

Dimensioning of Container Terminals: Validation and Application Fields for a Stochastic Process

Vinicius Das Chagas[1], Maria Eugenia Lopez Lambas[2], Cristiano Marinacci[1], Stefano Ricci[1](✉), and Luca Rizzetto[1]

[1] Department of Civil, Building and Environmental Engineering (DICEA), Sapienza Università di Roma, Via Eudossiana, 18, 00184 Roma, Italy
stefano.ricci@uniroma1.it

[2] Escuela de Ingenieros de Caminos, Universidad Politecnica de Madrid, Canales y Puertos, C/Profesor Aranguren S/N, 28040 Madrid, Spain

Abstract. The maritime terminals design process includes a series of strategic decision involving the engagement of relevant amount of resources. In fact, operating conditions near the maximum capacity generate congestion and the related negative consequences on capacity and regularity. The authors developed different methods and models capable to support some of these key decisions. These methods allow at selecting the most suitable parameters to describe terminals, to determine dimensional and equipment characteristics and to verify the production of the terminals. For all them, various extended investigations on operated port terminals for data acquisition and homogenization are available: surveys on operated terminals, sampling criteria to ensure quality of derived design parameters, analysis and correlations to provide design and operational elements. Past and present surveys cover a sampling of 40 European terminals for the setup of the method in 1985, a sampling of 93 terminals within 49 European ports in 2008 and a geographical extension to Latin America and the Carribean and an update of the method in 2021, specific object of the present paper.

Keywords: Ports · Terminals · Containers · Design · Operation

1 Introduction

Following the standardization of TEU containers in the 1960s, global container traffic increased significantly nowadays, which represents a quarter of maritime trade. Today, their handling is normally in two different typologies of ports: hubs and gateways. The maritime hubs are terminals, in which the main operations carried out are concentration and distribution by transhipment with final destinations outside the hinterland. Meanwhile, gateway ports, also known as import/export, carry out significant traffic volumes from and to powerful hinterland generating large loads. This type of port is usually located nearby industrial and consumer areas.

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According to [1], container terminals typically include their equipment and stacking facilities. However, from a logistical perspective, terminals only have two components: stocks and transport vehicles. Stocks' definition depends statically on their ability to store containers, while stowage or loading instructions are required dynamically to define the rules on how and where containers must be stored. The services of container terminals do not include routing and scheduling of ships, trains and trucks, while wage instructions exist in any case to define the location of the containers to be loaded. Two-dimensional or three-dimensional transport of containers include cranes and horizontal transport vehicles. Their logistical peculiarities include the assignment of tasks and the work sequences to perform, normally resulting in a range of alternative approaches and solutions [2].

In order to maximize the effectiveness of this process, robust and systematic methodological support is necessary. In this respect, the authors developed different methods and models [3] capable to support key decisions. In particular, stochastic methods, trained by the background data from operated terminals, largely demonstrated their ability to manage the preliminary dimensioning of container [4, 5] and bulk [6] terminals in ports. They are able to integrate dimensions and handiness of ships, terminal morphology, handling equipment, storage areas, etc., with the aim to support planning and design process as well as the operational management themselves.

These methods allow at selecting the most suitable parameters to describe the terminals, to determine their dimensional and equipment characteristics and to verify their production.

2 Background

The synthesis of structures and performances of terminals is within the three main clusters: Dimensional parameters (D), such as quay length, total stacking area, covered stacking area and uncovered stacking area; Equipment parameters (E), such as gantry cranes, other cranes, storage cranes and various loaders; Production parameters (P), such as: number of handled containers, TEU and container tonnage.

For all them, various extended investigations on operated port terminals for data acquisition and homogenization are available [4, 5] according to the methodological steps described below.

1) *Surveys on operated terminals* include: a) check of available database, b) enquiries to operators, c) direct measurements.
2) *Sampling criteria* to ensure quality of derived design parameters include: a) dimensional and geographical variety, b) randomness of terminals' selection, c) reliability of acquired data.
3) *Analysis and correlations* aimed at providing: Design elements, such as Dimensioning (D) and Equipment (E) parameters, from P parameters; Operational elements, such as Production (P) parameters, starting from D and E parameters.

The correlation of the parameters are by linear regressions, both within the same groups (D-D, E-E, P-P) and between various groups (D-E, D-P, E-P), qualified by the calculation of Pearson coefficients and the Student stochastic test.

Past and present surveys cover a sampling of 40 European terminals for the setup of the method in 1985 and a sampling of 93 terminals within 49 European ports for the update and the validation of the method in 2008.

3 Methodology

The present paper deals with a geographical extension of the model application to Latin America and the Carribean, as well as an update of the method.

The first step was the investigation on available public online database concerning the parameters required to proceed with the analysis by searching in public websites, such as *Marine Traffic*, *Fleetmon* and *Sea Rates* for general information about location of terminals at ports. The following step aimed at ministries, economic organizations and governmental websites. Lastly, after a careful selection of ports with container terminals, the research focus moves to the port authorities and terminal operators' themselves.

The following step was the preparation of a questionnaire for port authorities and terminal operators to gather the information not available or incomplete from the online sources. The questionnaire, developed in *Google Forms*, was in English, Portuguese and Spanish, covered 212 port authorities and terminal operators, though the rate of answers after the first round was not exceeding 3%. More rounds are anyway in plans. Nevertheless, the global data collection covered in Europe 208 terminals located in 34 countries and in Latin American and the Carribean 112 terminals located in 17 countries.

After the confirmation of the typology of terminal, containers only or multipurpose, the questions raised in the questionnaire concerns quay length, stacking areas (covered, uncovered and total), number of gantry cranes (STS, RTG, RMG), mobile harbor and storage cranes (straddle carriers, reach stackers, forklifts) and other loaders (semitrailers, tractors) as well as number of handled containers, TEU and tons.

The data analysis tackles the results of the survey, referred to 2019, by establishing a correlation between couples of parameters, measured by the Pearson correlation coefficient:

$$R = \frac{N\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{\left[N\sum x^2 - \left(\sum x^2\right)\right]\left[N\sum y^2 - \left(\sum y\right)^2\right]}}$$

Where are:

- N = number of couples of scores;
- Σxy = sum of the products of paired scores;
- Σx = sum of x scores;
- Σy = sum of y scores;
- Σx^2 = sum of squared x scores;
- Σy^2 = sum of squared y scores.

The most direct relationships between the parameters corresponding to the shortest paths on the graph from any input to any output parameter is searchable using the Dijkstra algorithm [7].

Everything refer to three different scenarios: European terminals, Latin America and the Caribbean terminals, all terminals. The validation of the method bases on applications to test terminals not used for feeding the model.

4 Survey Results and Method Application

In Europe the largest amount of investigated terminals are from Belgium (10), Finland (10), France (16), Italy (20), Norway (20), Portugal (11), Spain (30), Sweden (14) and United Kingdom (18). Other terminals, ensuring better geographic coverage, are from Albania (1), Austria (2), Bulgaria (5), Croatia (2), Denmark (6), Estonia (3), Faroe Islands (2), Georgia (2), Germany (8), Gibraltar (1), Greece (3), Iceland (5), Ireland (4), Latvia (2), Lithuania (2), Malta (3), Moldova (1), Netherlands (9), Poland (5), Romania (1), Russia (7), Slovakia (1), Slovenia (1) and Ukraine (3).

In Latin America and the Caribbean the largest amount of terminals are from Argentina (18) and Brazil (36). Terminals from Bahamas (1), Chile (12), Colombia (7), Costa Rica (1), Dominican Republic (1), Ecuador (7), French Guyana (1), Guatemala (1), Guyana (1), Jamaica (1), Mexico (8), Panama (5), Paraguay (3), Peru (7), Surinam (1) and Uruguay (1) ensure a wide geographic coverage.

Despite the different sources investigated, the information is anyway not complete for all terminals. Table 1 shows the number of terminals with available data per parameter: the production parameters are the most difficult to find for the single terminals, meanwhile they are more frequently available globally at the port level.

Table 1. Number of available data per parameter

Dimension (D) parameters	*Terminals with available data*
1) Quay Length	240
2) Total Stacking Area	69
3) Covered Stacking Area	58
4) Uncovered Stacking Area	56
Equipment (E) parameters	*Terminals with available data*
5) Gantry Cranes	201
6) Other Cranes	104
7) Storage Cranes	155
8) Various Loaders	93
Traffic (T) parameters	*Terminals with available data*
9) Handled Containers	53
10) Handled TEU	111
11) Handled Tons	55

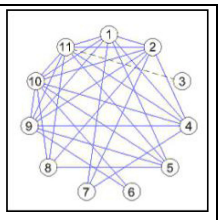
Intuitively, the greater is the number of couples of related parameters, the more reliable is the result. The matrix in Table 2 summarizes the number of couples of parameters. The minimum number of available data per couple of parameters (12) is enough to calculate correlations. Using a linear regressive method, the calculated correlation coefficients *R* populate Table 3, where the green color highlights the values of R > 0.55, also represented by the graph in the corner. Under this hypothesis, the dimensional parameter 3 (Covered Stacking Area) is not significantly correlated with any parameter, meanwhile the production parameter 11 (Handled Tons) is the most correlated with all others. The correlation coefficients are the first indicators of the robustness of the link between the parameters and, consequently, of the reliability of results achievable.

Table 2. Number of available data per couple of parameter

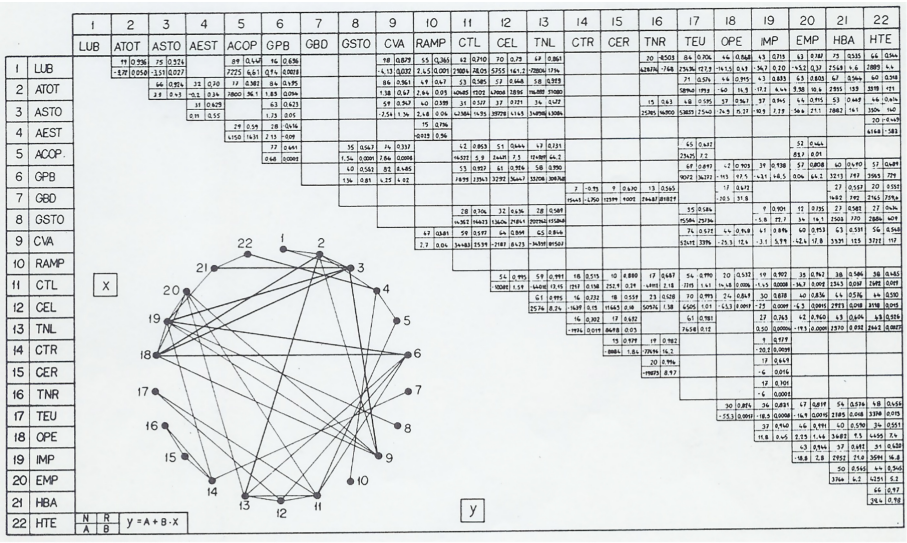
1											
2	64										
3	56	34									
4	55	35	34								
5	189	58	45	42							
6	93	34	29	32	79						
7	143	51	36	39	136	79					
8	87	37	25	26	89	50	89				
9	37	18	15	19	31	24	30	20			
10	78	35	25	30	60	42	56	37	53		
11	39	17	12	16	32	25	32	21	28	54	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**

Table 3. Linear regression correlation coefficients between parameters

1											
2	0.648										
3	0,108	0.312									
4	0.650	0.999	0.264								
5	0.569	0.375	-0.070	0.401							
6	0.139	0.119	0.238	-0.056	-0.005						
7	0.589	0.623	0.044	0.696	0.282	0.224					
8	0.493	0.576	0.238	0.535	0.656	0.111	0.396				
9	0.875	0.817	0.185	0.762	0.977	0.702	-0.182	0.203			
10	0.690	0.771	0.124	0.739	0.954	0.647	0.462	0.757	1.000		
11	0.829	0.824	0.438	0.738	0.986	0.023	0.329	0.641	1.000	0.999	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**



For a comparison synthetic comparison at a glance, Fig. 1 reports the corresponding matrices of correlation coefficients for the previous studies developed in 1985 [4] and 2008 [5].



1	LUNGHEZZA BANCHINE	—
2	AREA DI STOCCAGGIO TOTALE	0,892	—
3	AREA DI STOCCAGGIO COPERTA	0,518	0,963	—
4	AREA DI STOCCAGGIO SCOPERTA	0,621	0,971	0,921	—
5	GRU A PORTALE	0,745	0,925	0,228	0,032	—
6	GRU NON A PORTALE	0,217	0,410	0,118	0,827	0,000	—
7	GRU DI STOCCAGGIO	0,769	0,805	0,905	0,100	0,809	0,232	—
8	CARICATORI VARI	0,551	0,601	0,551	0,330	0,542	0,212	0,764	—
9	CONTAINER [numero]	0,349	0,925	0,966	0,825	0,935	0,815	0,844	0,777	—
10	CONTAINER [TEU]	0,706	0,910	0,207	0,134	0,770	0,224	0,823	0,559	0,999	—
11	CONTAINER [tonnellate]	0,513	0,945	0,983	0,173	0,947	0,462	0,936	0,738	0,999	0,996	—

Fig. 1. Original correlation coefficients matrices from previous 1985 [4] and 2008 [5] studies

Indeed, the goals of the research is to link the parameters by direct or indirect correlations on a probabilistic basis: e.g., in the design phase, production parameters with dimensional and/or equipment parameters.

For this purpose, a shortest path search (by Dijkstra algorithm with length $= -|R|$ in the present application) identifies the most reliable direct or indirect link to the other parameters starting from the three production parameters: number of handled containers, TEU and tons (Fig. 2).

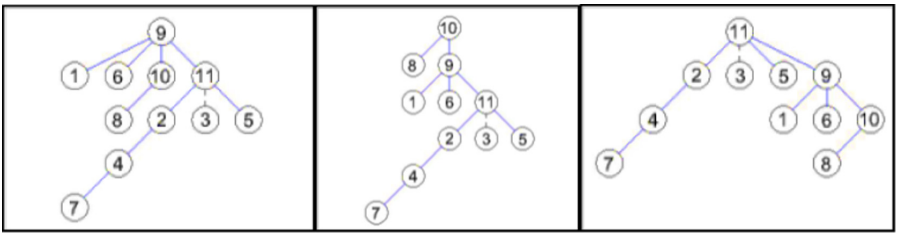


Fig. 2. Most reliable direct or indirect links (shortest paths) to calculate various dimensional and equipment parameters from production parameters (Handled containers, TEU and tons respectively)

5 Method Validation

The application of the methodology, with validation purposes, was for two case studies:

- Tersado, in the port of Setubal, Portugal;
- Tecon, in the port of Rio Grande, Brazil.

The application is including the estimations of dimensional and equipment parameters having traffic as inputs, by the best direct and indirect correlations. Figures 3, 4 and 5 report the results for some key dimensional and equipment parameters, such as quay length, total stacking area and gantry cranes both measured in the real terminal and estimated by general (full sampling) and specific (continental sampling) models, both for Tersado (Europe) and Tecon (Latin America and the Carribean).

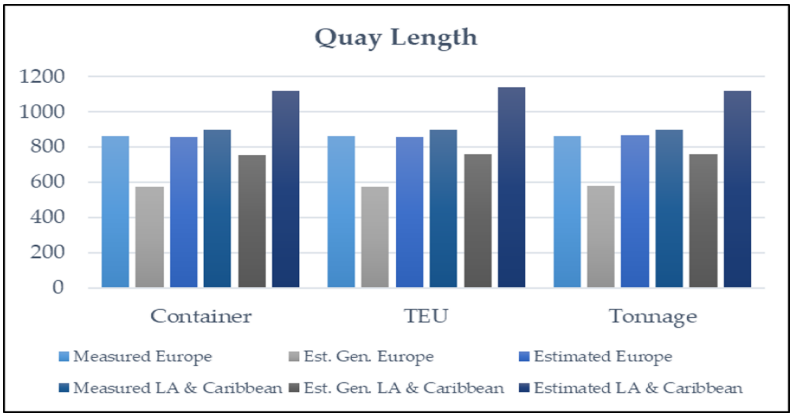


Fig. 3. Measured and estimated quay length [m] having as inputs various traffic parameters

In Tersado, the results obtained by the application of the general model for all input traffic parameters are quite reliable for equipment (about 5% deviations for gantry cranes), meanwhile by the Europe specific model the reliability increases relevantly for dimensional parameters (<10% deviations for length of quays and total stacking area).

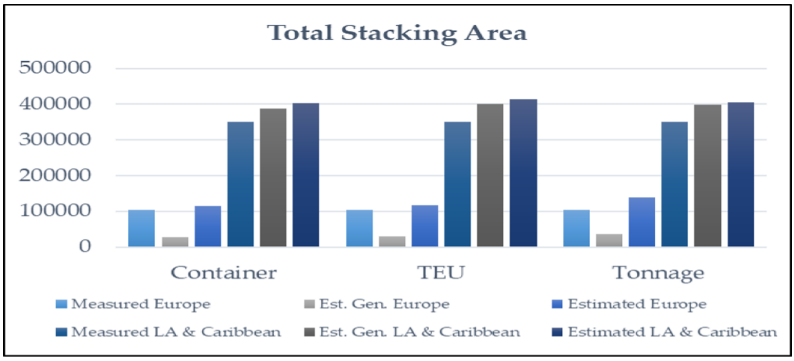


Fig. 4. Measured and estimated total stacking area [m^2] having as inputs various traffic parameters

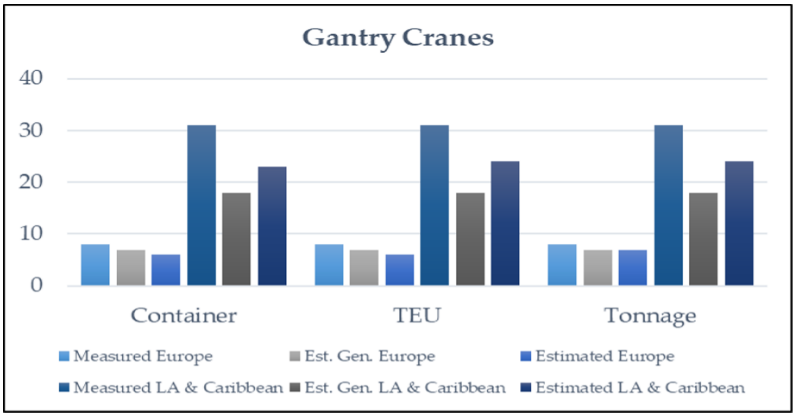


Fig. 5. Measured and estimated number of gantry cranes starting having as inputs various traffic parameters

In Tecon, the results obtained by the application of the general model for all input traffic parameters are quite reliable for dimensions (about 25% deviations for length of quays and total stocking areas), meanwhile by the Latin American and Carribean specific model the reliability increases for equipment parameters (about 35% deviations for gantry cranes).

In particular, for the length of quays the model is very well working for the European terminal (less than 5% deviation) when trained with the European database only, meanwhile for the Latin American terminal the model it is less reliable, anyway providing with good results (about 25% deviation) when trained with the General database. For the total stacking area, the results are very similar for the European Terminal and for the Latin American terminal, though with a better reached reliability (about 15% deviation). For the number of gantry cranes, the results are different for the European terminal, where the better results (about 15% deviation) are reached already by the model trained with the general database, and for the Latin America terminal, where the better results

(about 35% deviation) are reached by the model trained with Latin American and the Caribbean database.

In all situations the model is almost unaffected by the selected container traffic input parameters (number of containers, TEU or tons). As a consolidated result of this validation, the model shows is ability to reach a reliability of less than 10% deviations in the European terminal and less of 30% deviations in the Latin American terminals. The difference could be due to the smaller dimension of the Latin American and Carribean sampling. Moreover, the use of more specific continental characterized model increases in both the case studies the reliability of the results, which is possibly due to the differences in traffic and terminal operational models across the Atlantic.

The results are generally different from those achieved in the previous researches carried out in 1985 and 2008, mainly for European terminals. The differences are mainly in the lower level correlation between parameters, which is largely in line with the evolution of technologies and operational models, as well as with the larger dimension of the sampling set, generally including also smaller terminals, which do not ensure a full homogeneity and comparability of results.

6 Conclusions

The regressive method developed by some of the authors and described in [3] for the preliminary dimensioning of container terminals calibrated with a European database, mainly form North Sea and Mediterranean area was the basis of the present work. The upgrades of this research were the extensions of data collection to the entire European area, including Russia, Scandinavia, Great Britain and Balkans and to the to Latin America and the Caribbean area, which resulted easier due to the lager availability of public data.

The validation on two typical terminals located in Europe and Latin America, demonstrated that model confirms, also in this extended version, its ability to reach a satisfying reliability, always less than 10% deviation in the European terminals and 30% deviation in the Latin American terminals. The difference could be due to the smaller dimension of the Latin American and Carribean sampling. Moreover, the use of more specific continental characterized model increases in both the case studies the reliability of the results, which is possibly due to the differences in traffic and terminal operational models across the Atlantic.

Main achievements are also the recommendations for future research developments and extensions (e.g. Asia and North America at first): segmentation of the terminals by size and technological advances, geographical areas, both to prevent that regional cultural or operational habits affect the global reliability of the results.

Moreover, the methodology is very open and extensible to other relevant parameters, such as environmental/energetic ones, presently under development, as well as to different typologies of terminals.

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