UNCTAD
Ad Hoc Expert Meeting on
Assessing Port Performance

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The Capacity in Container Port Terminals

by

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THE CAPACITY IN CONTAINER PORT TERMINALS

Ad Hoc Expert Meeting on Assessing Port Performance

Geneva, 12th December 2012

VALENCIAPORT FOUNDATION

Ana María Martín Soberón– *R&D Project Manager*

INTRODUCCIÓN: Valenciaport Foundation

The **Valenciaport Foundation for Research, Promotion and Commercial Studies of the Valencian region (Valenciaport Foundation)** has been conceived to further expand the reach of the logistics - ports community by serving as a **research, training and cooperation** centre of excellence.

The Valenciaport Foundation manifests an initiative of the **Port Authority of Valencia (PAV),** in collaboration with various other associations, companies and institutions.

The Valenciaport Foundation is presently active in numerous cooperation and internationalisation projects in well **over twenty countries**, principally located in **Europe**, **the Far East** and **Latin America**. It also works extensively at the service of the Spanish logistics chain providing both research and training services.

INTRODUCCIÓN: Planning and Port Development Team

The Planning and Port Development Department of the VPF is a team of individuals with substantial experience and prestige, which come from both the academic and professional fields. It consists of R&D&I specialists in **the field of ports, transport economics, logistics and intermodality.**

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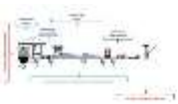
Green Cranes

EfiCont

Port Cluster Governance Committee

PCGC



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INTRODUCCIÓN: MASPORT

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AUTOMATION AND SIMULATION METHODOLOGIES FOR THE EVALUATION AND IMPROVEMENT OF PORT CONTAINER TERMINALS

FUNDACIÓN Valenciaport · UNIVERSIDAD POLITÉCNICA DE VALENCIA · TCV SA · TMS · okode

Expte: P 19/08 – Convocatoria 2008 de Ayudas a Proyectos I+D en Transporte e Infraestructura - Plan Nacional de I+D+i 2008-2011

www.masport.es

INTRODUCTION: Categories to measure port performance

Category		Definition
Operational port performance	Output	It 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. *Examples: Annual traffic or throughput (t/year; TEUs/year)*
	Productivity	It 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. *Examples: Berthing facility productivity (TEUs/m y year); Vessel productivity at port (TEUs/h); Crane productivity (movements/h)*
	Utilisation	It is the ratio (expressed in percentage form) between the utilisation of a given resource and the maximum utilisation possible over a period of time. *Examples: Berth facility utilisation (% of occupancy)*
Efficiency		It is the utilisation of ratios that express the coefficient between a result (output) – traffic- and a resource (input) –infrastructure and equipment-.
Capacity		**It is the maximum traffic a port terminal can handle in a given scenario.**
Level of Service		It provides a measure of the quality perceived by system clients and users.

Source: Monfort et al. (2011)

CONTENTS

A. **Levels of Service in Container Terminals**

B. **Capacity calculation in Container Terminals**

A. LEVELS OF SERVICE IN CONTAINER TERMINALS

It provides a measure of the quality perceived by system clients and users.

Main clients of a container terminal:

SHIPPING LINES

They perceive the quality of the service provided in two ways:

- **Total amount of charges or tariffs that shipping lines must pay every time their vessels call at a port** → €
- **Duration of the call at port**

A. LEVELS OF SERVICE IN CONTAINER TERMINALS

$$\frac{T_P}{Q}$$

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

$$T_P = T_w + T_m + T_s$$

T_w: Waiting time (anchorage), that is, due to port congestion the vessel must wait for a berth;
T_m: Manoeuvring time; and,
T_s: Service time or gross berthing time, that is, the time the vessel is at the berth

$$\frac{T_P}{Q} = \frac{1}{Q}(T_w + T_m + T_s)$$

A. LEVELS OF SERVICE IN CONTAINER TERMINALS

$$\frac{T_P}{Q} = \frac{1}{Q}(T_w + \cancel{T_m} + T_s)$$

0

$$\frac{T_P}{Q} = \frac{1}{Q}(T_w + T_s)$$

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

A. LEVELS OF SERVICE IN CONTAINER TERMINALS

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

Relative waiting time:

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

T_w: Waiting time (anchorage), that is, due to port congestion the vessel must wait for a berth;

T_s: Service time or gross berthing time, that is, the time the vessel is at the berth

$$\frac{T_P}{Q} = \frac{T_s}{Q}(1 + \varepsilon)$$

A. LEVELS OF SERVICE IN CONTAINER TERMINALS

$$\frac{T_P}{Q} = \frac{T_s}{Q}(1+\varepsilon)$$

Productivity:

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

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)

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

A. LEVELS OF SERVICE IN CONTAINER TERMINALS

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

So, the quality of service perceived by the shipping lines depends on:

- **The relative waiting time**
- **The berth productivity**

A. LEVELS OF SERVICE IN CONTAINER TERMINALS

Innovative contribution to the existing bibliography

VALENCIAPORT FOUNDATION PROPOSAL OF LEVELS OF SERVICE FOR THE SHIP-TO-SHORE SUBSYSTEM

LEVEL OF SERVICE	Relative waiting time	LEVELS OF SERVICE			
D	> 0,2	-	-	-	-
C	0,1 - 0,2	-	CC	BC	AC
B	0,05 - 0,1	-	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: Monfort et al. (2011)

A. LEVELS OF SERVICE IN CONTAINER TERMINALS

Road transport companies:

- ❑ Similar approach (but simplier)
- ❑ Much few operations inside the terminal (usually 1 o 2)
- ❑ Total operating time = waiting time + gate time + service time

A. LEVELS OF SERVICE IN CONTAINER TERMINALS

Cargo (importers and exporters):

- ❑ **The amount of time that cargo stays in a terminal**
- ❑ **It depends on external factors including (the desire of freight forwarders themselves to use the terminal as a warehouse to regulate their freight, the efficiency of customs and inspection authorities)**

B. CAPACITY CALCULATION IN CONTAINER TERMINALS

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.

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.

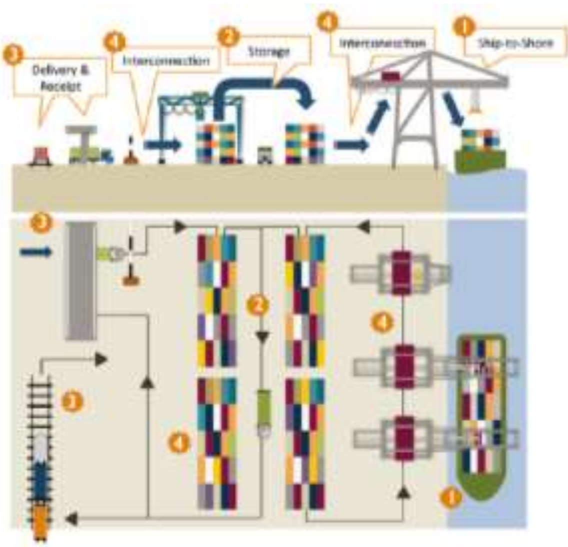
Capacity calculation is an important terminal planning tool, as it does not only establish a terminal’s limits, but also different scenarios to see how the terminal would respond in those situations.

B. CAPACITY CALCULATION IN CONTAINER TERMINALS

1. **HYPOTHESIS**
2. **BERTH CAPACITY**
   a) Formula
   b) Number of berths
   c) Acceptable berth occupancy ratio
   d) Annual average productivity of vessel
   e) Recommendations for annual berth capacity per metre of berth
3. **STORAGE CAPACITY**
   a) Formula
   b) Area density: ground slots per area
   c) Operational average stacking height: static storage capacity
   d) Dwell time
   e) Recommendations for annual storage capacity per hectare of yard
4. **CONCLUSIONS**

1. HYPOTHESIS

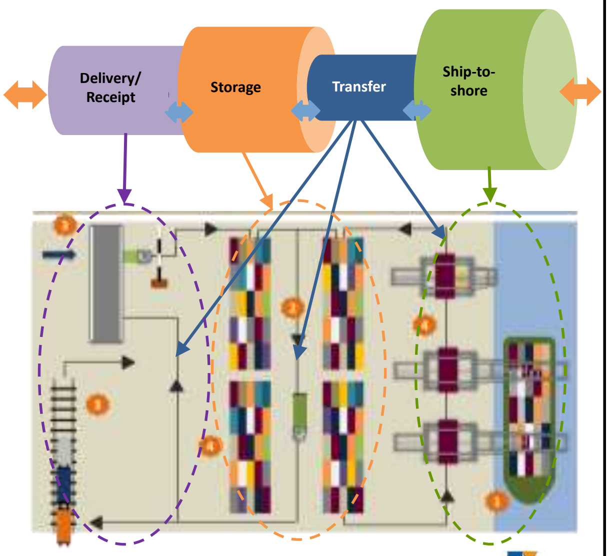
- **Enough draft**
- **Calculation by subsystems**



Source: Monfort et al. (2011)

1. HYPOTHESIS

- Enough draft
- Calculation by subsystems



1. HYPOTHESIS

- Transfer subsystem
- Delivery/Receipt subsystem

} Not restrictive for the capacity

- Ship-to-shore subsystem: Analytical method and Simulation
  - Berth: f (number of berths, berth occupancy)
  - Vessel loading/unloading: f (number of cranes, number of transfer vehicles, equipment productivity)

- Storage subsystem: Empirical and analytical methods
  - Storage area
  - Operational average stacking height
  - Dwell time

  } f (yard equipment)

2. BERTH CAPACITY

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

n: number of berths
Φ: acceptable berth occupancy ratio
t_{year}: hours the terminal is operational per year
P: annual average productivity of vessel at berth

n: number of berths

n **depends on:**

- **Lenght of berthing facility**
- **Lenght of standard vessel**
- **berthing gap or distance between vessels at berth**

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

The result can be a decimal number. It is recommended to round down in order to not overestimate the capacity.

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

ϕ : acceptable berth occupancy ratio

Associated to:

- **Traffic characterisation : a distribution for the vessel inter arrival time probabilities (f1), and another distribution that depends on service time probabilities (f2)** — **$f_1/f_2/n$ System**
- **Number of berths** (n)
- **Relative waiting time** $\varepsilon = T_w/T_s$

Not consider the ϕ dependence on the relative waiting time and ono the system $f_1/f_2/n$ is a mistake

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

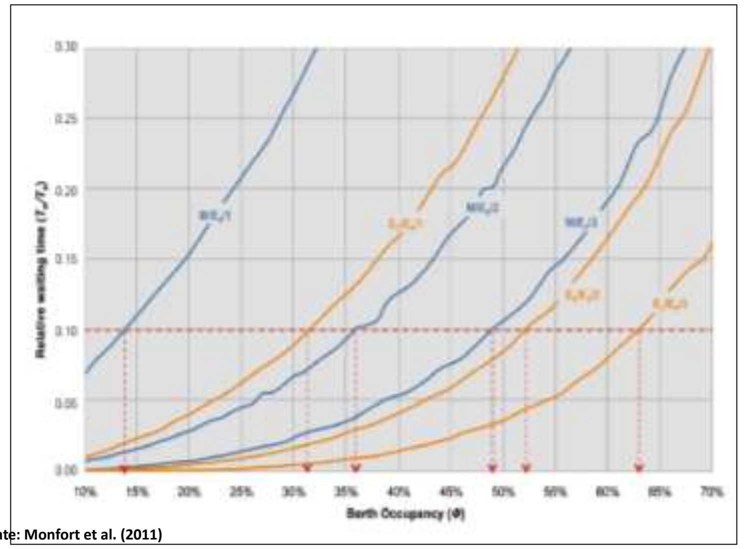
$f_1/f_2/n$ system

It is recommended to use the following queue systems depending on the type of terminal:

- Common user terminals: $M/E_K/n$ system
  - Inter arrival distribution: Random M
  - Service time distribution: Erlang distribution of order K (K=4)
  - n berths
- Terminal with tightly scheduled calls: $E_K/E_K/n$ system
  - Inter arrival distribution: Erlang distribution of order K (K=2) / random
  - Service time distribution: Erlang distribution of order K (K=4)
  - n berths

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

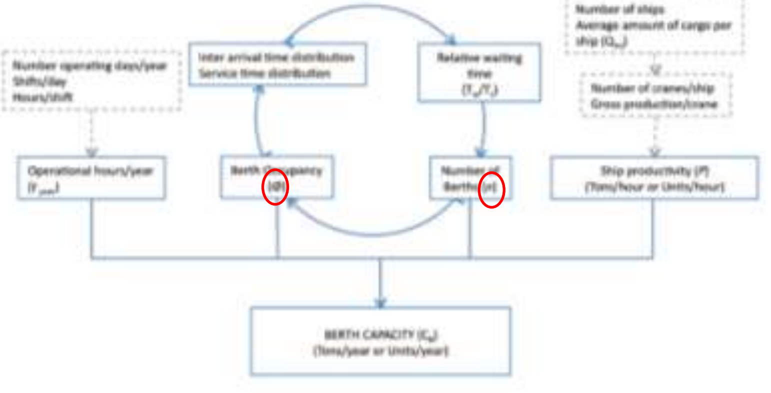
BERTH OCCUPANCY RATIO ϕ DEPENDS ON THE RELATIVE WAITING TIME, THE NUMBER OF BERTHS AND THE TRAFFIC CHARACTERISATION (**$M/E_4/n$ o $E_2/E_4/n$**)



Fuente: Monfort et al. (2011)

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

Berth capacity is not directly proportional to the number of berths



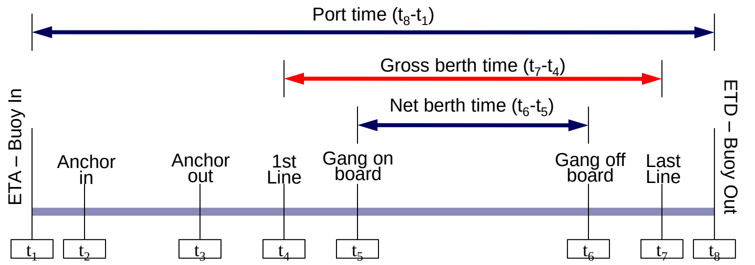
Source: Monfort et al. (2011)

***P*: annual average productivity of vessel**

$$P = \frac{\text{Annual output (container movements)}}{\sum \text{Gross berth times}}$$

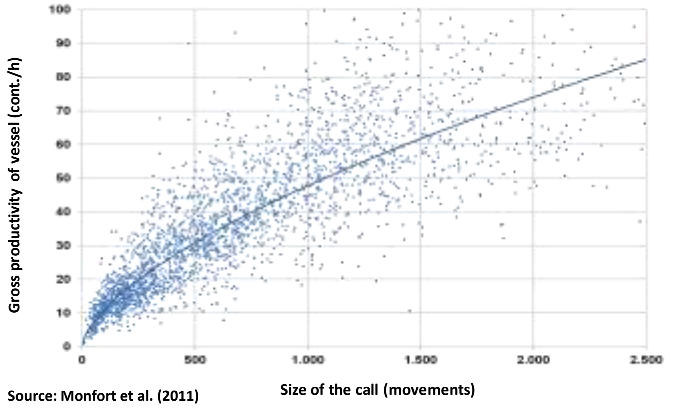
Annual output:

- Inland origin/destiny containers
- Transhipment containers



The annual average productivity of vessel depends on:

- The average number of cranes deployed
- The productivity of the cranes
- The unoperating times
- The average size of the call → P is a "dynamic" variable

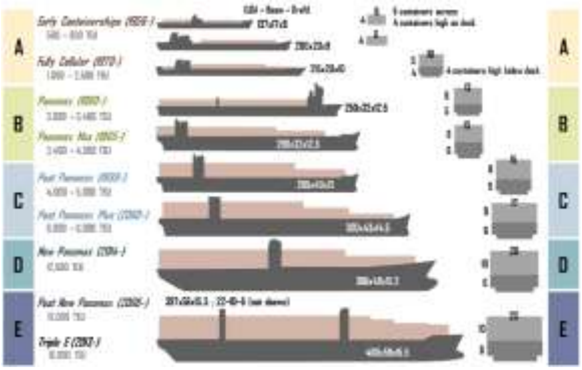


Source: Monfort et al. (2011)

$C_B = n \text{ x } \phi \text{ x } t_{year} \text{ x } P$

P is a dynamic variable:

Δ vessel size $\left\{ \begin{array}{l} \textbf{Δ call size} \\ \textbf{Δ average number of cranes} \end{array} \right.$ ⟹ **Δ*P*** ⟹ **Δ C_B**



Increasing the size of the vessel can reduce the number of berths

Source: The geography of the Transport Systems

$C_B = n \text{ x } \phi \text{ x } t_{year} \text{ x } P$

t_{year}: hours the terminal is operational per year

- f (the operating days of the port and the labour and climatological conditions)

$$t_{year} = \frac{360 \text{ days}}{\text{year}} \text{ x } \frac{24 \text{ hours}}{\text{day}} = 8.640 \text{ hours/year}$$

$$C_B = n \times \phi \times t_{year} \times P \qquad \textit{(Containers/year)}$$

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

$$C_B{}^{*} = \phi \times t_{year} \times P \qquad \textit{(Containers/m of berth y year)}$$

f(lenght of berthing facility)

$$C_B = C_B{}^{*} \times \textit{lenght of berth}$$

DREWRY RECOMMENDATION FOR C_B

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 THE TERMINAL		
	Small > 250 m < 500 m	Medium > 500 m < 1.000 m	Large > 1.000 m

Source: Drewry (2002 y 2010)

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

FVP RECOMMENDATION FOR C_B

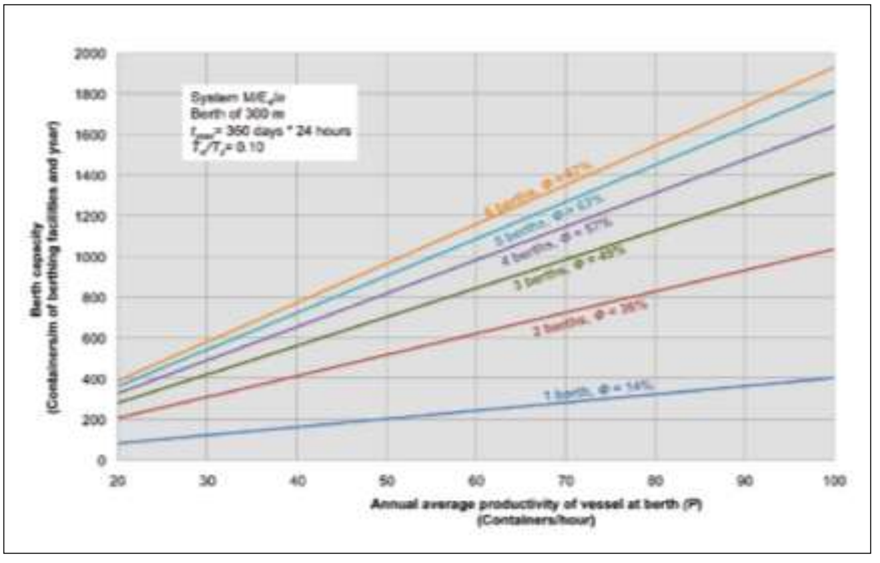
- Lenght of berth
- Relative waiting time
- Number of berths
- Traffic charactisation and system
- Average number of cranes deployed

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	[illegible]	505 · 720 · 990	990 · 1,210 · 1,450	1,210 · 1,450 · 1,655	1,405 · 1,610 · 1,795	1,510 · 1,680 · 1,885	1,590 · 1,770 · 1,930
	[illegible]	440 · 625 · 865	865 · 1,065 · 1,270	1,065 · 1,270 · 1,450	1,130 · 1,410 · 1,570	1,330 · 1,470 · 1,630	1,390 · 1,550 · 1,690
	[illegible]	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
	[illegible]	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	[illegible]	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
	[illegible]	120 · 240 · 425	465 · 620 · 845	670 · 845 · 1,050	810 · 985 · 1,175	930 · 1,085 · 1,260	1,000 · 1,155 · 1,310
	[illegible]	100 · 200 · 345	385 · 515 · 705	560 · 705 · 875	675 · 820 · 975	775 · 905 · 1,050	835 · 965 · 1,090
	[illegible]	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: Monfort et al. (2011)

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

C_B OF $M/E_4/n$ SYSTEM, ε=0,10 and BERTHS of 300 m



Source: Monfort et al. (2011)

3. STORAGE CAPACITY

Two problems:

- **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.**

$$C_Y = \#ground\_slot \text{ x } h \text{ x } \frac{365}{T_{dw}}$$

#ground_slots: number of TEU positions

h: average operational height of stacks

T_{dw}: average dwell time of containers in the storage area (days)

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

3. STORAGE CAPACITY

$$C_Y = \#ground\_slot \text{ x } H \text{ x } K \text{ x } \frac{365}{T_{dw}}$$

#ground_slots: number of TEU positions

H: maximum height of stacks or nominal height of equipment

K: operational factor (0,55-0,70)

T_{dw}: average dwell time of containers in the storage area (days)

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

Area density: ground slots per area

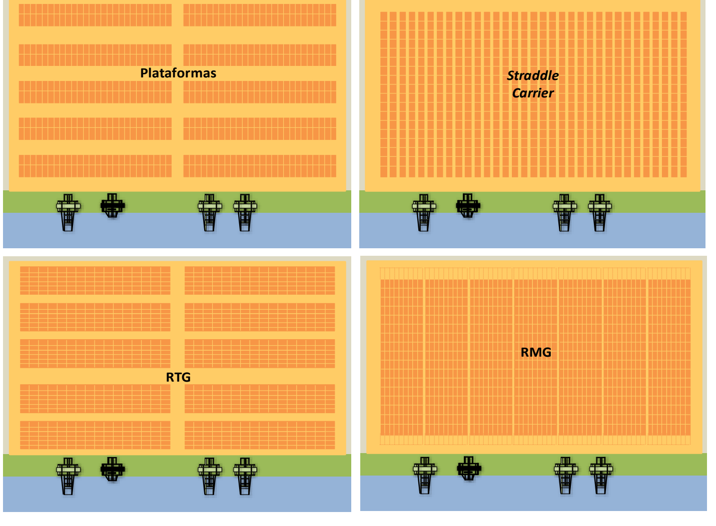
- Depends on:
  - The distribution of blocks, roads and aisles between blocks
  - The yard shape
  - The yard organization (areas)

- Calculation
  - Empirical: based on aerial photos ⟶ Monfort *et al*. (2011)
  - Analytical: based on the dimensions of slots, roads and aisles

↓

Wieschemann y Rijsenbrij (2004) and Kuznetsov (2008)

TYPE OF YARD EQUIPMENT



Source: Monfort et al. (2011)

h: Operational average stacking height

- The operational average stacking height is directly proportional to storage capacity
- This factor is very sensitive to the level of development of the TOS (Terminal Operating System)

FVP RECOMMENDATION FOR C_B

For each type of yard equipment:

Area density x Operational average stacking height = Static capacity (C_S)

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

Source: Monfort et al. (2011)

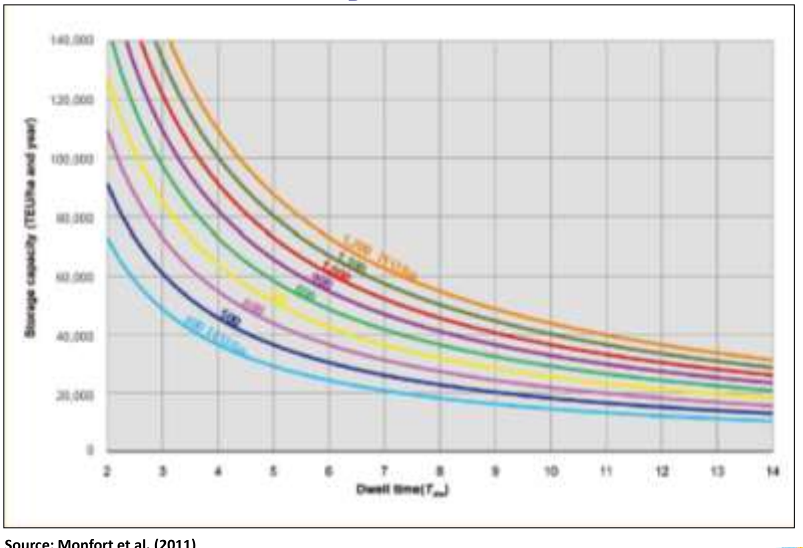
$C_Y = \#ground\_slot \text{ x } h \text{ x } \frac{365}{T_{dw}}$

T_{dw}: Dwell time

- It 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.
- 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.
- Depending on their necessity of space, port terminals can impose pricing initiatives in order to encourage or discourage the use of their facilities for the long term storage.

$C_P = Nº\ Huellas\_TEU \text{ x } h \text{ x } \frac{365}{T_a}$

FVP RECOMMENDATION FOR C_B



Source: Monfort et al. (2011)

4. CONCLUSIONS

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

n: number of berths
f (the size of the standard vessel)

ϕ: acceptable berth occupancy rate (%)
f (the relative waiting time and the $f_1/f_2/n$ system)
Common user terminal: $M/E_4/n$
Terminal with tightly scheduled calls : $E_2/E_4/n$ (o $M/E_4/n$)
Relative waiting time: 5% - 20%

Depends on the quality of the service

P: annual average productivity of vessel (cont/h)
f (average number of cranes, their productivity and the unoperating times)
f (average size of the call)

Level of Service

Relative waiting time

Annual average productivity of vessel

4. CONCLUSIONS

$$C_P = \#ground\_slot \times h \times \frac{365}{T_a}$$

Area density
f (the yard equipment and the layout)

h: Operational average stacking height
f (the yard equipment and level of development of the TOS)

Depends on the yard equipment

T_{dw}: Dwell time
f (external factors)

4. CONCLUSIONS

BERTH CAPACITY | STORAGE CAPACITY

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

(containers)

$$C_P = \#ground\_slot \times h \times \frac{365}{T_a}$$

(TEUs)

Conversion factor TEUs/container

Transhipment containers are included twice in the berth capacity calculation, but only once in the storage capacity calculation.

$$C_{Y\ eq\ B}$$

4. CONCLUSIONS

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

Where,

$C_{Y\ eq\ B}$: Annual storage capacity equivalent to annual berth capacity

K_{YTS}: Container yard capacity vs. container berth capacity transformation coefficient

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

Where,

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

%TS: percentage of transhipment traffic over total traffic

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.

SUMMARY: Sea Port Capacity Manual

- **Printed version available in Spanish**
- **Electronic version (CD) available in English and Spanish**

SUMMARY: Sea Port Capacity Manual

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