be recorded by quays with a large number of berths, the natural variability of the berth occupancy ratio is not negligible (see *n*=5 in Graph 22)

**Graph 22. Natural variability of berth occupancy ratio. The M/$E_4$ /5 case**




Source: Obrer-Marco and Aguilar (2011)

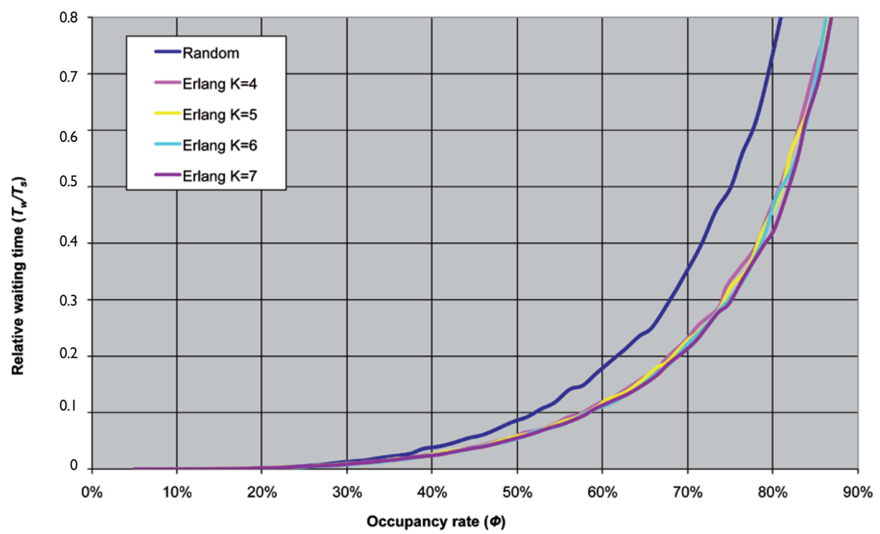
Graph 22 shows the change in natural variability as the berth occupancy ratio rises for the M/$E_4$/5 system. The curves in the graph comprise 50 points and each point has been determined using 25 simulations (25 years). The graph represents the average values of those simulations, the average plus the standard deviation and the average minus the standard deviation. This trend is similar for all inter arrival time distributions, service times and for any given number of berths that can achieve high berth occupancy ratios.

As a result, it is concluded that as the berth occupancy ratio grows, the values calculated on the basis of data taken in one year alone become progressively less representative, longer simulation periods being required to calculate the averages. Consequently, recurring congestion crises or an absence of them is not enough to conclude that the situation is close to or well short of the terminal threshold. Therefore, simulations must take into account longer periods of time to confirm the situation.

## 2. (K) degree in the Erlang function less important in service time distribution

It is worth highlighting that results hardly vary for K values equal to or greater than 4 for an $M/E_K/n$ system. As these K values are normally frequent, ascertaining K of the service time density function is not indispensable. Instead, we would only be interested in whether or not this variable actually displays an Erlang distribution function of K greater than or equal to 4. Graph 23 shows how the $M/E_K/n$ curves are overlapping, in this case calculated for 4 berths and with K values ranging from 4 to 7. The graph also shows the random distribution of service times (M/M/*n*) for comparative purposes.

**Graph 23. Curves superimposition for $M/E_K/4$ queue systems, with K from 4 to 7**




Source: Obrer-Marco and Aguilar (2011)

## 3. Discrete versus continuous quay models

In order to calculate berth capacity, the ship-to-shore subsystem is assumed to comprise a finite number of identical berths (discrete model). This assumption does not appear to be debatable in some terminals, but large container terminals do not normally conceive the quay in this way, but rather as a continuous berth where, depending on the length of the vessels that are calling at the terminal at each time, the number of berthed vessels varies.

Unlike a discrete quay model, in the case of a continuous model, vessels join the queue not because the quay is completely full, but because they do not fit in the space available at that time. This poses two issues to be considered:

- In order to optimise infrastructure use, berth allocation logic is important, particularly when there is congestion. Allocation can be simple, affecting only space (deciding the most suitable place to allocate each vessel) or more complex, also affecting the time a vessel berths and even the order they arrive (deciding when each vessel should berth and changing (or not) arrival order), all aimed at optimising the use of the infrastructure. It is evident – and proven – that optimising berth allocation reduces the length of periods of congestion, varying vessel waiting time and, as a result, ideal quay capacity.

- In the case of a discrete quay model, whenever there is a queue, the quay is 100% occupied. In contrast, when a quay is operated as a continuous model, it is not fully occupied even during the worst periods of congestion. This means that continuous models can expect lower berth occupancy ratios than discrete quay models. For this reason, before continuing, we must rewrite the equation for calculating berth occupancy ratios to adjust to the new situation.

Indeed, when a discrete quay simulation is undertaken, the berth is considered to be occupied when a vessel is berthed there, which does not reflect, depending on how long it is, whether that vessel fully occupies the berth or not. In this case and for a given period of time, $\Phi$ is obtained as follows:

$$\Phi = \frac{\sum_{i=1}^{n} \frac{t_{oi}}{t_{year_i}}}{n}$$

Where,

- $\Phi$: Berth occupancy ratio calculated in discrete mode
- $i$: Berth counter
- $n$: Number of berths
- $t_{oi}$: Hours berth i is occupied
- $t_{yeari}$: Berth i operating hours per year

However, when quay operations are continuous, as the concept of "berth" does not exist, only the space a vessel takes up is considered occupied, to which we must add the safety allowance, which together can be valued on the basis of the vessel separation coefficient ($K_{Separation}$). In this sense, the value of $\Phi_C$ for a given period of time (generally a year) can be obtained as follows:

$$\Phi_C = \sum_{j=1}^{B} \frac{K_{Separation} \times L_{Vj} \times t_{sj}}{L_B \times t_{year}}$$

Where:

- $\Phi_C$: Berth occupancy ratio calculated in continuous mode
- $j$: Counter of vessels that call at the terminal during the time considered
- $B$: Number of vessels that call at the terminal during the time considered
- $K_{Separation}$: coefficient that when applied to the length of a vessel, provides the safety distance between vessels (of the order 1.1)
- $L_{Vj}$: Length of vessel *j*
- $t_{sj}$: Hours of service of vessel *j*
- $L_B$: Length of the quay
- $t_{year}$: Quay operating hours per year

If we wish to compare situations, these two concepts of $\Phi$ will be used as if they represented the same thing – and they do to a certain extent – even though they are calculated using different equations.

Apart from the above, there are other aspects to be considered that yield new possibilities. The first is the implicit need for vessels to be characterised by their length distribution function, as it is not evident – but rather quite the opposite – that results will be the same if vessel length distribution is well spread or concentrated around average values. Furthermore, if we compare the results of the various cases, each of which is idealised as discrete and continuous mode, not only do we have to change the formula for the berth occupancy ratio, but we also have to reconsider the concept of equivalent berths used in the discrete calculation. The main problem that arises is choosing the "standard vessel". The choice of "standard vessel" defines vessel length and provides the number of equivalent berths, on the basis of the length of the quay and the safety allowance between ships. As the calculation of berth capacity aims to assign a value to traffic over a period of time during which the number of vessels berthed at the quay is not constant, we must ascertain the distribution function of the length of the vessels that call at the terminal. If we are defining a standard vessel for a terminal that is still in the project stage, it is worth estimating the possible distribution functions of vessel length. As mentioned previously, after obtaining *neq* as the ratio between the length of the quay and "standard vessel" length (adjusted for safety reasons), the result could be fractional. Note that when the lengths of vessels that call at the terminal vary, which is common over time, the number of equivalent berths will also change.

As we saw in section 5.1.2, the relationship between $\Phi$ and $T_w/T_s$ is known for integer values of the number of equivalent berths. However, this value will more than likely be fractional. This poses a problem for obtaining $\Phi$ as we must justify which curve should be used.

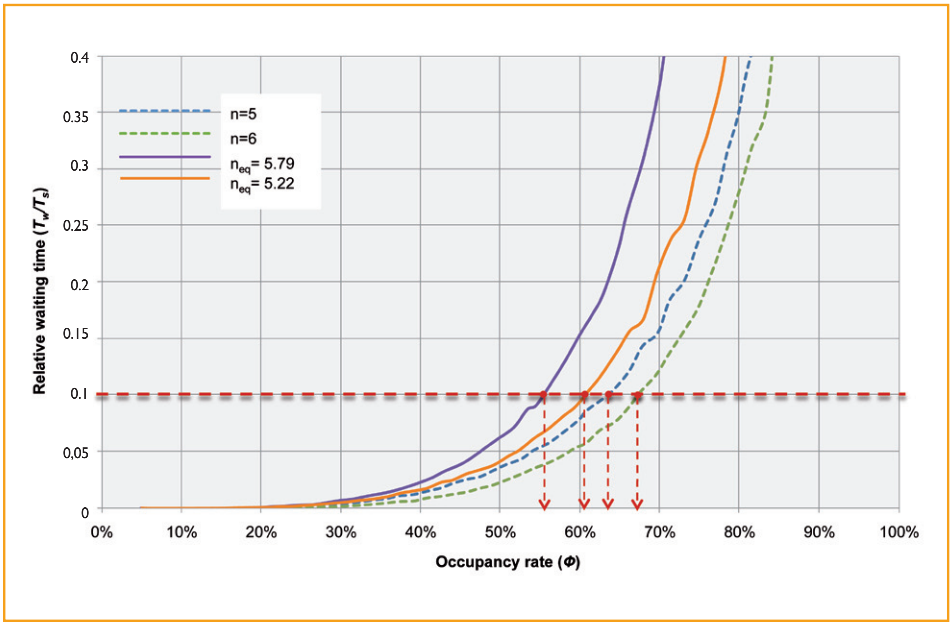
With the objective of comparing the two possible berth models, Obrer-Marco and Aguilar (2011) present comparisons for a series of quays, modelled in both ways, which match a series of vessel distributions. In order to easily solve the berth allocation logistics problem, in the case of the continuous model, the foregoing study considers FIFO queue management (arrival order is not changed), but as mentioned by Agerschou (2004), adjustments are made to the vessels berthed, moving them so that no space is lost between them – every time a ship departs. Although this practice is not carried out in reality, it does provide a maximum value for the berth occupancy ratio. The results yield differences between the two models.

### 3.1. Differences when the distribution of vessel length is constant

When constant vessel lengths are simulated, the fractional part of the number of equivalent berths is very high, in a way that, the greater it is, the greater the difference between the two values of the berth occupancy ratio (the one associated to a continuous model and the one associated to a discrete model made up (composed) of a number equal to the integer part of the previous one). Indeed, as can be observed in Graph 24, when the number of equivalent berths is fractional, the value of $\Phi_C$ associated to a value of $T_w/T_s$ is always lower or equal to the value of $\Phi$ for a discrete quay comprising an equal number of berths to the foregoing Integer number of equivalent berths. As that graph shows, both in the case of the number of equivalent berths of the quay operated continuously being 5.79 or 5.22, the berth occupancy ratio associated to $n$=5 is higher. In the same graph and in all the graphs that follow, the discrete simulations are represented by dotted lines and continuous simulations by continuous lines.

This situation can be explained by the difference in the definition of the berth occupancy ratio between a quay operated in a discrete mode and another operated in continuous model, as we already presented in this chapter. The former results show the effect of not making the most of the quay when it is not a multiple of vessel length (constant in this case), which means it is impossible to achieve the asymptote when the berth occupancy ratio equals 1.

**Graph 24. Berth occupancy ratio correspondence with the relative waiting time of M/$E_4$/*n* queue systems, for *n* between 5 and 6, and constant vessel lengths**




Source: Obrer-Marco and Aguilar (2011)

Therefore, when the simulated vessel lengths are constant, if the fractional part of the number of equivalent berths tends to zero (5.1; 5.05;...), an approach will be made with growing occupancy rates – from the left – to the results of the simulation of a quay composed by a number of berths equal to the integer number of equivalent berths mentioned previously (5). In this process, terminal capacity does not change. This increasing estimation of berth occupancy ratios occurs because they correspond to reductions in the length of the quay such that both effects offset each other.

In contrast, as the fraction of the number of equivalent berths increases (5.7; 5.8; 5.9;...), the curve will move further away to lower berth occupancy ratios –to the left- than the corresponding to the integer part of the number of berths. When quay growth is such that the integer part of the number of berths increases by a unit, the curve will shift abruptly to the next whole number (6). This discontinuity reveals a sharp increase in capacity only at the time one more vessel fits on the quay. Intuitively, the fractional part of a number of berths just represents the length of the quay that cannot be used. This is, 6.8 berths, in a discrete mode, it means just 6 berths and 0.8 of useless berth. So, the bigger the fractional part of the number of berths, the lower the occupancy ratio. If we just extend the quay to pass from 6.8 to 7.0 berths, this means 7 berths rather than 6, which is a big difference.

### 3.2. Differences when vessel lengths are variable

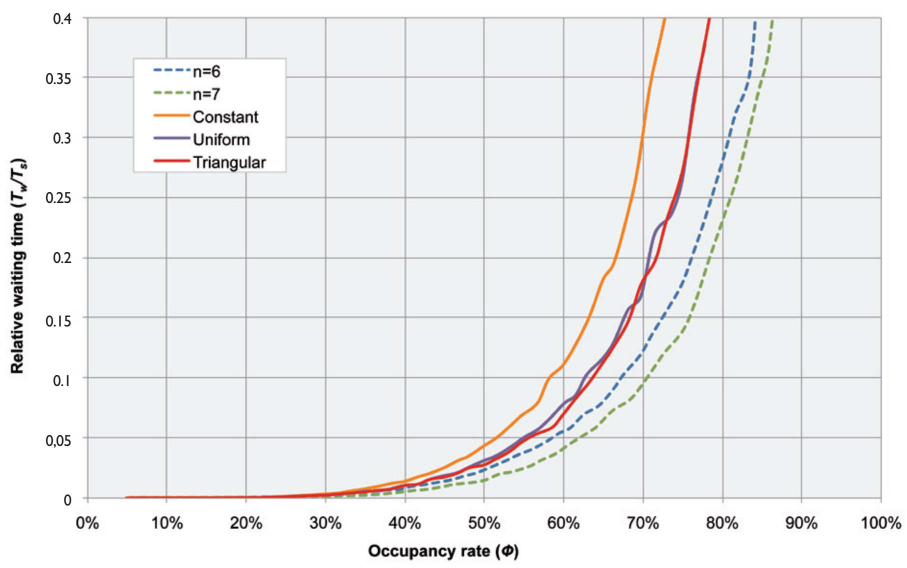
According to that same study, vessel length variability can improve or worsen the berth occupancy ratio for the same relative waiting time in relation to the case when vessel lengths are constant (an improvement being the equivalent of higher values of $\Phi_C$, while worsening is the equivalent of lower values of $\Phi_C$). It has been verified that when the fractional part of the number of equivalent berths is greater than 0.5, an improvement occurs, but when it is less than 0.5 it worsens and when it is around 0.5 there are no substantial differences.

In order to illustrate these results, Graph 25 and Graph 26 respectively show examples of improving and worsening of berth occupancy ratios.

Graph 25 presents the results of the simulation of a 2,000 metre-long quay where vessels with an average of length of 250 metres are berthing. The curves of the berth occupancy ratio – $T_w/T_s$– have been represented for the case in which the quay is operated in continuous mode in three situations: 1) vessel length distribution is constant; 2) vessel lengths fit a uniform distribution with a maximum standard deviation of +/-100 metres; and 3) vessel lengths fit a triangular distribution with a maximum standard deviation of +/-100 metres. Assuming a safety coefficient of 0.15, the number of equivalent berths is equal to 6.95. In order to be able to make a comparison with the results of the discrete simulation, the results of the quays comprising 6 and 7 berths have also been portrayed. As it can be appreciated, the curves associated to the simulations of vessel length variability (uniform or triangular distribution) are to the right of those associated to constant vessel lengths, which implies **an improvement in berth occupancy ratios** for the same value of $T_w/T_s$. This also means that vessel length variability provides results that are closer to those obtained when simulating the quay in discrete mode.

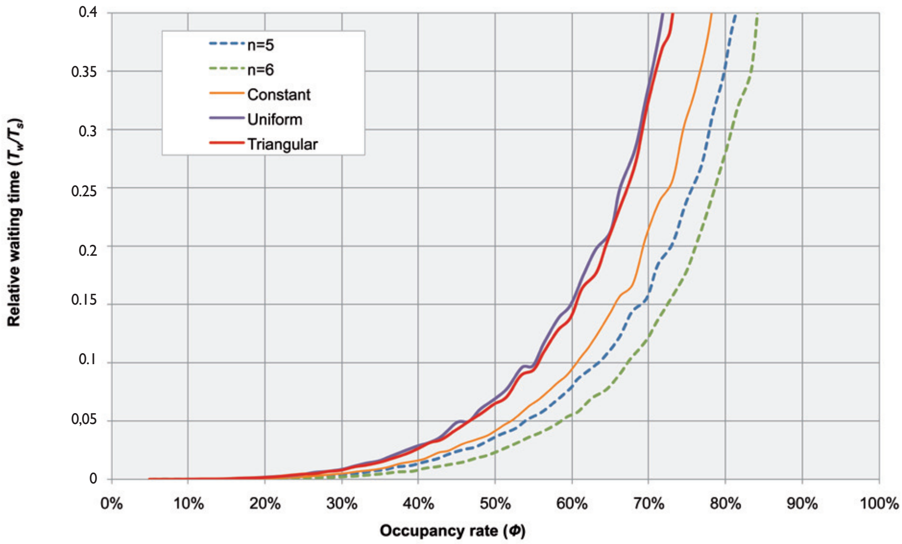
Graph 26 presents the results of the simulation of a 1,500 metre-long quay where vessels with an average length of 250 metres are berthing. Therefore, assuming the same safety allowance between ships as previously, the number of equivalent berths is equal to 5.22. In this case, the curves associated to the simulations with vessel length variability (uniform or triangular distributions) are to the left of those associated to the simulation of vessel lengths with a constant distribution, which implies lower values of $\Phi_C$ for the same value of $T_w/T_s$. This graph reveals marked differences between existing vessel length variability (uniform or triangular distribution) or not existing (constant distribution of the vessel length), but once variability exists, it matters little whether it is concentrated (triangular) or spread (uniform). In addition to this, vessel length variability is observed to yield **worse berth occupancy ratios** which are also further from those obtained when simulating the quay discretely.

**Graph 25. Improvement of berth occupancy ratio**




Source: Obrer-Marco and Aguilar (2011)

**Graph 26. Worsening of Berth occupancy ratio**




Source: Obrer-Marco and Aguilar (2011)

Finally, the same work verified that when the fractional part of the number of equivalent berths is around 0.5, vessel length variability does not affect the results, as practically all the curves are on top of each other.

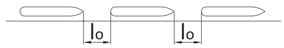
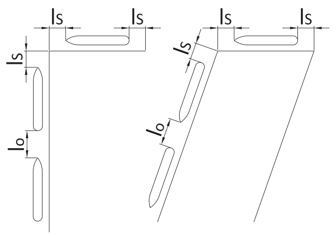
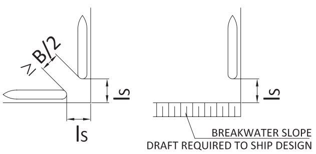
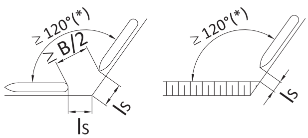
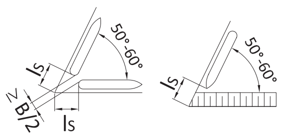
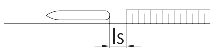
In general, when using discrete simulation, the growth of the size (length) of the quay implies an increase of the capacity of the subsystem in two ways: increasing the number of berths and an increase in the berth occupancy ratio. In the continuous simulation mode case, it is obvious that an increase in the quay size implies an increase in capacity (although such an increase can sometimes be almost nonexistent), even though the contribution of the berth occupancy ratio is much less direct, as observed.

These comparisons show the differences that appear when modelling the quay discretely or continuously, differences that could be even greater, as it is worth recalling that in the case of calculating the continuous model, it has been assumed that vessels re-allocation are made systematically on the quay. These differences suggest it is worth undertaking capacity studies using continuous models, particularly when the aim is to value the effect of small quay enlargements, the result of which is almost impossible to quantify using a discrete model.

From all the foregoing information, we can deduce that, when the number of berths obtained is a rational (fractional), it is convenient to use the integer part of this number in the capacity formula and to use the curve corresponding to that same integer number for the berth occupancy ratio. However, it is not advisable to interpolate values to the curves corresponding to whole numbers higher and lower than that value, as capacity would be overestimated. Nevertheless, it is possible to learn more about the specific case at hand by performing the subsequent simulations.

# Appendix 2: Safe distance (berthing gap)

The table below shows the ROM 2.1 proposal (González-Herrero *et al.*, 2006) for the calculation of safe distance at the quay between vessels (berthing gap).

| REPRESENTATIVE QUAY SKETCH | VALUES OF THE VARIABLES ACCORDING OF THE TOTAL LENGTH (L in m) OF THE LARGEST VESSEL AFFECTING THE DETERMINATION OF THE ANALYZED DIMENSION | | | | |
|---|---|---|---|---|---|
| | MORE OF 300 | 300 – 201 | 200 – 151 | 150 – 100 | LESS OF 100 (1) |
| 1.- DISTANCE "lO" BETWEEN SHIPS DOCKED IN THE SAME ALIGNMENT (m)   | 30 | 25 | 20 | 15 | 10 |
| 2.- GAP "ls" BETWEEN VESSELS AND CHANGES IN THE ALIGNMENT OR IN THE STRUCTURAL TYPE (m) a)   | 30 | 25 | 20 | 10 | 5 |
| b)   | 45/40 | 30 | 25 | 20 | 15 |
| c)   | 30/25 | 20 | 15 | 15 | 10 |
| d)   | - /60 | 50 | 40 | 30 | 20 |
| e)   | 20 | 15 | 15 | 10 | 10 |

**(1) FOR VESSELS WITH TOTAL LENGTH LESS THAN 12 m VALUE WILL BE TAKEN AS "lo" THE 20% OF "L", RESETTING PROPORTIONALLY THE OTHERS VALUES.**
**(B) BEAM OF THE BIGGEST VESSEL THAT AFFECT TO THE DETERMINATION OF THE ANALYZED DIMENSION.**
**(*) THE ANGLE IS CONSIDERED TO BE LIMITED TO 160°. FOR BIGGEST ANGLES APPLY CASE 1.**
**Source: González-Herrero *et al.* (2006)**

# Appendix 3: Annual capacity per metre of berth with berths of 250 and 350 metres in length

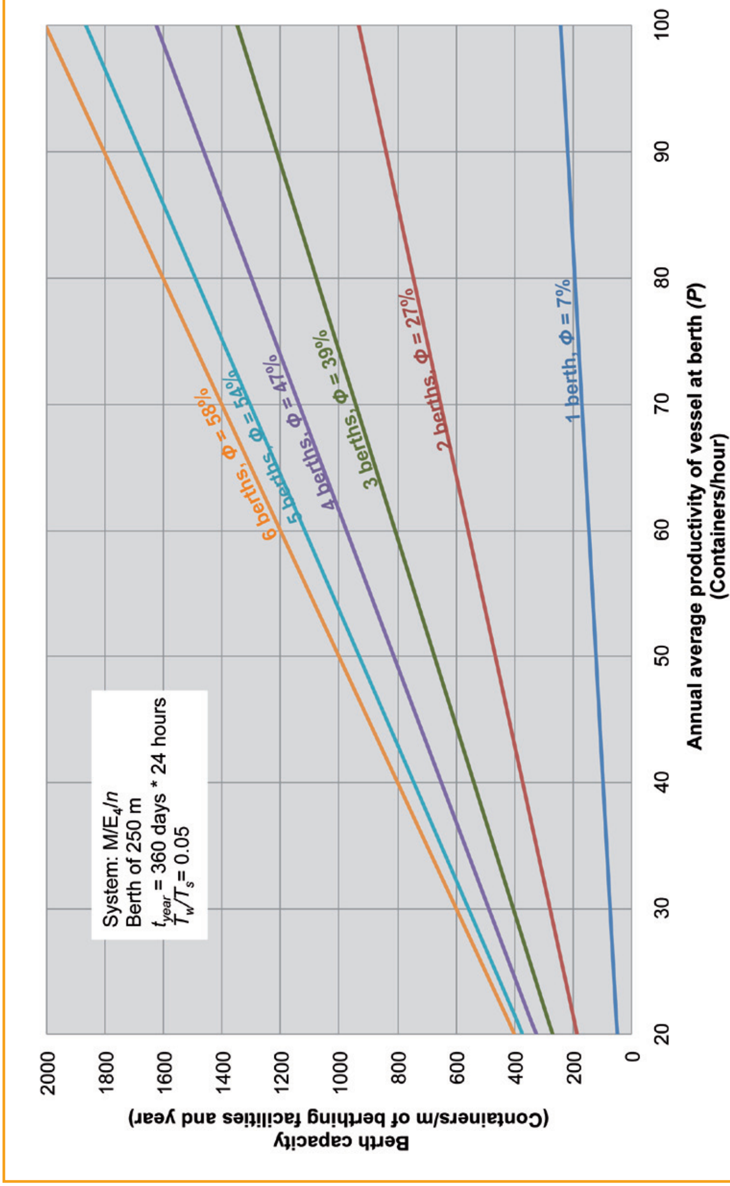
This appendix presents the estimate of the annual berth capacity per metre of quay according to type of traffic ($M/E_4/n$ and $E_2/E_4/n$), annual average productivity of vessel at berth and number of berths, considering berths of 250 metres (Table 45 and its respective graphics) and 350 metres (Table 46 and its respective graphics) in length, and three quality of services associated to relative waiting time ($T_w/T_s$): 5%, 10% and 20%.

**Table 45. Annual berth capacity per metre of quay according to type of traffic, annual average productivity of vessel at berth and number of berths, considering berths of 250 metres in length**

| System and traffic profile | Annual average productivity of vessel at berth ($P$) (Cont./ h) | BERTH CAPACITY – CONTAINER TERMINAL (Containers / metre of berth and year) Length of each berth= 250 m; $t_{year}$ = 8,640 h Relative waiting time: $T_w/T_s$ = 0.05 – **0.10** – 0.20 | | | | | |
|---|---|---|---|---|---|---|---|
| $E_2/E_4/n$ Tightly scheduled calls | 80 | 605 – **855** – 1,185 | 1,185 – **1,465** – 1,740 | 1,465 – **1,740** – 1,990 | 1,685 – **1,935** – 2,155 | 1,825 – **2,015** – 2,235 | 1,905 – **2,125** – 2,320 |
| | 70 | 530 – **750** – 1,040 | 1,040 – **1,280** – 1,520 | 1,280 – **1,520** – 1,740 | 1,475 – **1,690** – 1,885 | 1,595 – **1,765** – 1,960 | 1,665 – **1,863** – 2,030 |
| | 60 | 455 – **640** – 890 | 890 – **1,095** – 1,305 | 1,095 – **1,305** – 1,490 | 1,265 – **1,450** – 1,615 | 1,365 – **1,510** – 1,800 | 1,430 – **1,595** – 1,740 |
| | 50 | 380 – **535** – 740 | 740 – **915** – 1,085 | 915 – **1,085** – 1,245 | 1,050 – **1,210** – 1,345 | 1,140 – **1,260** – 1,400 | 1,190 – **1,330** – 1,450 |
| $M/E_4/n$ Random inter arrivals times | 70 | 165 – **335** – 580 | 650 – **870** – 1,185 | 940 – **1,185** – 1,475 | 1,135 – **1,375** – 1,645 | 1,305 – **1,520** – 1,765 | 1,400 – **1,620** – 1,835 |
| | 60 | 145 – **290** – 495 | 560 – **745** – 1,015 | 805 – **1,015** – 1,265 | 975 – **1,180** -1,410 | 1,120 – **1,305** – 1,510 | 1,200 – **1,385** – 1,575 |
| | 50 | 120 – **240** – 415 | 465 – **620** – 845 | 670 – **845** – 1,050 | 810 – **985** – 1,175 | 930 – **1,085** – 1,260 | 1,000 – **1,155** – 1,310 |
| | 40 | 95 – **190** – 330 | 370 – **495** – 675 | 535 – **675** – 840 | 650 – **785** – 940 | 745 – **870** – 1,005 | 800 – **925** – 1,050 |
| Number of berths ($n$) | | 1 | 2 | 3 | 4 | 5 | 6 |

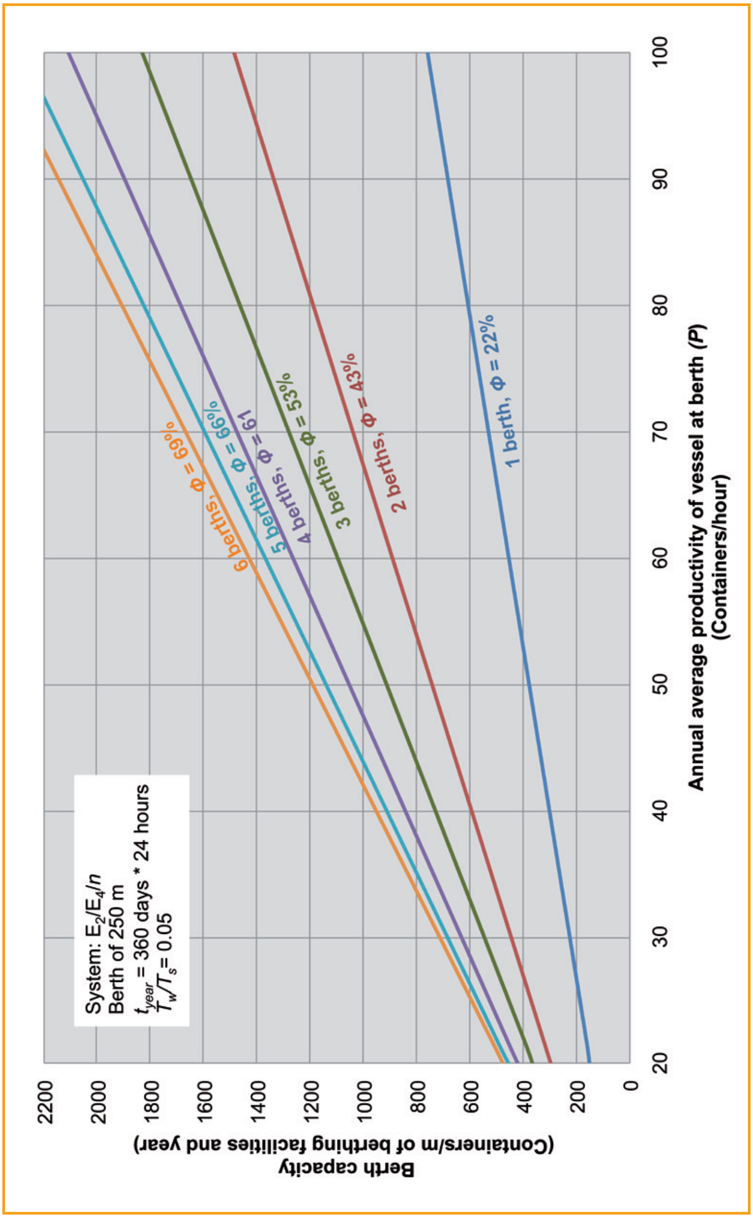
**Source: Fundación Valenciaport**

Graph 27. Annual berth capacity for M/$E_4$/*n* queue system and relative waiting time of 0.05 with berths of 250 metres in length



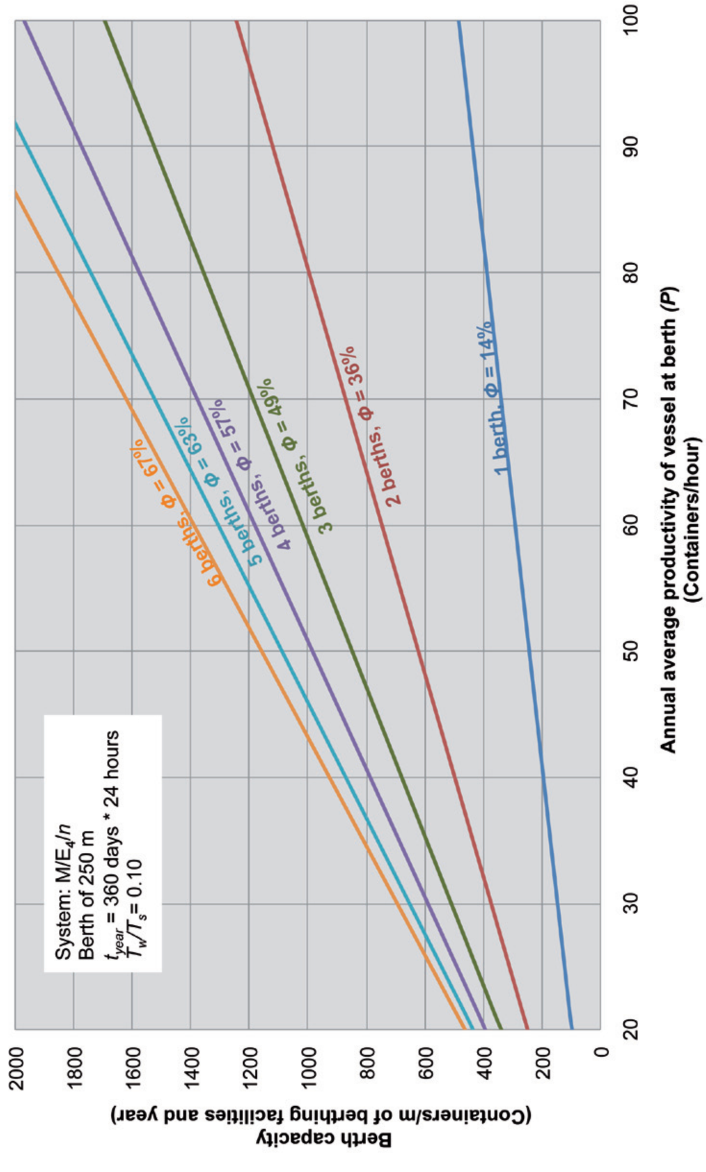

Source: Fundación Valenciaport

**Graph 28. Annual berth capacity for $E_2/E_4/n$ queue system and relative waiting time of 0.05 with berths of 250 metres in length**



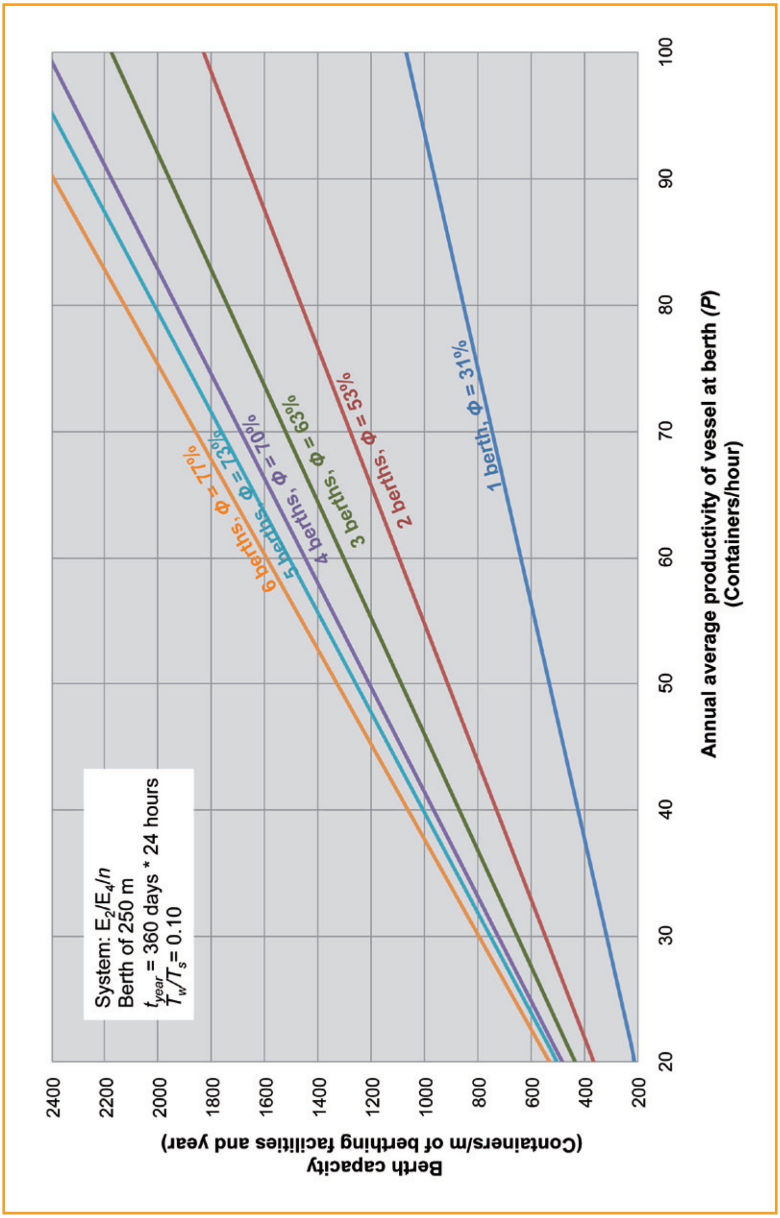

Source: Fundación Valenciaport

Graph 29. Annual berth capacity for $M/E_4/n$ queue system and relative waiting time of 0.10 with berths of 250 metres in length



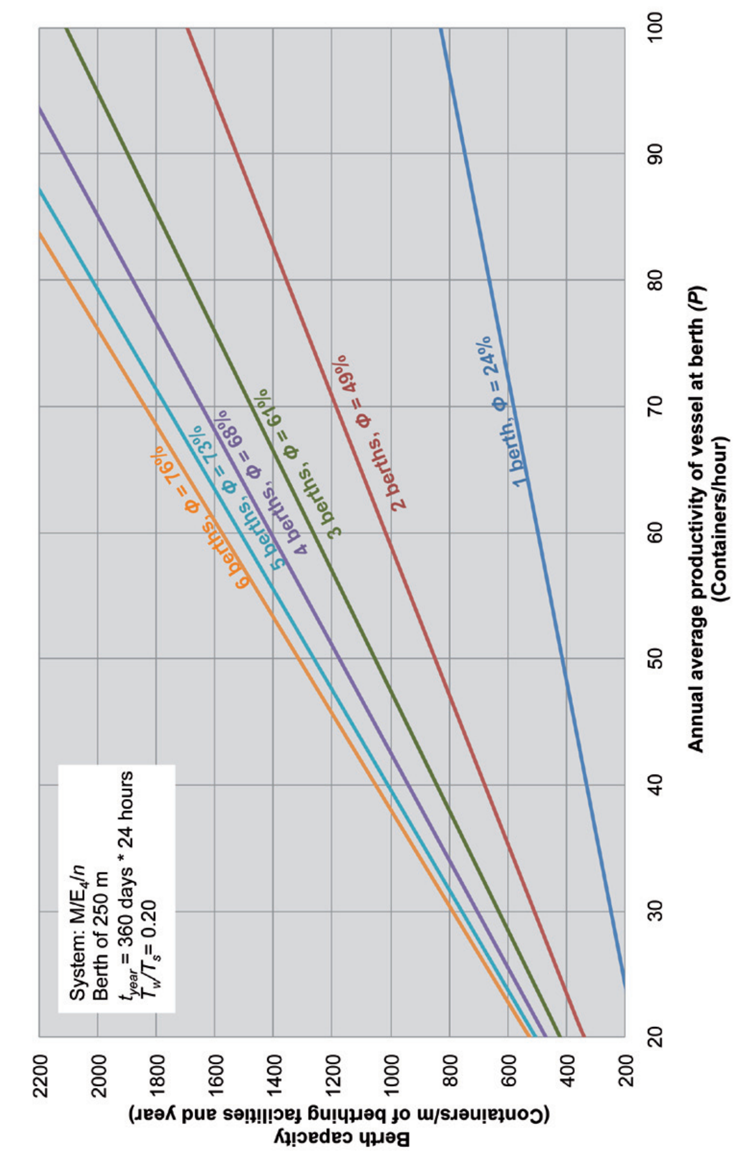

Source: Fundación Valenciaport

Graph 30. Annual berth capacity for $E_2/E_4/n$ queue system and relative waiting time of 0.10 with berths of 250 metres in length



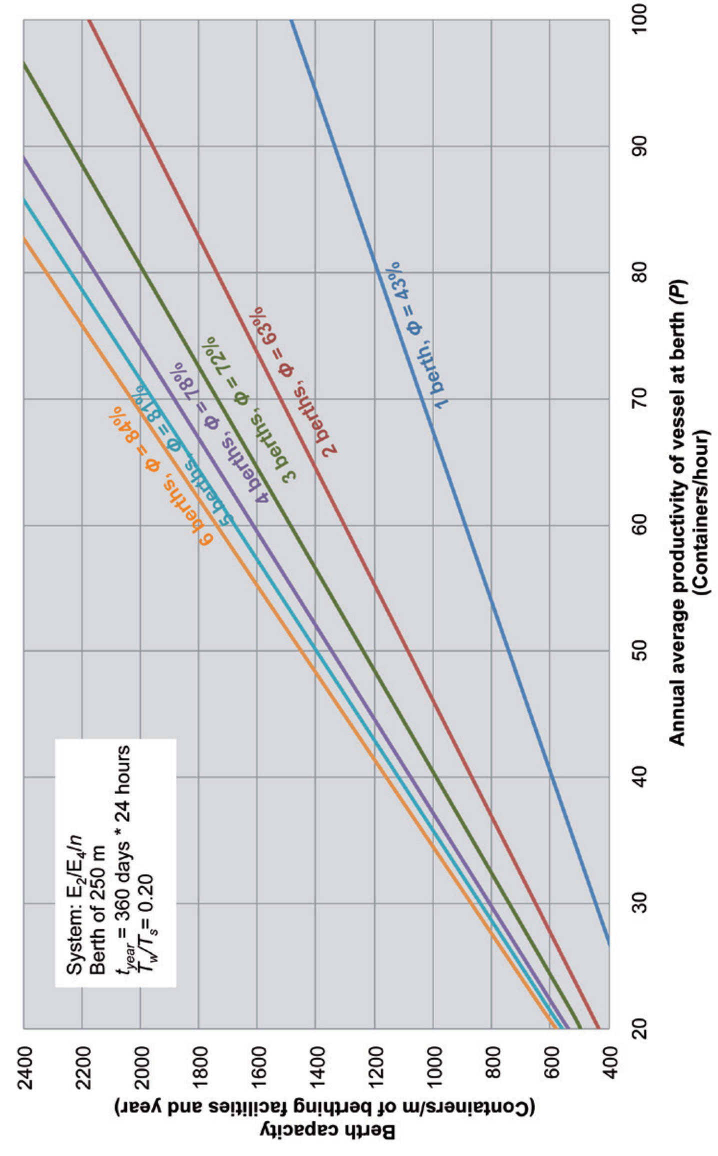

Source: Fundación Valenciaport

Graph 31. Annual berth capacity for M/$E_4$/*n* queue system and relative waiting time of 0.20 with berths of 250 metres in length




Source: Fundación Valenciaport

Graph 32. Annual berth capacity for $E_2/E_4/n$ queue system and relative waiting time of 0.20 with berths of 250 metres in length



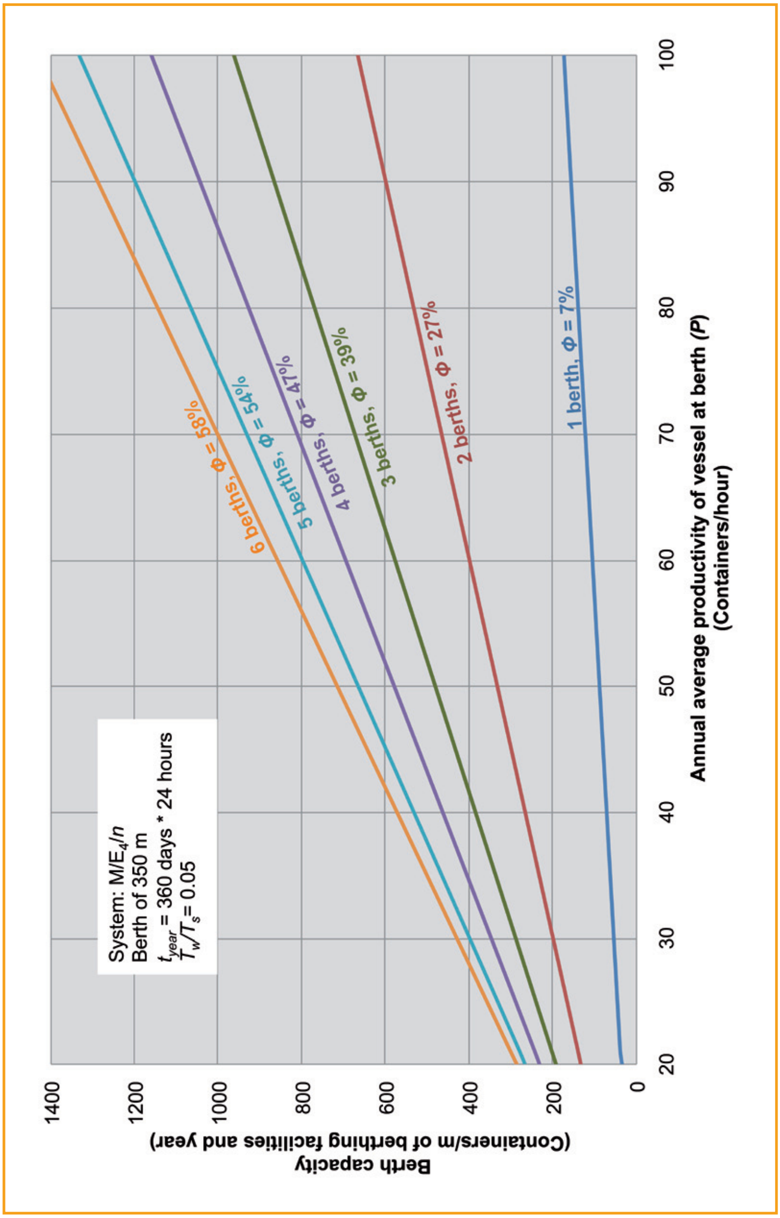

Source: Fundación Valenciaport

**Table 46. Annual berth capacity per metre of quay according to type of traffic, average annual productivity of vessel at berth and number of berths, considering berths of 350 metres in length**

| System and traffic profile | Annual average productivity of vessel at berth (*P*) (Cont./h) | BERTH CAPACITY – CONTAINER TERMINAL (Containers / metre of berth and year) Length of each berth= 350 m; $t_{year}$ = 8,640 h Relative waiting time: $T_w/T_s$ = **0.05** – 0.10 – **0.20** | | | | | |
|---|---|---|---|---|---|---|---|
| $E_2/E_4/n$ Tightly scheduled calls | 80 | 430 – **610** – 845 | 845 – **1,045** – 1,240 | 1,045 – **1,240** – 1,420 | 1,205 – **1,380** – 1,540 | 1,300 – **1,440** – 1,600 | 1,360 – **1,520** – 1,655 |
| | 70 | 380 – **535** – 740 | 740 – **915** – 1,085 | 915 – **1,085** – 1,240 | 1,050 – **1,210** – 1,345 | 1,140 – **1,261** – 1,400 | 1,190 – **1,330** – 1,450 |
| | 60 | 325 – **455** – 635 | 635 – **785** – 930 | 785 – **930** – 1,065 | 900 – **1,035** – 1,155 | 975 – **1,080** – 1,200 | 1,020 – **1,140** – 1,240 |
| | 50 | 270 – **380** – 530 | 530 – **650** – 775 | 650 – **775** – 885 | 750 – **860** – 960 | 815 – **900** – 1,000 | 850 – **950** – 1,035 |
| $M/E_4/n$ Random inter arrivals times | 70 | 120 – **240** – 415 | 465 – **620**- 845 | 670 – **845** – 1,050 | 810 – **985** – 1,175 | 930 – **1,085** – 1,260 | 1,000 – **1,155** – 1,310 |
| | 60 | 100 – **205** – 355 | 400 – **530** – 725 | 575 – **725** – 900 | 695 – **840** – 1,005 | 800 – **930** – 1,080 | 855 – **990** – 1,125 |
| | 50 | 85 – **170** – 295 | 330 – **440** – 605 | 480 – **605** – 750 | 580 – **700** – 835 | 665 – **775** – 900 | 715 – **825** – 935 |
| | 40 | 65 – **135** – 235 | 265 – **355** – 480 | 385 – **480** – 600 | 460 – **560** – 670 | 530 – **620** – 720 | 570 – **660** – 750 |
| Number of berths (*n*) | | 1 | 2 | 3 | 4 | 5 | 6 |

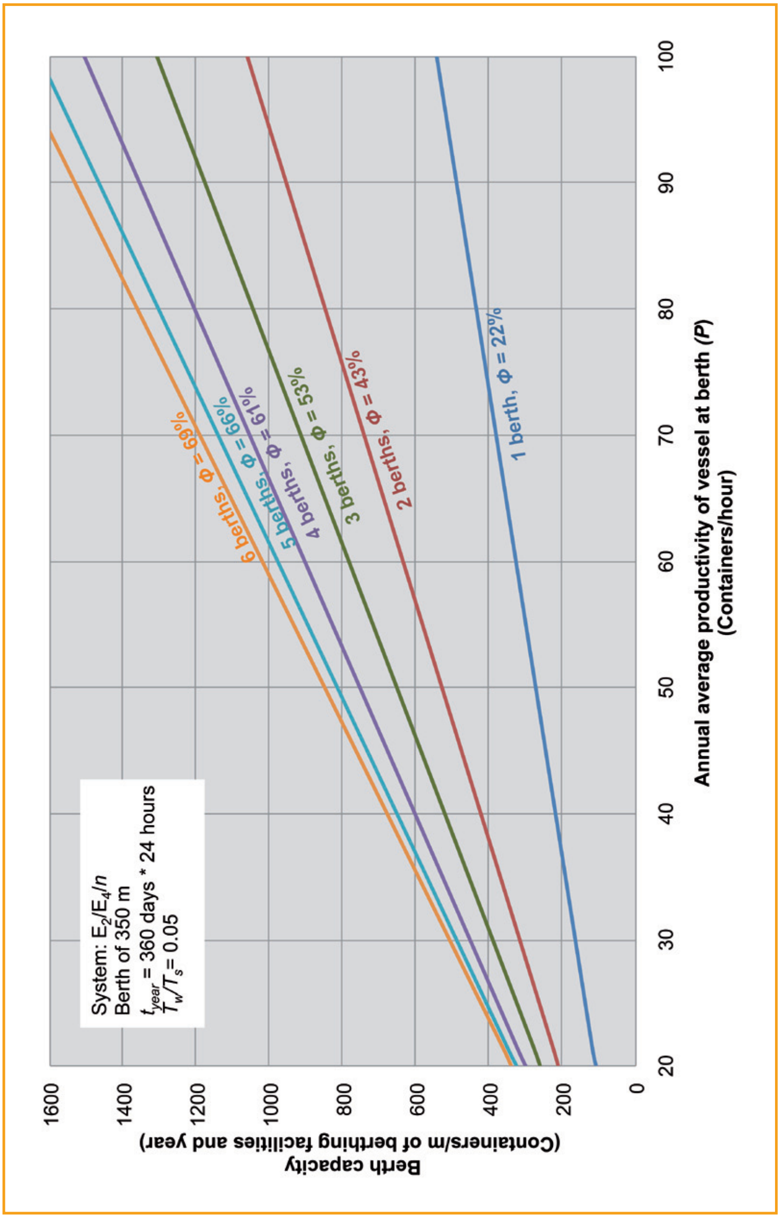
Source: Fundación Valenciaport

**Graph 33.** **Annual berth capacity for M/E$_4$/*n* queue system and relative waiting time of 0.05 with berths of 350 metres in length**



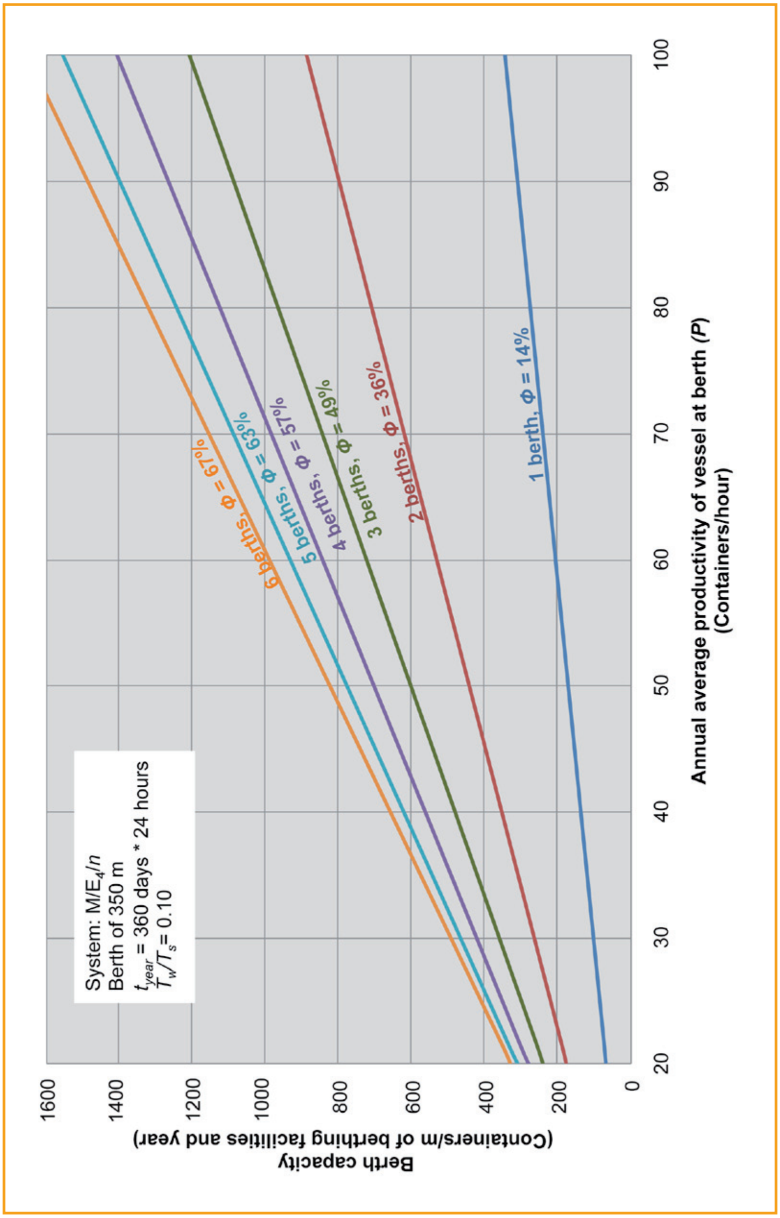

Source: Fundación Valenciaport

Graph 34. Annual berth capacity for $E_2/E_4/n$ queue system and relative waiting time of 0.05 with berths of 350 metres in length



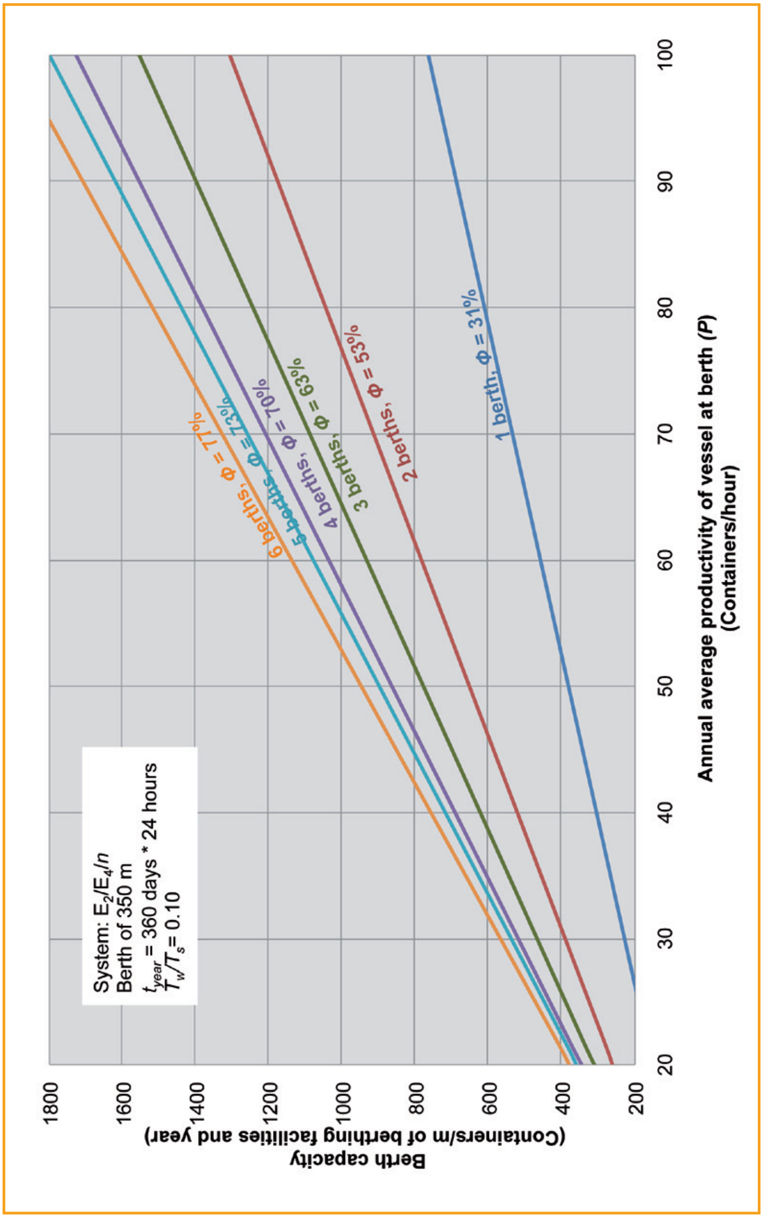

Source: Fundación Valenciaport

**Graph 35. Annual berth capacity for M/E$_4$/*n* queue system and relative waiting time of 0.10 with berths of 350 metres in length**



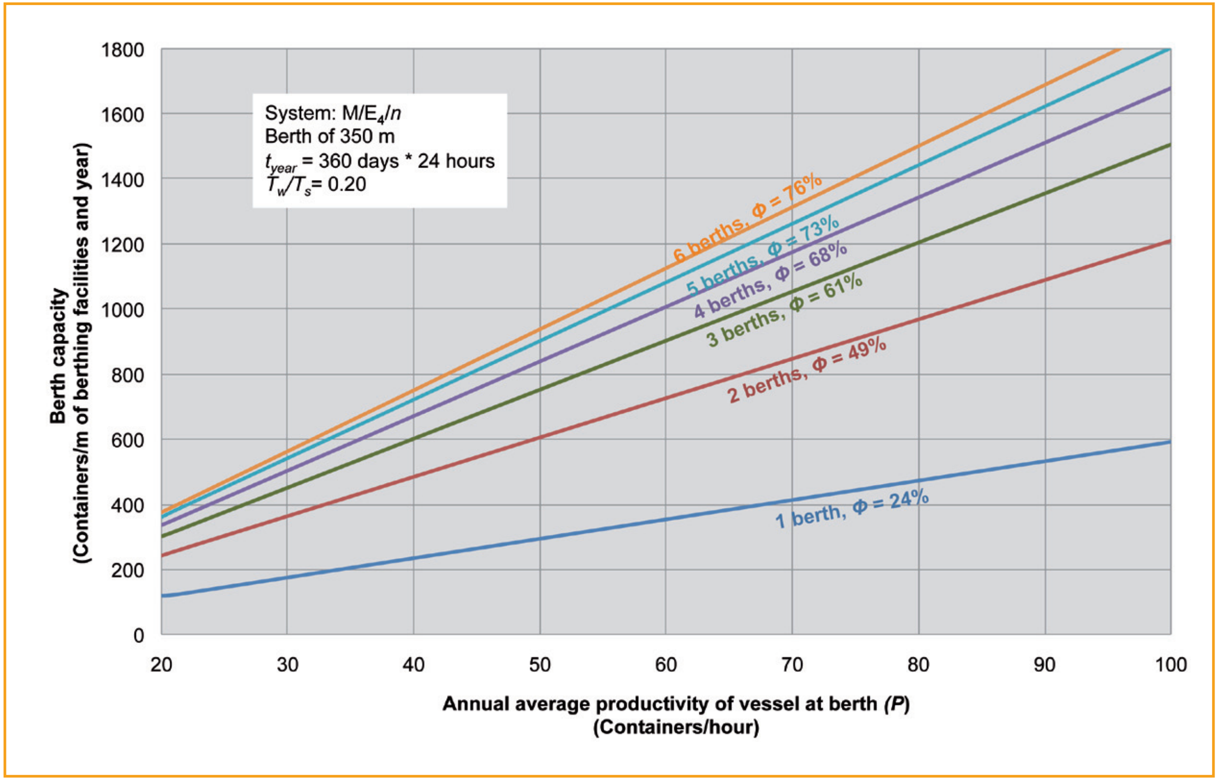

Source: Fundación Valenciaport

**Graph 36. Annual berth capacity for $E_2/E_4$ /*n* queue system and relative waiting time of 0.10 with berths of 350 metres in length**



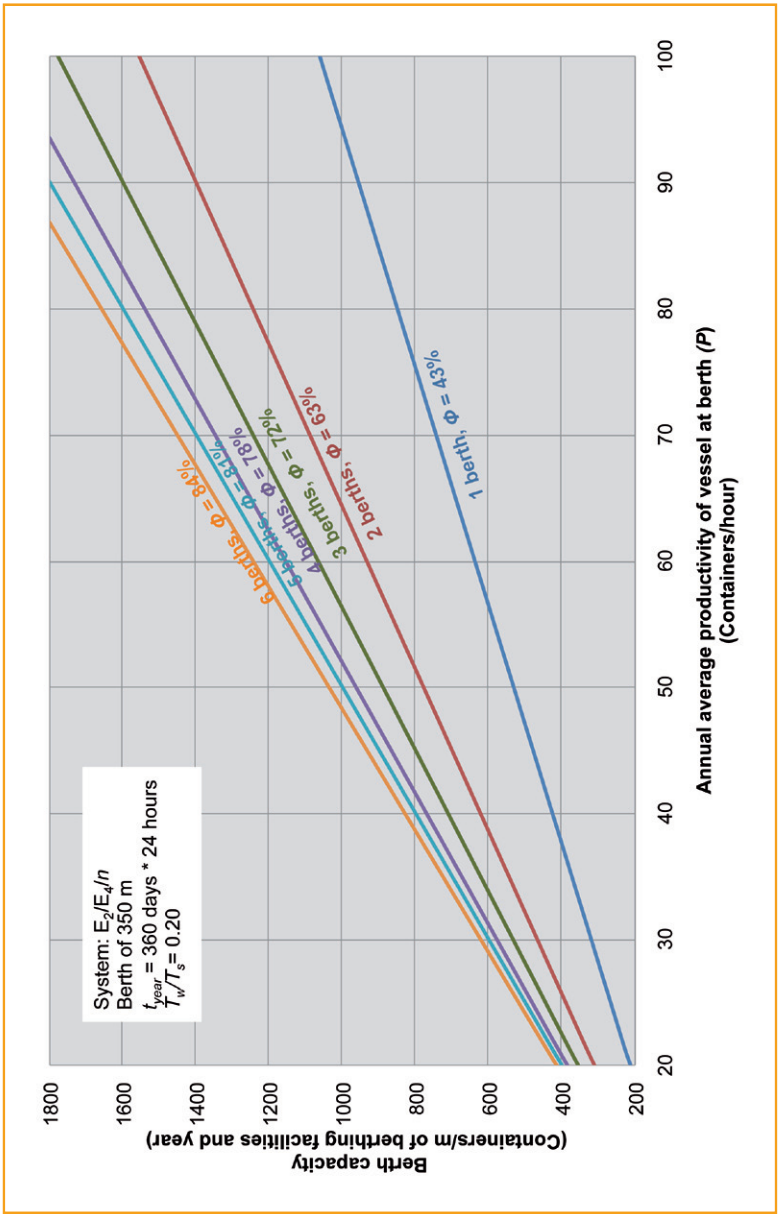

Source: Fundación Valenciaport

**Graph 37. Annual berth capacity for M/E$_4$/*n* queue system and relative waiting time of 0.20 with berths of 350 metres in length**




Source: Fundación Valenciaport

Graph 38. Annual berth capacity for $E_2/E_4/n$ queue system and relative waiting time of 0.20 with berths of 350 metres in length



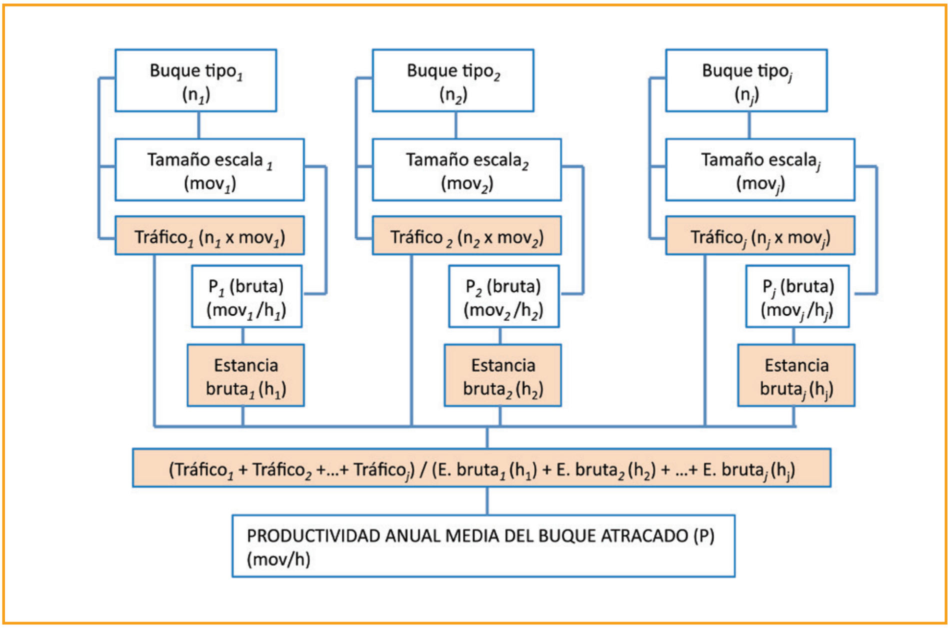

Source: Fundación Valenciaport

# Appendix 4. Estimation of the Average Annual Berth Productivity

Estimating the average annual productivity of a berthed ship (*P*) is important when calculating the berth capacity of a terminal, because for an inter arrival time and service time distribution system, a number of berths and a value of relative waiting time, both variables are proportional.

The range of values to be considered for *P* is related to the scenarios included in the exercise to forecast maritime traffic. Those scenarios are specified by ship queue systems that have different capacities (types of ship) and sizes of calls (inland O/D and transhipment container movements) throughout a year and by different levels of productivity ($mov_j/h_j$) for each type or category of ship (see Figure 58). The latter mainly depend on the number of transfers to be performed, the average number of cranes and crane productivity.

**Figure 58. Calculation of annual average productivity of vessel at berth (*P*)**

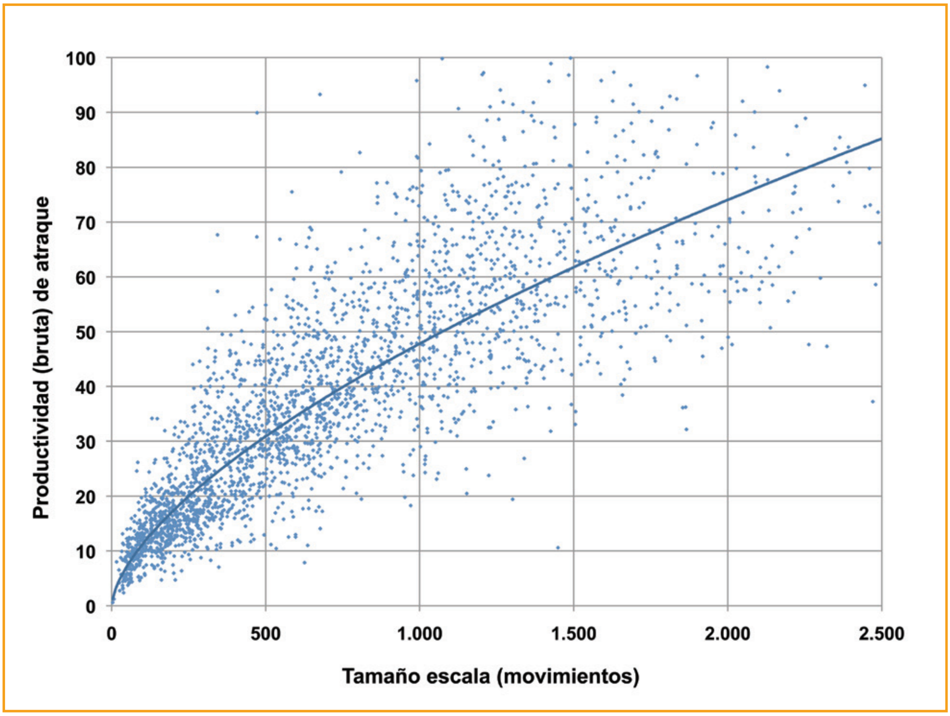



Source: Fundación Valenciaport

Furthermore, as verified by Graph 39, berth productivity is related to the size of the call (inland O/D and transhipment container movements), so it rises as the number of movements (ship to shore) to be performed increases. This is mainly due to the fact that the more movements there are, more cranes can be deployed simultaneously, which is in keeping with the objective of minimising the time a ship is operating at berth.

It is obvious that if calls are on average small, the level of productivity achievable will also be low and that mass transfers yield high levels of productivity, as in the case of dedicated terminals. In many terminals, the long-run increase in average annual productivity per berthed ship, and therefore in capacity, has occurred alongside growth in the average size of calls. In other words, traffic has increased while the number of ships has either risen less or stabilised.

**Graph 39. Relation between number of movements and productivity (gross) of vessel at berth (sample of Port of Valencia, 2010)**




Source: Fundación Valenciaport based on data from the Valencia Port Authority

By way of example, Table 47 shows the case of calculating *P* on the basis of the values in Stenvert and Penfold (2004) included in Table 21 in Chapter 5, which are shaded in purple and blue.

Table 47. Example of calculating annual average productivity of vessel at berth (*P*)

**Data: system $M/E_4/4$**

**Relative waiting time = 0.10 supposes a berth occupancy = 57%**

**To achieve a capacity of 1,500,000 TEU, *P* required is 50 cont,/h**

| Occupancy | Vessel size (TEU) | Vessels ($n_i$) | Call size ($mov_i$) | Traffic (moves) | $P_i$ berth ($mov_i/h_i$) | Gross berth times ($h_i$) | hours/year |
|---|---|---|---|---|---|---|---|
| | 4,400 | 492 | 1,067 | 524,800 | 44 | 11,808 | 8,640 |
| | 5,200 | 190 | 1,261 | 239,515 | 53 | 4,560 | 8,640 |
| | 6,200 | 115 | 1,503 | 172,848 | 63 | 2,760 | 8,640 |
| | 6,200 | 30 | 2,104 | 63,127 | 88 | 720 | 8,640 |
| | 8,800 | 0 | 2,987 | 0 | 124 | 0 | |
| 57% | | 827 | Total cont. | 1,000,291 | 50 | 19,848 | 34,560 |
| | | | Total TEU | 1,500,436 | *P* | | |
| | | | | 4 berths of 300 m | Length of quay | 1,200 | m |
| | | | | | Berth productivity | 834 | cont./m |
| | | | | | TEU/cont. | 1.5 | |
| | | | | | | 1,250 | TEU/m |

Source: Fundación Valenciaport based in values of Stenvert and Penfold (2004)

Table 48 provides the aavresult of applying the methodology presented in the Handbook to calculate the average annual productivity of a berthed ship in the terminals employed by Ashar (2009), based on the value of berth productivity presented by the author for the cases of common-user terminals ($M/E_4/n$ queue system) and dedicated terminals ($E_2/E_4/n$ y $M/E_4/n$ queue system).

**Table 48. Calculation of annual average productivity of vessel at berth (*P*) for referred terminals of Ashar (2009) based on the berth productivity**

| Ashar (2009) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type of Berth | Design Vessel | Length of berth | Berths (*n*) | Length of quay | Capacity | | |
| | | | | | Berth | Terminal | Berth-metre |
| | (TEU) | (m) | (Ud) | (m) | (TEU) | (TEU) | (TEU/m year) |
| Sub Panamax | 3,000 | 250 | 3 | 750 | 350,000 | 1,050,000 | 1,400 |
| Panamax | 4,500 | 280 | 3 | 840 | 450,000 | 1,350,000 | 1,607 |
| Post Panamax I | 5,700 | 300 | 3 | 900 | 500,100 | 1,500,300 | 1,667 |
| Panamax | 4,500 | 280 | 4 | 1,120 | 495,000 | 1,980,000 | 1,768 |
| Post Panamax I | 5,700 | 300 | 4 | 1,200 | 550,000 | 2,200,000 | 1,833 |
| Post Panamax II | 8,000 | 350 | 4 | 1,400 | 700,000 | 2,800,000 | 2,000 |
| Post Panamax III | 12,000 | 400 | 4 | 1,600 | 1,000,000 | 4,000,000 | 2,500 |

| | Seaport Capacity Manual (Fundación Valenciaport, 2011) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Annual berth capacity (TEU/m) | | | | Berth productivity: *P* (cont./h) | | | | |
| Type of Berth | Dedicated | | Dedicated or Common-User | | Dedicated | | Dedicated or Common-User | | Range |
| | $E_2/E_4/n$ | | $M/E_4/n$ | | $E_2/E_4/n$ | | $M/E_4/n$ | | Several |
| | 0.05 | 0.1 | 0.1 | 0.2 | 0.05 | 0.1 | 0.1 | 0.2 | |
| Sub Panamax | 1,401 | 1,404 | 1,422 | 1,423 | 51 | 43 | 56 | 45 | 43-56 |
| Panamax | 1,619 | 1,609 | 1,610 | 1,609 | 66 | 57 | 71 | 57 | 57-71 |
| Post Panamax I | 1,671 | 1,687 | 1,672 | 1,687 | 73 | 62 | 79 | 64 | 62-79 |
| Panamax | 1,779 | 1,782 | 1,768 | 1,794 | 63 | 55 | 67 | 57 | 55-67 |
| Post Panamax I | 1,845 | 1,845 | 1,847 | 1,851 | 70 | 61 | 75 | 63 | 61-75 |
| Post Panamax II | 2,010 | 2,022 | 2,005 | 2,014 | 89 | 78 | 95 | 80 | 78-95 |
| Post Panamax III | 2,510 | 2,517 | 2,512 | 2,512 | 127 | 111 | 136 | 114 | 111-136 |

Source: Fundación Valenciaport based in values of Ashar (2009)

Table 49 compares the values in Drewry (2002 and 2010) and Ashar (2009) using the results of Table 48 and calculating the values for the cases of 2 and 3 berths that fall within the range of 500 to 1000 metres of berth considered by Drewry (see Table 19 in Chapter 5). This approach once again enables us to deduce the *P* used, but inversely. In the upper section of the table, Drewry's proposal of 1,000 TEU/m for common-user terminals with competition and lower occupancy factors (less relative waiting time) is compared to the equivalent range proposed by Ashar from 1,400 to 1,667 TEU/m. The fact that increasing the number of berths at a terminal from 2 to 3 implies an "automatic" increase in capacity of 36% (for $M/E_4/n$ queue system) explains the best part of the difference between the results. That is, the cases of 2 and 3 berths fall inside the range of 500-1,000 metres of berth, Drewry's proposal of 1,000 TEU/m recording an average value that overestimates the case of 2 berths and underestimates that of 3 berths.

The aforementioned over and underestimation also occurs in the second section, around the value of 1,200 TEU/m, although in this case the difference in relation to Ashar's values for 3 berths is smaller, as the comparison is made for a relative waiting time of 0.20 (Drewry identifies this as the common-user terminal scenario with the highest quay occupancy factor).

Finally, in the third section, this time around 1,600 TEU/m, both authors record similar results for *P* with values even coinciding entirely at *P* = 66 containers/hour in the case of the $E_2/E_4/3$ queue system and a relative waiting time of 0.05.

**Table 49. Calculation of annual average productivity of vessel at berth (*P*) for 500-1,000 range of Drewry (2002 and 2010) for referred terminals of Ashar (2009) and comparison**

| Drewry (2002 y 2010) | | | | | | Seaport Capacity Manual (Fundación Valenciaport, 2011) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Berth productivity: *P* (cont./h) | | | | | | | | | Comparison | | | |
| | | | | | | Drewry | | | | | Ashar (2009) | | | | % Ashar > Drewry | | | |
| Tipo de atraque | Design Vessel | Length of berth | Berths | Length of quay | Berth capacity | CUT | | DT | | Range | CUT | | DT | | CUT | | DT | |
| | | | | | | $M/E_4/n$ | | $E_2/E_4/n$ | | Several | $M/E_4/n$ | | $E_2/E_4/n$ | | $M/E_4/n$ | | $E_2/E_4/n$ | |
| | (TEU) | (m) | (Ud) | (m) | (TEU/m) | 0.1 | 0.2 | 0.05 | 0.1 | | 0.1 | 0.2 | 0.05 | 0.1 | 0.1 | 0.2 | 0.05 | 0.1 |
| Sub Panamax | 3,000 | 250 | 2 | 500 | 1,000 | 54 | | | | 40-60 | | | | | | | | |
| Panamax | 4,500 | 280 | 2 | 560 | | 60 | | | | | | | | | | | | |
| Post Panamax I | 5,700 | 300 | 2 | 600 | | 65 | | | | | | | | | | | | |
| Sub Panamax | 3,000 | 250 | 3 | 750 | | 40 | | | | | 56 | | | | 40% | | | |
| Panamax | 4,500 | 280 | 3 | 840 | | 45 | | | | | 71 | | | | 58% | | | |
| Post Panamax I | 5,700 | 300 | 3 | 900 | | 48 | | | | | 79 | | | | 65% | | | |
| Sub Panamax | 3,000 | 250 | 2 | 500 | 1,200 | | 48 | | | 38-78 | | | | | | | | |
| Panamax | 4,500 | 280 | 2 | 560 | | | 53 | | | | | | | | | | | |
| Post Panamax I | 5,700 | 300 | 2 | 600 | | | 78 | | | | | | | | | | | |
| Sub Panamax | 3,000 | 250 | 3 | 750 | | | 38 | | | | | 45 | | | | 18% | | |
| Panamax | 4,500 | 280 | 3 | 840 | | | 43 | | | | | 57 | | | | 33% | | |
| Post Panamax I | 5,700 | 300 | 3 | 900 | | | 46 | | | | | 64 | | | | 39% | | |
| Sub Panamax | 3,000 | 250 | 2 | 500 | 1,600 | | | 72 | 59 | 49-87 | | | | | | | | |
| Panamax | 4,500 | 280 | 2 | 560 | | | | 81 | 66 | | | | | | | | | |
| Post Panamax I | 5,700 | 300 | 2 | 600 | | | | 87 | 70 | | | | | | | | | |
| Sub Panamax | 3,000 | 250 | 3 | 750 | | | | 59 | 49 | | 56 | 45 | 51 | 43 | 10% | 9% | 16% | 14% |
| Panamax | 4,500 | 280 | 3 | 840 | | | | 66 | 55 | | 71 | 57 | 66 | 57 | 8% | 4% | 0% | 4% |
| Post Panamax I | 5,700 | 300 | 3 | 900 | | | | 70 | 59 | | 79 | 64 | 73 | 62 | 13% | 8% | 4% | 5% |

**NOTE: CUT is used for "Common-User Terminal" and DT for "Dedicated Terminal"**
**Source: Fundación Valenciaport based in values of Drewry (2002 and 2010) and Ashar (2009)**

Finally, it is worth reiterating the "intrinsic" importance (together with the fact that both variables are proportional) of the number of berths in terms of terminal capacity. As can be observed in Table 50, the "intrinsic" or "structural" capacity of an $M/E_4/n$ queue system increases by 36% when the number of berths increases from 2 to 3, which is the equivalent of raising the average productivity of a vessel at berth from 55 to 75.

**Table 50. Comparison between the capacity increase result of raising the average productivity of vessel at berth or to change 2 into 3 berths**

| Increase of average productivity of vessel at berth (*P*) (cont,/h) | | | | | |
|---|---|---|---|---|---|
| P | | Capacity increase | | | |
| from | 35 | 29% | 57% | 86% | 114% |
| from | 45 | | 22% | 44% | 67% |
| from | 55 | | | 18% | 36% |
| from | 65 | | | | 15% |
| from | 75 | | | | |
| to | P | 45 | 55 | 65 | 75 |

| System $M/E_4/n$ | | | |
|---|---|---|---|
| Relative waiting time | | 0.1 | |
| Berths (*n*) | Acceptable berth occupancy ratio % | Capacity increase % | To change *n* into "*n* + x" berths Cases |
| 1 | 14% | | |
| 2 | 36% | 157% | from 1 to 2 |
| 3 | 49% | 36% | from 2 to 3 |
| 4 | 57% | 58% | from 2 to 4 |
| 5 | 63% | 75% | from 2 to 5 |
| 6 | 67% | 86% | from 2 to 6 |

Source: Fundación Valenciaport

*[…] be quiet when the wisest person talks, learn to listen, that is the key, if your intention is to know.*

**Alberto Cortez, poet and singer**

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*Seaport capacity manual:*
*application to container terminals*

This Manual is the second tangible result of the project entitled "MASPORT: Automation and Simulation Methodologies for the Assessment and Enhancement of the Capacity, Performance and Level of Service of Port Container Terminals" financed by the National Plan for Scientific Research, Development and Technological Innovation (R+D+i) 2008-2011. As part of the same project, another monographic paper entitled "The Port Container Terminal as a Node System in the Logistics Chain" was published prior to the Manual, while a third paper is envisaged on the subject of technological innovations and the management of such terminals to complete the trilogy.

Following a brief overview of the developments in berth productivity, this Manual addresses the different types of port terminals and pays specific attention to calculating the capacity of port container terminals, after introducing the concepts of performance, throughput, productivity, utilisation, capacity and level of service. The Manual concludes with a detailed example of how to apply the methodology to calculate the capacity of a public terminal and a dedicated terminal.

The objective of the Manual is to present a methodology to calculate the capacity of port terminals, specifying the case of container terminals, which can be used as a practical guide to planning such facilities, while at the same time proposing an innovative framework of levels of service.

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