PERFORMANCE EVALUATION FROM THE INFRASTRUCTURE PERSPECTIVE IN PORTS AND CONTAINER TERMINALS

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Keywords

Port Infrastructure, Containerized Cargo, Performance Evaluation, Logistics Efficiency, Maritime Adaptation, Port Infrastructure Variables.

Abstract

The increasing global demand for maritime transportation and the significant rise in vessel sizes present an urgent challenge for port infrastructure. The emergence of larger vessels, driven by the pursuit of efficiency and cost reduction, underscores the pressing need for adaptation and modernization of ports to accommodate these new classes of ships. This scenario poses a challenge to port managers and government authorities to rethink and adjust their operational strategies, considering not only the physical capacity of terminals but also the efficiency and flexibility required to address the growing logistical complexity. In this context, it is identified the need to fill an existing gap, the understanding of the impact of infrastructure-related variables on the performance evaluation of ports and containerized cargo terminals.

The focus is on immediate adaptation and preparing ports for future challenges in containerized cargo movement. The guiding research question is: "How do infrastructure-related variables influence the performance of these facilities?" The overarching objective is to analyse and identify critical variables in the infrastructure dimension affecting performance, with the aim of highlighting opportunities for improvement in efficiency and competitiveness in containerized cargo movement.

The research confines its scope to the internal areas of ports, emphasizing facilities and processes related to infrastructure and superstructure. Variables such as storage capacity, physical arrangement, number of berths, STS cranes, as well as the use of automation technologies in container handling are considered. The analysis also encompasses specific investments in this dimension.
The study's justification underscores the importance of raising awareness among port authorities and the Brazilian government regarding the need to optimize port operations. Efficiency in containerized cargo movement is crucial for global competitiveness, and understanding infrastructure variables will empower port managers to make informed decisions. The study aims to drive operational efficiency and prepare Brazilian ports to tackle emerging challenges in the sector.

1 INTRODUCTION

In recent years, we have observed a significant increase in the global demand for maritime transport, since 90% of world trade relies on this modal (Rambo et al., 2023), accompanied by a growing trend in the size of vessels used in this sector, such as the recent deliveries and orders of mega container ships with a capacity exceeding 24,000 TEUs, for example, MSC - Mediterranean Shipping Company, on November 20, 2023 held a naming ceremony for the mega container ship, MSC Celestino Maresca, in the port of Gioia Tauro, Italy. This mega container ship belongs to MSC's innovative series, making up the fleet of the world's largest and most efficient container ships (MSC Mediterranean Shipping Company, 2023). They are 400 meters long and can carry more than 24,000 TEUs. (OOIL, 2023; OOCL, 2023a; OOIL, 2023b; MSC Mediterranean Shipping Company, 2023).

To meet this demand, ports and port terminals that handle containerized cargo are looking for investments in infrastructure and superstructure in line with the organization of the storage yard and its types of equipment to move this type of cargo (cranes, straddle carriers, RTG - Rubber-Tired Gantry Cranes, AGV - Automated Guided Vehicles, etc.) in the internal area of ports and container terminals (Greco, 2021; Steenken, Voß, Stahlbock, 2004; Kim & Günther, 2007; UNCTAD, 2010). This evolution represents an urgent challenge for port infrastructure, as the ability of ports to adapt and modernize becomes essential to cope with the demands imposed by these new classes of ships. The push for larger vessels, motivated by the search for efficiency and cost reduction, further highlights the urgent need to reassess the operational strategies of ports and terminals (Iyer & Nanyam, 2021; Güner, 2015; Carlo, Vis, Roodbergen, 2014).

In this context, ports and terminals face the challenge of optimizing their infrastructure and processes to ensure efficiency and competitiveness in the movement of containerized cargo. This concern is not only limited to the physical capacity of terminals, but also the need for flexibility and efficiency to handle the increasing logistical complexity associated with container shipping. The present study aims to analyze and identify critical variables in the size of the infrastructure that affect performance, aiming to highlight opportunities for improvement in efficiency and competitiveness in the movement of containerized cargo.

To achieve this goal, the study restricts its scope to the internal areas of ports, with an emphasis on facilities and processes related to infrastructure and superstructure. Variables such as storage capacity, physical arrangement, number of berths, STS cranes, as well as the use of automation technologies in container handling will be considered (Trujillo, 2008; Carlo et al., 2014; Park & Suh, 2019; Sandrini Perin et al., 2020). Therefore, areas outside the port, such as highways, railways and waterway access channels are not covered in these analyses, since port authorities do not have the legal competence to deal directly with these issues.

The rationale for this research lies in the importance of making port authorities and governments aware of the need to optimize port operations to ensure global competitiveness, as well as serving as a solid basis for investments in infrastructure and superstructure. Understanding how infrastructure variables influence performance will enable port managers to make informed decisions to drive operational efficiency and address emerging challenges in the industry.

Thus, this study will not only contribute to the academic literature on port logistics but will also provide practical insights and guidance to improve the efficiency and competitiveness of ports and containerized cargo terminals, especially by presenting the characteristics of the main Brazilian ports and port terminals.

2 THEORETICAL BACKGROUNDS

This chapter aims to provide a solid foundation of concepts regarding the variables related to infrastructure and how they influence the performance of ports and containerized cargo terminals.

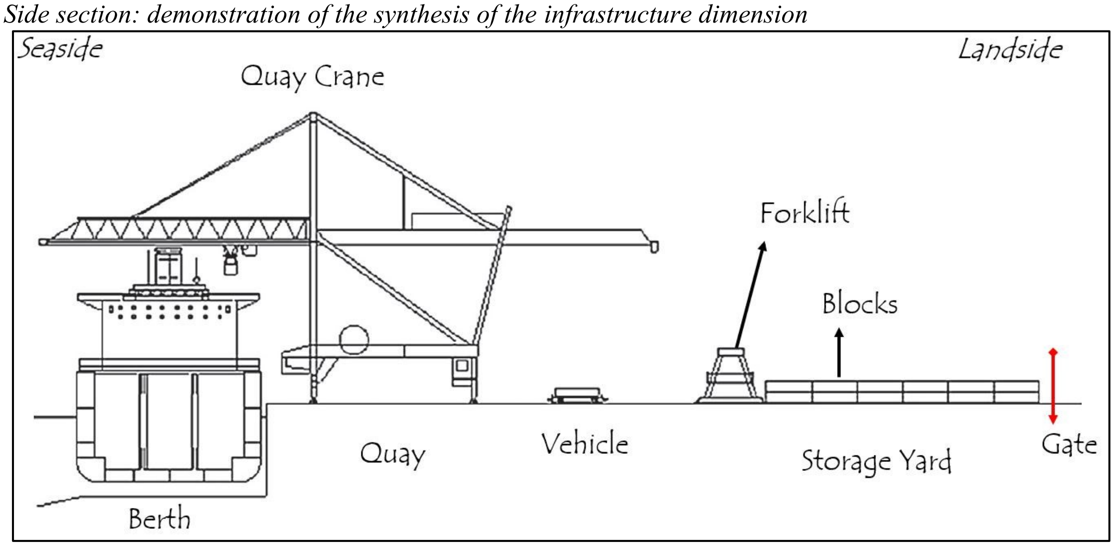
The concept of ports as adopted by the European Union covers an area that encompasses berths, docks and land spaces where cargo handling operations are conducted (European Parliament, 2008). In addition, it argues that the port transcends the physical infrastructure, which includes docks, storage areas, and shipyards, to also encompass the superstructure, composed of fixed units built on the infrastructure, such as buildings and maintenance workshops, as well as mobile equipment, such as cranes and hoists (Trujillo, 2008), called the superstructure. Access to the port area requires maritime infrastructure, such as access channels and aids to navigation, and terrestrial infrastructure, such as roads, railways and inland rivers (Trujillo, 2008). However, for the purposes of this research, analyses of maritime and land accesses are excluded, although they are relevant.

Port infrastructure is subdivided into internal infrastructure, which encompasses elements such as the length of the terminal quay, container gantry cranes, and terminal area, and external infrastructure, which includes the ship's draft, direct rail access, and ship size (Sandrini Perin et al., 2020). In addition, external infrastructure is associated with institutional theory, since, in most cases, it is the government that holds the responsibility for decisions related to investments, maintenance, and execution of works, (Sandrini Perin et al., 2020), that is, it is not up to the port authority to make decisions regarding external infrastructure.

According to Carlo et al. (2014), the infrastructure of container terminals can be divided into five main areas, namely: i. gate (entrance/exit of the terminal); ii. storage yard (composed of container blocks and forklifts); iii. vehicles (transport between the storage yard and the quay); iv. wharf, and; v. cradle, as shown in Figure 1. The landside takes into account the storage yard () and the gate. The vehicle makes up the areas of intersection of the land and littoral (sea) areas. The seaside (seaside) comprises the berth and the pier.

Figure 1

Side section: demonstration of the synthesis of the infrastructure dimension

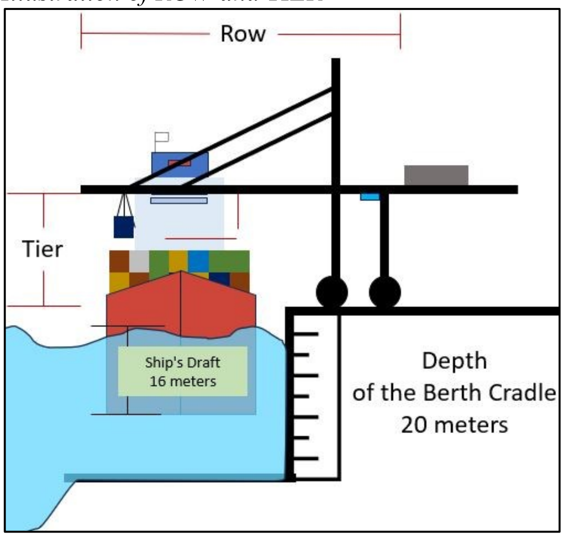


Note.: Adapted from Carlo et al. (2014).

This illustration does not exhaust the layout options, equipment, and other variables that make up the infrastructure dimension. For example, the size of the vessels, which affect the water level of the terminals, the unloading equipment and the structure of the quay wall, as well as the strength of the pavement to support the weight of the loaded cranes, and other equipment (Park & Suh, 2019). As already mentioned, the shipowner Orient Overseas (International) Limited - OOIL, which is part of the COSCO SHIPPING Group, received two megaships in 2023, the OOCL Spain and OOCL Piraeus, with a capacity of 24,188 TEUs, and with the following dimensions, total length of 399.99 meters, width (beam) of 61.3 meters, in addition to 16,317 meters of draft (OOCL, 2023a; OOIL, 2023; OOCL, 2023b). Infrastructure must be upgraded to receive megaships (Iyer & Nanyam, 2021). These characteristics suggest that the performance requirements of container terminals have increased significantly, highlighting necessary changes in their layout, infrastructure, and superstructure from the trends of the insertion of mega container ships on world routes for the years following 2023 (Park & Suh, 2019). Taking into account that megaships, with a capacity of more than 24 thousand TEUs, are calling at ports, mainly in Europe and Asia, it raises concerns regarding the stacking area (yards) available, the number of equipment for handling containers, may not be sufficient, and for this it is necessary to evaluate the adequacy of this equipment.

The equipment physically closest to the ship is the quay crane (which may or may not be automated), or quay equipment for loading and unloading ships (ship to shore), in which the characteristics of maximum horizontal reach (rows) and maximum vertical reach (tier) must be observed and the maximum vertical reach (tier) can determine an adequate service to the vessel or not (Park & Suh, 2019; Yang & Shen, 2013; Coelho & Simão, 2021). As illustrated in Figure 2, no measurement scales were used.

Figure 2
Illustration of ROW and TIER



Note. Prepared by the authors (2023) based on Park & Suh (2019), Yang & Shen (2013), Coelho & Simão, (2021).

It may be an operational limitation, and it will impact the performance of the port and port terminal that handles containerized cargo (Park & Suh, 2019). Several studies take into account the number of quay cranes, especially when the DEA methodology is used, for example, in the study by Rios and Maçada (2006), when measuring the efficiency of ports, and presents as input variables, the number of cranes, number of berths, number of employees and terminal area and as the output unit TEU (Rios & Maçada, 2006). Without taking into account the characteristics to meet the needs of the market (capacity of ships/shipping lines/customers).

Similarly, the study by Sislioglu, Celik and Ozkaynak (2019) that used the DEA as a method, with a DMU being the input decision-making unit of the port and as inputs: the length of the quay (m), number of quay cranes, number of yard trucks, number of yard cranes. In the study by Wang, Song, and Cullinane (2003), the suggested inputs are: quay length, quay size, number of gantry cranes, number of yard cranes, number of SCs, and container handling volume.

Among the variables for the application of an infrastructure efficiency model, non-mobile entrances that are related to port ownership should be included, such as terminal area, terminal length, quay length, berth length, number of berths, yard space, among others (GÜNER, 2015), which are related to physical infrastructure.

Regarding the efficiency of the superstructure, it refers to the use of equipment and considers the effective use of the terminal's equipment, such as the number of cranes, the number of gantries, the number of container carriers, the number of tugboats, the number of forklifts (GÜNER, 2015), among other variables that impact the performance evaluation of ports and port terminals that handle containerized cargo.

Among the yard equipment includes RTG (Rubber Tired Gantry) rubber gantry cranes, RMG (Rail Mounted Gantry), top handler and reach stacker cranes (Park & Suh, 2019; Yang & Shen, 2013). The most common types of yard cranes are RMG cranes, RTG cranes, straddle carrier (SC) and reach stackers (RS), and chassis-based conveyors (Yang & Shen, 2013; Stahlbock & Voß, 2008). Of the cranes mentioned, only RMG cranes are considered suitable for fully automated container handling (Gunther & Kim, 2006; Yang & Shen, 2013; Stahlbock & Voß, 2008). The container storage yard acts as a buffer for loading, unloading, and transshipment of containers, and is generally divided into blocks: each container block is serviced by one or more yard cranes, which can be RTG or RMG cranes, or SCs. SCs, Automated Guided Vehicles (AVGs)) and trucks are commonly employed to move containers between the dock and the yard, between the yard and the gates, as well as to reposition containers within the yard (Yang & Shen, 2013).

In short, one of the operating flows in a container terminal follows: the quay crane hoists the container from the ship, then secures the container in a vehicle (electric or combustion) of the port authority itself, or in some cases directly to the land carrier (Park & Suh, 2019; Yang & Shen, 2013). In general, the function of the vehicles is to move the container from the dock to the storage yard (temporarily), where the forklift will transfer the container from the vehicle to the stacks or blocks of containers, depending on the type of equipment used, the height of this pile may change as well as assist in the performance of the port and port terminal (Park & Suh, 2019; Yang & Shen, 2013), as for example in the study by Stahlbock and Voß (2008) that presents an outline of the practical capacity in TEU/hectare between chassis, RS, SC, RTG and RMG. In Rotterdam and Hamburg, which are fully automated terminals, AGVs are often used to move containers, and ASCs (Automated Stacking Cranes) are used in the stacking process (Yang & Shen, 2013; Stahlbock & Voß, 2008). The stacking area: The stacking area and the management of site layout planning have a greater influence on the productivity of the terminal. Increased stacking area and better management leads to greater efficiency of the terminal that handles containerized cargo (Iyer; Nanyam, 2021).

Therefore, the equipment allocates the containers in storage areas, and depending on the type of container handled, other concerns are necessary, such as sockets, electric power points, to meet the thermal insulation technology, in order to ensure the cooling of the conditioned products, ensuring their integrity, required by the reefer type container, in addition to requiring human capital (people) to turn on/off and check the temperature of reefer containers (Coelho & Simão, 2021). In this aspect, Iyer and Nanyam (2021) corroborate, by presenting that the largest number of refrigerated plug points to serve reefer containers refers to refrigerated containers for transporting perishable products, being a necessary element for infrastructure updating. The growth of reefer containers in ports, such as the container port of Visakhapatnam, APM Pavav terminals, etc., has increased the requirement for outlet points (Iyer; Nanyam, 2021).

Among the infrastructure variables identified in the literature fragment, the authors Nanyam and Jha (2022) present the following as patio infrastructure: the patio equipment and the patio area. The upgrade of infrastructure and system initiatives, on the other hand, includes the addition of new mainline services; the adoption of modern container handling equipment; better connectivity inside; Single window clearance; Congestion-free approach roads; Private sector involvement; stacking area; deepening of the draft (dredging). Also, the facilities and policy of the terminal: availability of huge warehouse space; cabotage relaxation; railway scale in motion; Drive through container scanning. And finally, refrigerated systems and logistical advantage: direct delivery system to ports; refrigerated monitoring system; Handling of transshipment volumes; Increased number of refrigerated plug points.

According to Liu and Medda (2009), the basic infrastructure comprises the access channel, entrance, breakwater, locks and berths. The operational infrastructure corresponds to internal channels and turning, coatings, slopes, roads, rails, quay walls, jettier, navigation aids, buoys, mooring and docks. The superstructure concerns the paving, lighting, office and repair workshops. And finally, the equipment, consisting of tugboats, line handling vessels, dredging equipment, ship and shore handling equipment and cargo handling equipment.

When it comes to the quay line, i.e. the length of the quay in meters, the Ferrol Container Terminal (CTF) located in the northwest of the Iberian Peninsula, in the region of A Coruña, Spain has a total area of 29 hectares in the initial phase with a front pier of 780 meters expandable up to 1460 meters. This specific feature (quay length in meters) allows ships to dock with up to 20 meters of draft (Martins et al., 2017). The length of the berth and the total area of the terminal represent the infrastructure, the storage represents the superstructure, and the handling capacity fits into the category of equipment, providing an overview of port assets (Liu & Medda, 2009).

Competitiveness among ports and terminals handling containerized cargo has driven, drives, and will drive significant investments in infrastructure (Tijan et al., 2022; Iyer; Nanyam, 2021; Hyuksoo & Sangkyun, 2015). These investments aim not only to maintain competitiveness, but also to face competition from leading and emerging ports globally. The expansion of infrastructure, including terminals, docks, storage areas, and hinterland, is a key response to these competitive dynamics. Although the increase in the size of container port infrastructure in Asia is evident, the challenge persists in the search for substantial cargo volumes that justify the significant investments made (Hyuksoo & Sangkyun, 2015). The literature highlights infrastructure as a crucial resource and vital indicator of port competitiveness, revealing that countries such as Hong Kong and Singapore lead in offering high levels of port quality in the Asian region, while the Netherlands, Belgium and Finland stand out in Europe with relatively more robust port infrastructures (Hyuksoo & Sangkyun, 2015).

Among the competitiveness factors of the container seaport, the authors Tijan et al. (2022) discuss: I.

geographical location of the port; ii. length of the cradle; iii. quality of port infrastructure and superstructure; iv. access to road and rail infrastructure within the port (proximity and connectivity to the interior) and connection to inland waterways; v. depth of the port; vi. characteristics of the port area (the extension of the entire port area, the quality of the terminal layouts and common spaces, as well as their suitability to the needs of the port users); VII. Availability (number of berths, port congestion).

Finally, the Global Competitiveness Index (GCI) published by the World Economic Forum since 1979 makes the annual and comprehensive assessment of the main economies (countries) in the world, in 2019, it evaluated 141 countries representing 99% of the world's GDP, and Brazil resulted in the 71st position in the ranking, which is organized into 12 pillars, among them infrastructure (Secretaria Geral, 2021).

In relation to the Brazilian port infrastructure, the more the governments of these countries postpone the decision to modernize and expand it, the more severe the consequences for the economy and society can be. The lag of leading countries in terms of the level and competitiveness of infrastructure can only be overcome through large-scale investments (Varnavskii, 2021).

According to Lu, Park and Huo (2015) and Varnavskii (2021), one of the ways to maintain a port that handles containerized cargo in a competitive condition is through investments in sophisticated equipment or dredging channels to accommodate the most advanced and largest container ships, in order to facilitate cost reduction for the container shipping industry (Varnavskii, 2021). Most port authorities and terminal operators have made significant investments in infrastructure to reduce operating costs per container and improve quality of service, which influence terminal performance (Felicio, Caldeirinha, & Dionisio, 2015). The container port industry is highly capital intensive due to the need for massive infrastructure and facilities, and this implies that its main investment expense is the upgrading and expansion of the infrastructure network (Liu & Medda, 2009; Lu, Park, & Huo, 2015).

At the same time, investments in port infrastructure are projects that require high monetary capacity, since they are fundamental for fostering various economic activities through the provision of transport services, which include safety and reliability of transport between national and international destinations (Martins et al., 2017). They are even more important if we take into account the global trend of increasing international trade, both as an effect of economic growth, as is occurring in China or Brazil, and because of the effect of globalization that gives the logistics chain an international dimension (Martins et al., 2017), making them increasingly competitive (Varnavskii, 2021). The return on infrastructure investments comes after many years. Therefore, the volume of infrastructure construction needs to be increased significantly in the coming years (Varnavskii, 2021).

Developed countries, on the other hand, which already have their facilities, are undergoing modernization and/or reconstruction of their infrastructure, in order to adapt to the requirements of modern standards of service, security, control, and information support (Varnavskii, 2021). To this end, state-of-the-art equipment, technologies and materials are used. In general, the infrastructure of developed countries corresponds to the global level. However, its quality in many respects is inferior to the transport infrastructure of developing economies (Varnavskii, 2021). Not providing infrastructure and not responding to customer needs means a setback for any port (Sandrini Perin et al., 2020), regardless of the cargo profile handled.

The OECD and the International Transport Forum estimate that by 2030, the volume of maritime container traffic associated with international trade will grow by 100% compared to 2013, so the adequate equalization of port infrastructure in the face of local and global demand can represent significant advances in terminal growth rates, given that inadequate quay and yard infrastructure has reduced the growth rate at the container terminal (Varnavskii, 2021), such as the case of the Chennai Container Terminal (CCT) in India which since 2015 has been affected due to the poor adequacy of the infrastructure and superstructure, finally, the port infrastructure elements play a key role in evaluating the performance of container terminals (Nanyam & Jha 2022). Upon concluding the theoretical framework chapter, the methodology chapter follows, which presents the methodological design, research participants, data collection techniques, and data analysis methods.

3 METHODOLOGIES

To meet the objectives proposed in this research, a qualitative approach will be adopted, an approach will be adopted, as well as the impact of infrastructure variables on the performance of ports and containerized cargo terminals.

For the purposes of this research, it is incorporated as secondary data collection, defined by Richardson (1999) as information not directly related to the research object, but collected for other reasons. In addition, there is the documentary nature, obtained by the analysis of institutional documents of participating port authorities, by the Agência Nacional de Transporte Aquaviário (ANTAQ), bulletins, reports and reviews prepared by entities such as the United Nations Conference on Trade and Development (UNCTAD), World Bank (World Bank), World Economic Forum (World Economic Forum), in addition to specific legislation of the port sector, available on websites on the Internet. These documents allowed the survey of the amount of TEU handled in the main ports and port terminals that handle containerized cargo. In addition to targeting variables that impact performance.

The study will be exploratory (Gil, 2017), uma vez que busca explorar o fenômeno e identificar padrões estabelecidos na literatura. with the objective of identifying and analyzing the critical variables in the size of the infrastructure that affect the performance of ports and containerized cargo terminals. Additionally, research has descriptive objectives as defined by Gil (2017), aims to characterize the properties of a phenomenon. In this study, descriptive research will be employed to describe the infrastructure variables that influence the performance of ports and port terminals involved in containerized cargo handling.

The sample will be selected using convenience criteria, it is a non-probabilistic and non-random sampling technique, which selects participants in which the researcher denotes greater ease of access, in which there is greater availability of data (Freitag, 2018). Seeking to represent different types of ports and containerized cargo terminals in Brazil. The sample will include the five port authorities, terminal operators that achieved the best performance taking into account only the number of TEU handled.

The collected data will be analyzed using content analysis techniques (Mozzato & Grzybovski, 2011). The documentary analysis with the theoretical foundation will be complementary, allowing a more comprehensive understanding of the context and existing practices.

The results will be presented in a descriptive and analytical manner, highlighting the critical variables identified in the infrastructure dimension that affect the performance of ports and containerized cargo terminals. Specific recommendations will be provided to improve efficiency and competitiveness in the movement of containerized cargo, aiming to train port managers and contribute to the development of the Brazilian port sector.

As for the analysis from documents, bulletins, reports and reviews, they will serve to sustain the units of measurement, such as movement in TEUs, the variables infrastructure and superstructure. Opportunities for improvement and practical recommendations for ports and government authorities will be identified.

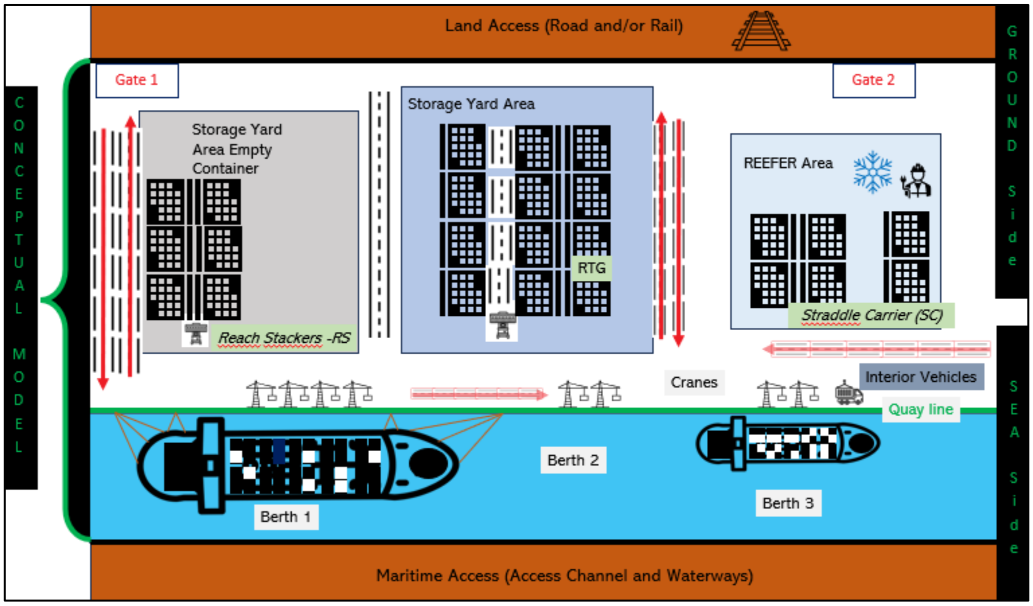
Through this methodology, this research seeks to provide valuable insights to ports and government authorities, aiding in informed decision-making to improve the efficiency and competitiveness of containerized cargo ports and terminals.

4 RESULTS

Several authors have brought numerous variables, similar nomenclatures per hour, some discrepancies, but which referred to the same purpose. After analyzing and sanitizing the data, i.e., the standardization of the terms, it is obtained taking into account the variables identified in the country he standardization of terms, taking into account the identified variables, an illustration is proposed that covers the scope of variables related to infrastructure (infrastructure and superstructure) that influence the performance of ports and terminals. containerized cargo, Figure 3.

Figure 3

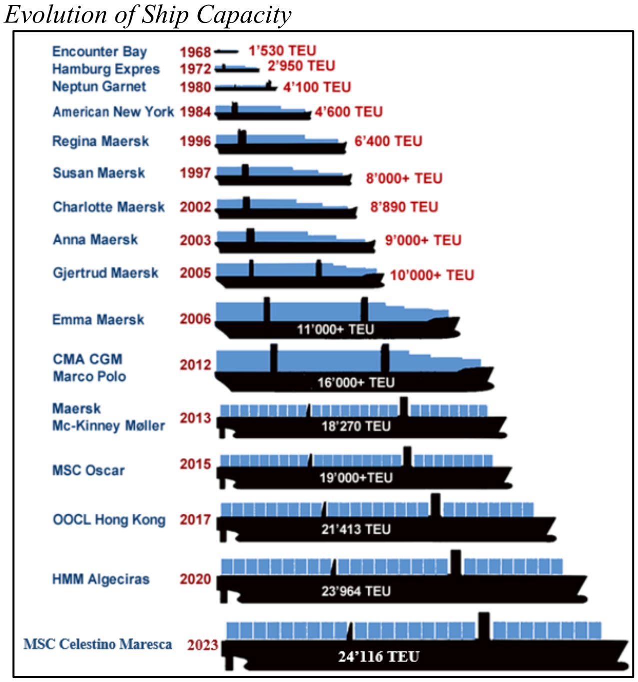
Summary of infrastructure variables that impact the performance of ports and port terminals that handle containerized cargo



It is worth mentioning that the orange rectangles are variables that the analysis will abstract, as they are the infrastructure external to the port authority, and that in most cases, they do not depend exclusively on the port authority to make investments, in addition to other legal requirements.

We understand that the modernization of port infrastructure is critical to meet the challenges posed by the increase in demand and the size of vessels, not only in capacity in TEUs, ship width (row) and ship depth (tier). The literature review highlights the need for investments in new equipment, capacity expansion, and adoption of advanced technologies to ensure the competitiveness of ports on the global stage. Especially in Brazil, when there is a gap of six generations of ships in relation to the megaships delivered in 2023, Figure 4 shows the main classes of ships and capacity in transport TEU.

Figure 4
Evolution of Ship Capacity



Note. Adapted from RAONLINE (2023).

Taking into account the case of the Chennai Container Terminal (CCT) in India, which is affected due to the poor adequacy of the infrastructure and superstructure, it is necessary to invest in port infrastructure as these variables play a crucial role in the modernization and adaptation of ports to new market demands. Investments must be strategic, covering both equipment and capacity expansion, as it has the capacity to significantly improve the operational performance of ports and port terminals that handle containerized cargo.

One of the recommendations highlighted in the studies is the adaptability of port infrastructure, as it is a crucial factor in dealing with the evolving demands of the maritime market. The authors argue that ports that are able to adapt their facilities and processes to accommodate larger, more efficient vessels are more likely to maintain their competitiveness.

Among the possibilities, the storage capacity and physical arrangement of port terminals play a fundamental role in operational efficiency, since a planned physical arrangement appropriate to the uniqueness of the port or port terminal can mean a reduction in waiting times and congestion, thus improving the flow of containers in the port, including greater agility in serving vessels (reduction of bottlenecks). At the same time, the implementation of automation technologies in container handling has been the subject of recent research (2021 onwards) and it is understood that automation can significantly increase the operational efficiency of ports, reducing human errors and optimizing cargo handling processes, reducing unwanted stops (risks of accidents among other factors).

By integrating these theoretical concepts into our analysis, we seek to identify opportunities to improve the efficiency and competitiveness of ports and port terminals, preparing them to address emerging challenges in the industry. And to this end, we selected the first six ports and port terminals that handled containers in Brazil in 2023 (ANTAQ, 2024). From this identification, it investigated on the website of the port authorities, government reports information regarding the variables and characteristics related to infrastructure, superstructure, management model, class of ships served, being evidenced in Table 1.

Table 1

The first five most ports that handled containerized cargo in Brazil in 2023.

Port	Public/ Private	Performance TEUs/year (2023)	Berth	Cradle Draft	Length	Gantry Crane	Annual Handling Capacity	Plugs Reefer	Vessels Type
Santos Brasil - Santos	Private	1.691.972	3	16 m	1.200 m	13	2,2 milion TEU	2.000	Super Post-panamax
BTP - Santos	Private	1.545.443	3	17 m	1.080 m	8	1,5 milion TEU	-	Super Post-panamax
Portonave - Navegantes	Private	1.267.504	3	14 m	900 m	6	1,5 milion TEU	3.210	Post-panamax
TPC - Paranaguá	Public	1.186.267	3	13 m	-	8	1,16 milion TEU	3.64	Post-panamax
Porto Itapoá	Private	1.066.088	2	16 m	800 m	6	1,2 milion TEU	2.892	Super Post-panamax
DP World Santos	Private	972.160	4	14,2 m	1.100 m	6	1,2 milion TEU	1.000	Post-panamax

Note. Compilation of data from by ANTAQ (2024), Portonave. (2024), Terminal De Contêineres De Paranaguá [TCP] (2024a), Terminal De Contêineres De Paranaguá [TCP] (2024b), Secretaria Nacional de Portos [SNP] (2018a), Secretaria Nacional de Portos [SNP] (2018b), Ministérios Dos Transportes, Portos E Aviação Civil [MTPA] (2017), Brasil Terminal Portuário [BTP] (2024), Santos Brasil. (2024), Porto de Santos (2024) e DP World. (2024).

In view of this range of information, numerous possibilities can be evaluated, such as, for example, the addition of a berth does not always mean an increase in TEUs performance per year, this evidence is given taking into account the number of berths at DP World Santos (4 berths), with a quay line of 1,100 meters and which occupies the sixth position in this cut, compared to Portonave which has 3 berths, 900m quay line and occupies the third position in the quantity of TEUs per year. Therefore, it assumes that the total area, container storage area (dry/reefer) and port layout can be the competitive differential for a 30% higher performance, which may mean that efficiency is related to superstructure variables such as RTG, ST, EV, internal vehicles (Terminal Tractors and Semi-trailers).

In addition to the aspects listed above, the port authority, when starting projects to expand or replace equipment with larger ones, must take into account the pavements where they will be allocated, the containers, the equipment, the pier, as they require prior preparation of the soil, so as not to give way with excess weight, that is, they must receive specialized foundation services and other specific to engineering. This situation demonstrates the concerns for the service of megaships to be implemented in global shipping lines in the coming years from 2022, maintaining their competitiveness.

Assuming as a premise that vessels will continue to increase in size (length, width and depth) over the next few years, a series of adaptations emerge, among them the depth of the channel and depth of the berth. According to the PIANC (Permanent International Association of Navigation Congresses) method, the depth of the channel is estimated from the ship's draft, tidal height, squatting, wave-induced motion, a margin depending on the type of bottom and density of the water. Considering these factors and in the case of a 25,000 TEU ship seeking attraction at a terminal, the recommended depth is 18.6 m to 22.0 m.

Finally, the literature analysis highlighted the main challenges faced by ports in terms of infrastructure, such as the need to adapt to new technologies, the efficient management of available space and the maintenance of operational capacity in the face of the superstructure. However, opportunities for improvement were also identified, including the implementation of higher crib draft than in the current scenario. In addition, a relevant concern, since there will be investments, infrastructure and digital superstructure options, automation and energy efficiency considerations, green equipment.

In summary, the results of the literature review corroborate the critical importance of port infrastructure and superstructure for the efficient performance of ports and containerized cargo terminals. These reflections provide valuable insights to guide the formulation of policies and investment strategies that aim to improve the competitiveness and sustainability of Brazilian ports compared to the global context.]

5 CONCLUSIONS

The increase in the size of vessels over the years highlights the importance of ports seeking adaptations to serve these new classes of ships, which can maintain a nation's competitiveness and income development, among many other direct and indirect factors. Brazil has an approximate coastline of 7,400 km, bathed to the east by the Atlantic Ocean, where there are routes (shipping lines) with the most varied ports around the world, encompassing continents of Africa, Asia, Europe, Central and North America. The contour of the Brazilian coast increases to 9,200 km if the protrusions and indentations of the coast are considered. The Brazilian coast is extensive and not very indented, which becomes a facilitator for the installation of ports.

On the relationship between infrastructure and performance of ports and containerized cargo terminals, it is possible to draw some important conclusions: Port infrastructure plays a key role in the operational efficiency and competitiveness of ports and cargo terminals. Variables such as storage capacity, physical arrangement (layout), number of berths, and use of automation technologies are considered to ensure efficient cargo flow. In addition to the superstructure variables, such as equipment, RTGs, STs, internal vehicles, among others.

Modernizing infrastructure is essential to meet the challenges posed by the increase in demand and the size of vessels. Investments in new equipment, capacity expansion, and the adoption of advanced technologies are necessary to ensure the competitiveness of ports on the global stage. Despite the challenges faced, such as the need to adapt to new technologies and efficiently manage the available space, there are also opportunities for improvement, including implementing sustainable practices, developing public-private partnerships, and investing in digital infrastructure.

In summary, the findings of this literature review highlight the importance of port infrastructure variables for the efficient performance of ports and containerized cargo terminals. These findings provide valuable insights to guide the formulation of policies and investment strategies aimed at improving the competitiveness and sustainability of ports in the global context. And finally, it is suggested the quantitative deepening of the identified variables, in order to exercise the comparison between the different categories of equipment, ton per equipment, height and operational efficiency rates, as a secondary objective to provide a solid basis for the best choice according to the needs of each port and port terminal.

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