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"The mega container vessels. Evolution and challenges"

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Patras, Greece, June 2024

“The mega container vessels. Evolution and challenges”

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Abstract

This dissertation deals with mega container ships. Container ships have been evolving over the last 80 years, driven by economies of scale and taking advantage of the development of technology, reaching today's ships that exceed 24,000 TEUs in capacity. Due to the ability to travel close to the coast and the long distance they have to travel, these ships mainly are deployed in the maritime trade route Far East – Europe – Far East. Shipping alliances between liner companies operating around the world now have great bargaining potential and can influence the choice of ports for berth and modify stops on maritime trade routes. For mega container ships, there are now few ports that can act as hubs and have the conditions to carry out the supply chain through the reception, unloading, handling, and support of intermodal transport, as well as the appropriate facilities to serve them, due to the existing restrictions. Investments in the Piraeus Port container terminal have made it an important hub of the Far East-Europe trade route and vice versa, and can play an essential part in the future in servicing mega container ships.

Keywords

Shipping alliances, maritime trade routes, container terminal, berth productivity.

"Τα υπερμεγέθη πλοία μεταφοράς εμπορευματοκιβωτίων. Εξελίξεις και προκλήσεις"

Αθανάσιος Κάιας

Περίληψη

Η παρούσα εργασία ασχολείται με τα υπερμεγέθη εμπορευματοκιβωτιοφόρα πλοία. Τα εμπορευματοκιβωτιοφόρα πλοία εξελίσσονται τα τελευταία 80 χρόνια με οδηγό τις οικονομίες κλίμακας και εκμεταλλευόμενα την ανάπτυξη της τεχνολογίας, φτάνοντας σήμερα να υπάρχουν πλοία που ξεπερνούν σε χωρητικότητα τα 24.000 TEUs. Ο θαλάσσιος εμπορικός δρόμος που χρησιμοποιεί αυτά τα πλοία, λόγω της δυνατότητας να ταξιδεύουν κοντά στην ακτή, αλλά και της μεγάλης απόστασης που έχουν να διανύσουν είναι κυρίως ο Άπω Ανατολή – Ευρώπη – Άπω Ανατολή. Οι ναυτιλιακές συμμαχίες μεταξύ των εταιρειών τακτικών γραμμών που δραστηριοποιούνται στον κόσμο, έχουν πλέον μεγάλες διαπραγματευτικές δυνατότητες και μπορούν να επηρεάσουν την επιλογή λιμένων για ελλιμενισμό και να τροποποιήσουν τις στάσεις στους θαλάσσιους εμπορικούς δρόμους. Για τα υπερμεγέθη εμπορευματοκιβωτιοφόρα πλοία, υπάρχουν πλέον λίγα λιμάνια που μπορούν να λειτουργήσουν ως κόμβοι και έχουν τις προϋποθέσεις πραγμάτωσης της εφοδιαστικής αλυσίδας μέσω της υποδοχής, εκφόρτωσης, διακίνησης και υποστήριξης των διατροπικών μεταφορών, αλλά και τις κατάλληλες εγκαταστάσεις για να τα εξυπηρετήσουν, λόγω των υφιστάμενων περιορισμών. Οι επενδύσεις στον τερματικό σταθμός εμπορευματοκιβωτίων του Λιμένα Πειραιά, τον έχουν ανάγει σε ένα σημαντικό κόμβο του εμπορικού δρόμου Άπω Ανατολή- Ευρώπη και αντίστροφα, και μπορεί να διαδραματίσει σημαντικό ρόλο στο μέλλον στην εξυπηρέτηση των υπερμεγέθη εμπορευματοκιβωτιοφόρων πλοίων.

Λέξεις – Κλειδιά

Ναυτιλιακές συμμαχίες, θαλάσσιοι εμπορικοί δρόμοι, τερματικός σταθμός εμπορευματοκιβωτίων, παραγωγικότητα ελλιμενισμού.

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List of Abbreviations & Acronyms

AIS	Automatic Identification System
BRI	Belt and Road Initiative
DWT	Dead-Weigh Tonnage
EU	European Union
ETS	Estimated Time of Sailing
GDP	World Gross Domestic Product
GRT	Gross Register Tonnage or Gross Tonnage
IMO	International Maritime Organization
ISO	International Organization for Standardization
PCT	Piraeus Container Terminal
PPA	Piraeus Port Authority
QCs	Quay Cranes
RTG	Rubber Tired Gantry
SLOCs	Sea Lines of Communication
SCA	Slot Charter Agreement
SIPG	Shanghai International Port Group
STS	Ship To Shore
TEU	Twenty-foot Equivalent Unit
TEU	Twenty-foot equivalent unit
ULCS	Ultra Large Container Ship
US	United States (of America)
VLCS	Very Large Container Ship
VSA	Vessel Sharing Agreement

1. Introduction

1.1 Literature review

Maritime transportation has undergone two major changes throughout history. The first has been the emergence of the container as a standardized unit of load, allowing the transport of most of the world's freight traffic, and the second is the implementation of technological advances in both ships and ports to enable efficient operations. The trend of ships increasing in volume has intensively crossed the leading tendencies of the container shipping industry in the last decades.

Liu & Ng (2010) point out that the structure of the maritime transport market is continuously evolving and growing, as reflected in UNCTAD's reports on maritime transport (UNCTAD, 2018). Ships have grown faster than expected when almost no one imagined that a 24,346 Twenty-foot Equivalent Unit (TEU) container ship[1] would be sailing right now. Consequently, we must bear in mind that the new mega vessels significantly impact terminal operations due to the concentration of a greater volume of loading and unloading in less frequent stopovers.

In recent years, several authors have paid attention to the exponential expansion in the volume of container ships under the theoretical justification of economies of scale (Rodrigue, 2017). In this sense, the role of economies of scale in lowering the cost of transport units is being highlighted. Haralambides (2019) highlights that "*the gigantism in shipping has been induced by both port competition and shipping alliances and that without the ability to use each other's ships, no carrier alone would be able to achieve a capacity utilization high enough to justify the use of present-day mega-ships, while at the same time offering the frequency that shippers require*". In another approach, the technological advancements applied to container ships and the port competition are the facts that have led to a new model dominated by gigantism and strategic alliances on the main maritime routes (Lian et al., 2019).

In the port sector, gigantism has materialized in the consolidation of global operators of container terminals and specialized facilities. Ports have been forced to expand and invest

[1] "*The Irina Class is currently the largest of container ship in the world with a capacity of 24,346 TEU*" (GOCOMET, 2023).

rapidly in infrastructure to cope with the new size of ships and preserve the port's competitiveness. In accordance with Schinas & Papadimitriou (2001) "*the era of mega-carriers imposes very radical changes to the port industry*". Despite the many benefits, the large size of ships creates several difficulties in ports, as in addition to the investments required in port infrastructure, large ships cause problems due to the peaks in port facilities and the congestion created as a result. Few ports are eligible to enhance into mega-hubs, and these harbors must invest in the new required yard and handling apparatus in order to serve the increased needs in the complex universal logistics framework. A series of changes are taking place in port facilities, such as the optimization of numerous procedures in each of the subsystems (loading, unloading, uploading, transportation, storage, delivery, etc.), induced by the transformation of vessels and the reforming of shipping companies and their services. Most of these operators are shipping companies that, in turn, control other links in the chain of logistics (De Souza Junior et al., 2003). Simultaneously, as Haralambides (2019) mentions, "*cargo handling time per TEU is longer after a certain ship size, and this is a distinct port diseconomy of scale*".

The significant acceleration of investments by the main shipowners in mega-ships intends to attain appropriate economies of scale and has guided the need to advance and adapt port infrastructure and handling systems for container traffic. Stopford (2009) and Rodrigue (2017) highlight the relevance of this aspect from an economic point of view, as well as its influence on the consolidation of intermodality. The service provided to the customer is very relevant since the competitiveness of the ports plays a leading role (Aronietis et al., 2010). In this way, the growing volume of business translates into greater demand for operations, and at the same time, scales must be shortened to optimize costs (Jong Sil, 2017).

In relation to efficiency in container terminals, Liu & Ng (2010) and Flack (2014) evaluated their performance to determine measures that could be implemented to improve it. Optimization in container ports can present various scenarios and affect the different subsystems that are integrated into them. Concerning quay operations, the productivity of the cranes in loading and unloading has been analyzed (Guzmán et al., 2018). To this end, some indicators of productivity and efficiency of the teams are examined, concluding that there is a relationship between these, the planning of operations and the allocation of the resources used. Regarding planning and resources, it is worth noting the added difficulty of operating mega-ships for terminals. Jong Sil (2017) focused on the adaptations required by port infrastructure and equipment and the large peaks in container traffic volume generated by mega-ships on their stopovers. Other publications also point out that the performance of these stopovers is lower in mega container ships compared to vessels of more moderate capacity (Bonardi Pinder, 2015).

Jian Gang et al. (2016) focused their studies on the management of storage in the yard, considering the problem posed by decisions of space allocation and the arrangement of cranes, added to congestion in terms of density, proposing integrated optimization methods. In this regard, there are a series of proposals and recommendations for the structuring of the design phase of container terminals, among which we can highlight those aimed at automation (PEMA, 2012; Alho et al., 2015). Moreover, Martín - Soberón et al. (2014) also presented a series of strategies to advance yard performance in container port terminals, highlighting that the upsurge in occupancy can cause a decline in the productivity of operations by increasing the cycle time of the machinery in the yard, which has an impact on the overall effective production. Combining the scope of quay operations with storage and internal movements carried out in the yard, Steenken et al. (2004) developed a study focused on the efficient and effective usage of communication technologies and the suitable optimization techniques for each of the main logistics processes. At the same time, they carried out a literature review on the implications of containers in maritime trade, as well as the structure, equipment, and operation of current terminals.

It is simple to contemplate the fact that mega container ships are the remedy to the concern of the availability of containers, the facilitation of the increasing freight volume, the decreasing transportation costs, and the control of fuel consumption and fuel expenses. But it is not that simple. Maritime transport has historically been accompanied by high uncertainty, linked to the multiplicity of interrelating influences in the business, such as economic, political, and social ones. Such interdependence was clearly exemplified in the current pandemic, which strongly impacted maritime transport (UNCTAD, 2021). Some of the influences that determine the expansion of large container ships are trade development and globalization, global shipping alliances, carrier strategies, etc.

This research offers a synopsis of the maritime transportation situation regarding to mega container vessels[2], discusses the developments, outlines the factors that led to the desire for the increased vessel size and digs into the challenges and limitations. Additionally, the research deals with shipping trade routes, shipping alliances, terminal systems at ports, and how all these interact and are influenced by mega container vessels. The research aims to help the public understand the interconnections among maritime transport links, logistic services, and port infrastructure and how these are affected by the volume of the container vessels. Moreover, the Piraeus port situation will be elaborated.

1.2 Research Methodology

The research aim is to clarify the current maritime state regarding mega container vessels by reviewing their evolution and determining the challenges that arise for ports, shipping companies, and the global maritime trade in general.

The objectives that can satisfy the aim above are:

The understanding of the evolution of the volume of container vessels. What drives this evolution, and what is the current situation? In addition, other questions are: What are the challenges and limitations, and how can companies and port authorities deal with these? A discussion of the market for container shipping and economies of scale is necessary. Why do shipping companies pursue even bigger ships? In addition, are ports prepared to continue receiving mega-ships? Can ports handle the evolution of container ships? What are the issues related to the management of container port terminals, and how are they affected by the existence and the increase of mega-ship capacity? How are the key performance indexes of the operations in the ports influenced? How can the transition of containers in these terminals be facilitated? Are the transportation routes of the mega container vessels going to be affected?

This research will follow an evaluation of previous research. Moreover, it will employ secondary data, data collected through books, articles, published reports, and electronic

[2] Complementing the definition of mega container ship, set out in next chapter, it is established for this Thesis, that when "mega container ships" is indicated, reference is made to ships with a capacity greater than 18,000 TEUs, based on the on the categorization that Alphaliner uses for its statistics (Alphaliner, 2022).

statistic databases, which will be assessed and presented in a way to conclude with useful observations.

1.3 Limitations

An effort was made to find a free edition of the Automatic Identification System (AIS) on the web, in order to gain access to the tracking history of mega container ships, their Estimated Time of Sailing (ETS), their stopovers, and various other details, but this has not been possible. So, only facts gained by the www.vesselfinder.com free edition site were elaborated on and presented in this research.

In addition, communication with the authorities of the Piraeus Port was attempted in order to get access to info such as the mega container ships that have approached the Piraeus port in the last years, etc., but there was no reply to the multiple emails that were sent. So, only facts that were found on the web were incorporated into this research.

1.3 Thesis Outline

The second chapter presents the expansion in the capacity of container ships, in terms of TEUs, over the years and which are the main acquisition factors of mega container ships. The third chapter exhibits the maritime shipping routes that exist, which are the key ones and which factors influence them. In addition, the today global shipping alliances are presented and a dig into the impact and the benefits is taking place. The fourth chapter deals with the characteristics of the ports and the container terminals. The questions that are answered are how the ports and the terminals are selected, and which are the key performance indicators that can someone be based on, in order to evaluate the harbors. The fifth chapter presents some facts about the mega container ships and the challenges that exist. The sixth chapter elaborates the case of the Piraeus port about which is the situation now and how Piraeus facilitates the mega container ships. Finally, the research sums up the conclusions, in order to display a full depiction of the subject dealt with.

2. Maritime Transport

Shipping has been a fundamental gear of trade and development since ancient times. The first civilizations had already established maritime routes that channeled important trade flows and that would be consolidated over the centuries to form the first maritime networks of international trade. The configuration of these networks has always been conditioned by the characteristics of the navigation areas, trade flows, and geopolitical factors (González, 2005).

Nowadays, sea transport is the most efficient, advantageous, and safe solution for transporting a large mass of cargo. The total cost of maritime transport is the lowest because large quantities are transported and thus the individual cost of cargo is reduced. Currently, it is estimated that maritime transport accounts for around 90% of world trade (ICS, 2023). The new trends derived from globalization and the changes in consumption have led to societies becoming increasingly dependent on transport networks, to the extent that they have to cover needs for energy supply, distribution of goods, and mobility of passengers and goods.

Maritime transport has grown dramatically over the last 60 years, and this increase can be recognized for many causes. Primarily, the finding of new raw material resources around the globe, accompanied by the extension of new bases of demand, accelerated some significant changes regarding the pattern of worldwide trade. Secondly, developments in ship construction have led to the production of innovative types of ships to convey the transportation of any cargo in an economical way. In addition, liberalization laws on trade rules have allowed firms to grow their businesses in various places and move their finished goods to any marketplace worldwide (Stopford, 2009). In addition, technological developments have been the driving force behind further expanded vessel constructions, aiming to progress economies of scale and to encounter the exact freight and trade course necessities (Alizadeh & Nomikos, 2009).

Accessibility is critical to the financial growth of modern societies, and naval transportation is the fundamental link in existing transport systems, which have been integrally transformed by the constant need to adapt the business model to the profound changes that are taking place within the framework of the so-called Fourth Industrial Revolution

(Shahbakhsh et al., 2022). Jo and D'Agostini (2020) mention that "*the maritime industry, like other industries, is embracing Industry 4.0 by adopting new technologies digitalized at different levels*". In addition to the above, the need for specialization of ships has commanded the creation of bulk carriers, cargo ships, containerships, tankers, and others[3], which endure in expanding with a gradual increase in size, implementing the new technologies that arise. Each type of vessel specializes in different product categories and "*can be divided into two categories, those operating fixed routes and those operating flexible routes*" (OECD, 2015). So, the disclosure of the evolution of container ships and their usage, which is developed in the following paragraphs, is vital to understanding the current situation referring to maritime transport.

2.1 The Container

The introduction of the container[4,5] dramatically reduced transport costs, supporting the boom that occurred in the spot following the end of 2nd World War, and was a primary factor in globalization[6]. The container eliminated the need to sort most cargoes manually and store transported goods in warehouses, displacing thousands of port workers who were previously needed to handle bulk cargo. The standard container led to considerable savings in freight transport by eliminating the need to multipack different types of cargo while reducing costs and overall transport time. Containers also improved cargo reliability and safety. In conclusion, the introduction of the container has strengthened construction industries and has been a driving force for globalization.

[3] "*Passenger ships are ships that carry passengers and under certain conditions cargo and vehicles. Such ships are coastal passenger ships, cruise ships and ocean liners. Special purpose ships are ships that were created because of the need for fast transport or because of the development of technology that forced us to build these ships. Special purpose vessels include Refrigerated ships, fishing boats, oceanographic ships, cable ships, training ships, meteorological ships. Auxiliary shipping ships were invented to cover the safe passage of other types of ships. Depending on the auxiliary purpose they fulfill, icebreakers, tugboats, dredgers, pilots, lighthouse ships, floating cranes and lifeguards have been designed*" (Chlomoudis, 2011).

[4] The container is a large metal box, usually made of iron or aluminum. Its use concerns the transport of dry cargoes, while it cannot be used for liquid or gaseous loads (Muller, 1966).

[5] In shipping, the term TEU (Twenty-foot equivalent unit) is used to refer to containers. So, we have containers that are 20 feet long or 6 meters long and containers that are 40 feet or 12 meters long. Shipping terms prevail in their name, a forty box for example is called FEU (Forty-foot equivalent unit). These are the standards defined by the International Organization for standardization (ISO).

[6] Vasiliauskas & Barysiene (2008) report that: "*The first regular container transportation took place in 1961 with a container service between the East Coast of the US and points in the Caribbean, Central and South America*".

World trade, until today, has had a steady upward trend for most of the period (with some exceptions), which was shown by the course of World Gross Domestic Product (GDP) and world seaborne trade (UNCTAD, 2023). Understandably, this trend is also reflected by data on container throughput. The chart given below shows the steady upward trend of container traffic in the largest commercial countries from 1985 to 2022. Global container traffic has roughly doubled in the last 40 years.

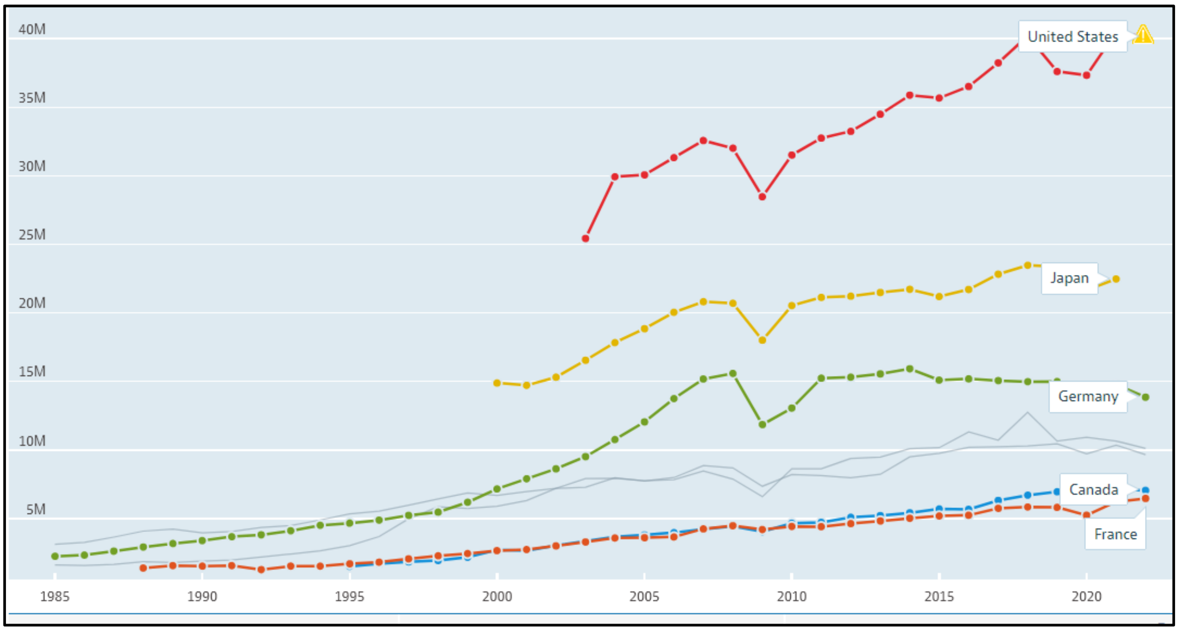


Figure 1. Annual container throughput per country, in millions (OECD, 2024).

Also, from the table below, it is understood that within twenty years, there is a total increase of 237.6% in the use of containers worldwide.

Year	TEU
2000	224.774.536
2005	376.268.146
2010	544.870.578
2015	694.479.839
2020	758.734.020

Table 1. Total containers worldwide (2000-2020) (World Bank, 2024).

2.2 The Evolution of Container Ships

2.2.1 Methods of measuring the container ships and generations

There are several ways to measure container ships, as below:

The method that measures the maximum number of twenty-foot containers that a ship can carry is the most prevalent. This kind of capacity is measured in TEU. Currently, the largest container ship is the "Irina class" and has a capacity of 24,346 TEUs. This method is followed in this current research.

Another measuring method that is somewhat related to the size of the ship is the gross tonnage (GRT), which shows the total internal volume of the ship. "Irina class" has GRT 233,328 gross tons.

Another method is measurement based on deadweight calculation in tonnes (DWT). DWT shows the maximum weight a ship can carry. It is used on all ships regardless of type. The DWT of “Irina class” is 240,000.

"*Since the beginning of containerization in the mid-1950s, containerships undertook five major general waves of changes, each representing the generations of containerships*" Rodrigue (2024). In addition, "*from its confirmed adoption in the late 1960s and early 1970s, the amount of shipped containers started to grow in parallel, and at the same rate as the growth of worldwide exported goods. Container shipping lines were holding onto their market share in the international ocean shipping world*" (Allyn International, 2023). The container changed the dynamics of transport as the different means of transport began to combine as links in the same chain, giving rise to intermodality. In this scenario, ports were beginning to perform a leading function as centers for the transfer of cargo. The combination of different sea routes made it possible to reduce ports of call and, with it, transit times. In addition, the transport network was extended through better interaction with road and rail land transport.

This research deals with the mega container ships, those naval units intended for the transport of containerized cargo that, due to their dimensions (length, beam and draught) far exceed those that constitute the average of those currently or previously used for this purpose, and which correspond to those that can operationally transport the largest cargo capacity measured in the amount of TEU. A historical review would be very useful at that point. A picture speaks a thousand words. So, the diagram and the picture bellow can project the evolution in the best way. "*Containers vessels have been through various phases. These phases have been classified as generations*" (Jha, 2022) and can be defined as below:

- First Generation – from 1956 to 1980.
- Second Generation – from 1980 to 1988.
- Third Generation – from 1988 to 2006.
- Fourth Generation – from 2006 to 2014.
- Fifth Generation – from 2014 till today.

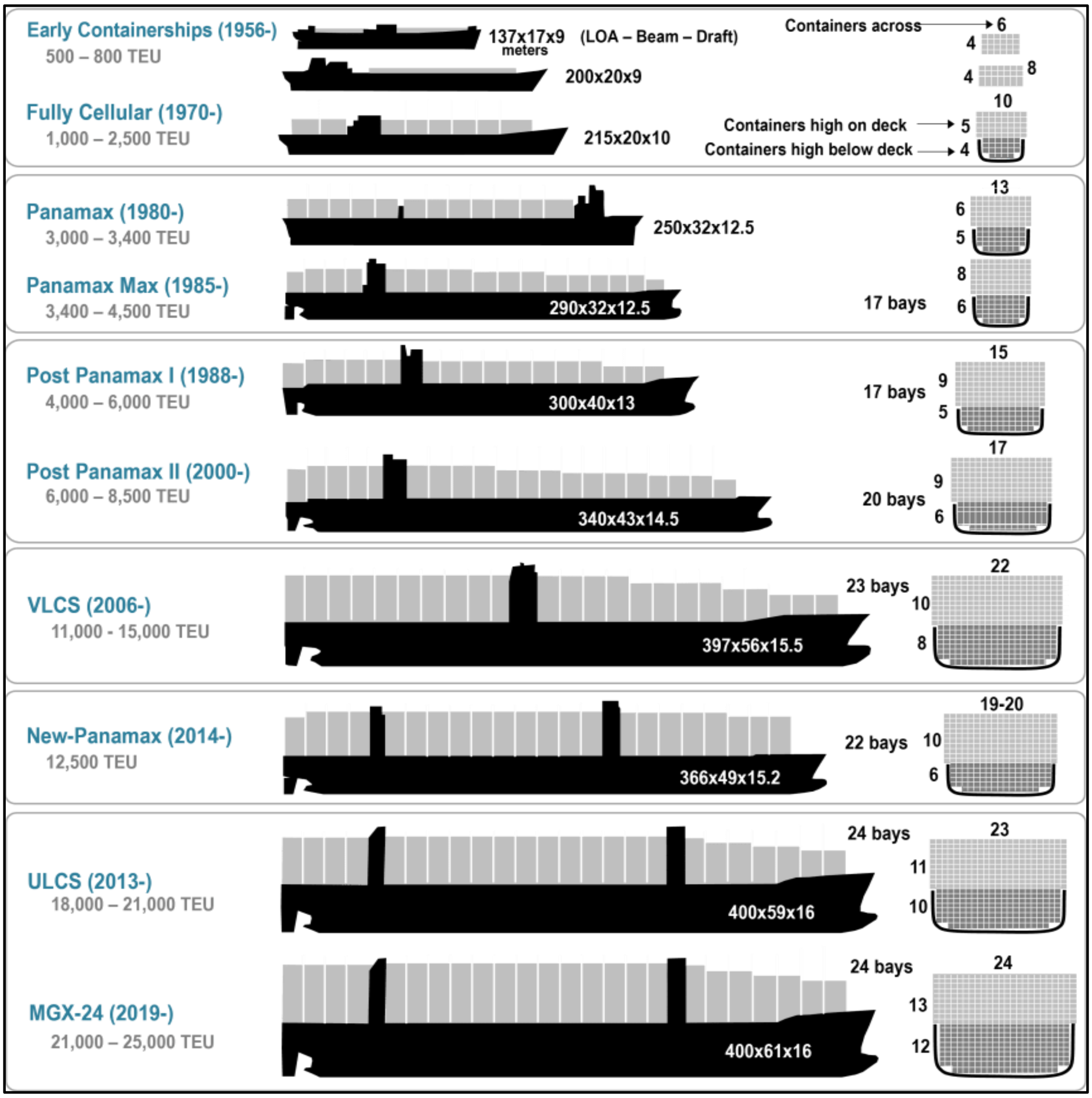


Figure 2. The generations/evolution of containerships (Rodrigue, 2024).

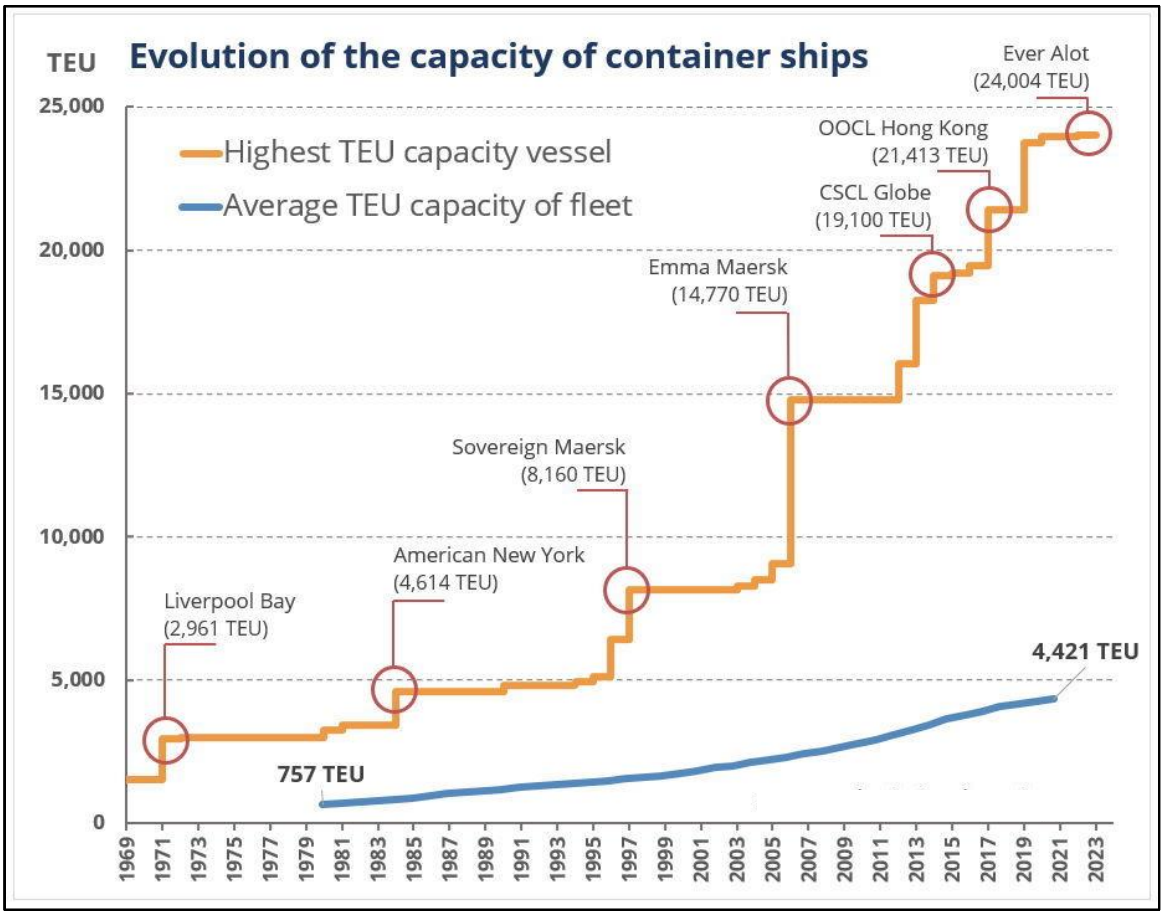


Figure 3. The evolution of container ship sizes and capacities – largest container ship by year (Allyn International, 2023). In 2024 the Irina Class is the largest class of container ships in the world with a capacity of 24,346 TEU.

2.2.2 Container ships 1st Generation

The primary container vessel, called "Ideal-X," was a modified tanker capable of transporting 96 current TEUs on a specially designed platform above the piping. Container shipping was a new form of freight transportation in the early 1960s, and converting prevailing vessels proved to be low-cost and less unsafe as an investment should it not thrive.

On converted cargo ships, containers were placed in specially modified holds and stacked in layers, enabling them to carry 226 containers. Cranes were placed on the deck of ships, but "*port terminals were not equipped to handle containers*" (Rodrigue, 2017).

Finally, with the evolution of technology, container ships managed, in the early 1980s, to carry up to 2,500 containers. These vessel sizes are now called "Small Feeder" up 1,000 TEUs, "Feeder" from 1,001 up to 2,000 TEUs and "Feedermax" from 2,001 up to 3,000 TEUs, which serve small ports (AIB Maritime, 2024). The role they play in world trade is very important even today. Feeders are a bridge between countries' major ports and smaller regional ones. The largest containerships sail to significant ports. Feeders carry out the transport of goods from larger ports to their final destination, and containerships of smaller size and smaller transport capacity are more flexible (Isalos, 2024).

2.2.3 Container ships 2nd Generation

During the 1980s, shipping companies, in order to benefit from the economies of scale, i.e., the greater the quantity of containers transported, the lower the operating cost per TEU, ordered the creation of grander container ships, the Panamax-type vessels. The result of these constructions was a combination of a large number of containers with the lower cost of transporting TEUs, which suggestively aided the spread of the container. For this type of ship, the construction criteria and the required draught limitation are set because of the specific magnitude of the Panama Canal gates[7]. Later, larger ships were designed in order to make the most of the constraints in width and dimensions, in general, of the Panama Canal basins and were named the Panamax-Max prototype (Rodrigue, 2017).

2.2.4 Container ships 3rd Generation

In the late 1980s, Post-Panamax I-type ships appeared, and later, at the start of the 2st century, the Post-Panamax II-type ships followed. The model and interpretation of larger ships than the dimensions of Panamax were considered risky in terms of the structure of the maritime trade organizations, terminal infrastructure, handling - storage of containers, as well as port draught restrictions.

[7] In order to cross the Panama Canal, ships had to comply with the following construction dimensions: maximum length 294.13 meters, maximum width 34 meters and draft at 13.56 meters. The ship type became known as the Panamax standard (ACP, 2005). In 1985, a Panamax container ship was built with a capacity of approximately 4,000 TEUs.

"The class of container ships with a capacity of 4,340 TEUs, appeared in 1988 and was the first class of ships to exceed the 32.2-meter width limit of the Panama Canal" (Rodrigue, 2024) and was the first to be placed on the Pacific Ocean trade line. By 1996, PostPanamax ships were built with volumes up to 6,600 TEUs. The primary PostPanamax ships did not have much difference in length from the Panamax ships, but they were wider, making them more efficient (Rodrigue, 2020). At the end of the 90s, the speedy progression of worldwide trade drove such vessels to become a merchantable and more attractive proposal to acquire.

Capacities were then increased to 8,000 TEUs (Post-Panamax I). Post-Panamax vessels caused structure questions in many ports, requiring deeper water as well as larger, more expensive container loading and unloading cranes. Port draught restrictions have led port terminals to dredge to accommodate these new container ships (Rodrigue, 2017). "*The increase of international trade (and even more so of the Asia - Europe one) from the mid-1990s, resulted in a dramatic increase of the number of containers needing to be moved, and the development of multiple major shipping routes originating in Asia and more specifically China. More and more dry goods were being produced in Asia and looking to be shipped to Europe or North America. Maersk*[8] *saw this as the opportunity to develop post-Panamax vessels – larger vessels that could not pass through the Panama Canal, but could perfectly serve the routes from Asia to Europe and from Asia to North America West Coast*" (Allyn International, 2023).

2.2.5 Container ships 4th Generation

After the Panamax, the first Very Large Container Ships (VLCS) appeared on the market. They are the New-Panamax type container ships. These ships are designed to fit right into the new gates of the enlarged Panama Canal[9], which launched in 2016. They are characterized by a volume of around 12,500-13,000 TEUs, but exist numerous deviations of the Neo-Panamax ships based on length (17-22 divided into sections, called Bays, by TEUs and is along the longitudinal length of the ship) and width (19 or 20 TEUs placed next to each other) (Rodrigue, 2017).

[8] Maersk is a Danish shipping and logistics company.
[9] In order ships to enter the new gates, they must comply with the construction dimensions, meaning 366 meters maximum length, 51.25 meters maximum width and 15.2 meters maximum permissible draft (eNautilia, 2021).

2.2.6 Container ships 5th Generation (Mega container Ships)

A further expansion of New-Panamax vessel design led to the insertion of the Mega container ships category, originally consisting of Ultra Large Container Ships (ULCS), vessels, thru a competence of more than 18,000 TEUs. Ships of such capacity were delivered for use in 2014 by Daewoo shipyards, on order from A.P. Moller - Maersk A/S. The "Maersk Mc-Kinney Moller" was the first of these, with a capacity of 18,340 TEUs[10]. These ships were constructed in accordance with the instructions required by the authorized company, which were based on three main characteristics or else "Triple E":

- "*Economy of scale*
- *Energy efficient and*
- *Environmentally improved*" (Marine Study, 2022).

This kind of vessels were further enlarged, and after 2017, vessels beyond 20,000 TEUs commenced to be constructed. This class was further expanded, and in 2019, a vessel with a capacity of 22,960 TEUs was delivered. ULCSs are approaching the mechanical limit which the Suez Canal is able to serve (Rodrigue, 2017). "*An additional expansion in 2019 introduced ships with 24 containers across and 24 bays, dubbed Megamax-24 (MGX-24). The ULCS/Megamax-24 is getting close to the technical limits that the Suez Canal can accommodate, beyond which commercial relevance declines substantially. Routes and ports Megamax ships can service are more limited, mostly to routes between Asia and Europe and potentially some transatlantic routes*" (Merk, 2018). In the scientific literature, there is no exact explanation or interpretation of the term "mega container ship", but its use is often found in various scientific and non-scientific articles. Translating it etymologically, we mean a ship of very large dimensions. The above term is characterized by a ship whose construction dimensions exceed those of the established types of ships and is one of the largest shipyards. In 2014, there were only 4 ULCSs on the market, and their number reached 40 ships in 2015. In 2022, based on the table below, there were 146 Mega container ships and there were orders for another 52 ships in the following years.

[10] The order for the construction of large ships by A.P. Moller - Maersk A/S was the beginning of similar orders from other shipping companies. Companies, with a strong presence in international merchant shipping and operational activity in liner shipping, lay the basis for the consolidation of ships of similar specifications, dimensions and carrying capacity.

VLCS Watch	Current Fleet		Orderbook	
Size range	Units	TEU	Units	TEU
>18,000	146	3,042,599	52	1,233,320
15,200-17,999	60	985,459	87	1,369,712
12,500-15,199 NPX	269	3,712,464	130	1,857,034
10,000-12,499	190	2,071,533	17	202,550
7,500-9,999	478	4,231,600	18	140,784
Total	**1143**	**14,043,655**	**304**	**4,803,400**

Table 2. Container Ships per size and the current orders (Alphaliner, 2022).

2.3 Main acquisition factors of mega container ships

The global demand for cargo transportation is one of the primary causes for the ordering and evolution of mega container ships. According to UNCTAD, "*International maritime trade increased by 4%, for the year 2017. This was the fastest growth in five years. reflecting the global economic recovery and improving world trade… Trade growth was also boosted on the most important East-West trade routes, namely Asia-Europe, the Trans-Atlantic and Pacific Ocean routes*" (UNCTAD, 2018). Thus, the increase in demand for containerized transport was expected to lead to an increase in demand for larger vessel sizes. The growing popularity of mega container ships is expected to increase maritime trade. The main factors leading to the construction of mega container ships are presented below.

2.3.1 Economies of scale

The demand for economies of scale and the interest in controlling the costs (Wu and Lin, 2015) led the container maritime sector toward the development of increasingly large container ships. By using these increasingly large ships, shipping companies have taken advantage of these economies of scale, which have allowed for continuous reductions in costs per TEU transported (Ge et al., 2021).

Rodrigue (2017) explained that maritime transport, more than any other form of transport, "*benefits from the application of economies of scale, as they have a direct impact on operating costs. The larger the ship, the more cargo it can carry, and therefore the lower* *the transportation cost per unit of cargo. There has therefore been a push to deploy larger and larger ships, which were placed on high-volume trade routes, such as between Asia and Europe and across the Pacific*".

Recent studies show that vessels of up to 25,000 TEUs keep generating economies of scale, with a regular volume utilization of 90% midst all vessel classes. That is, 25,000 TEU vessels are able to accomplish substantial gains over smaller vessels with 18,000 or 20,000 TEU capacities. However, with very low freight rates, they wouldn't encourage the profitability of 25,000 TEU vessels, in comparison with the smaller ones (Ge et al., 2021).

2.3.2 Relationship between fuel consumption and speed

The reduction in the speed at which a merchant ship moves was adopted in 2007 to 2008, a period when fuel costs had an increasing continuous trend and had reached $ 700 per ton. The increasingly expensive fuel has led many companies, starting with Maersk Line, to implement scheduled trips with reduced cruising speed in order to reduce fuel consumption (Ship & Bunker News, 2023). Also, the ship engine manufacturer Wärtsilä (Wartsila, 2011), calculated that the fuel consumption of a container ship that makes the Asia-Europe circular route can be reduced by 45% if it reduces its cruising speed, while it can reach 59% savings if it reduces its speed even more. Of course, external factors like the sort of loaded goods and climate conditions also play a big role in saving fuel consumption. The application of reduced speed allowed the market to absorb fleet overcapacity during periods of low demand, without affecting port congestion thanks to maintaining the port's call frequency.

2.3.3 New Technologies - Maritime Carrier Alliances

The emergence of revolutionary techniques makes it possible to build new oversized ships at relatively low prices (Stopford, 2009). In addition, modern ports are a dynamic hub in the distribution network, having been transformed into integrated transport centers and supply platforms. However, ports and container terminals around the world are already suffering from congestion caused by mega container ships, which may not be able to keep up with their ever-increasing size due mainly to outdated cranes and under-spaced piers.

It is also worth mentioning that alliances in liner shipping and the construction of large-scale ships make the affiliation among liner companies and harbors multifaceted, and have shaped new undercurrents where maritime companies have bigger negotiating control and impact. As we will see later, ship sizes are increasing since alliances can now support them.

3. The maritime shipping routes & global shipping alliances

International trade, primarily via sea, is the one that provides access to tons of goods all over the globe. "*Trade routes are one of the most important aspects of the shipping industry. They set the parameters and conditions, as well as the time required to travel to the destination and, of course, the cost*" (LianVisman, 2023). It is well known that the mass of goods circulated in our societies come from countries such as China, Japan, and Germany. Which routes are used, and which ones are the most important? These are some of the questions that the current chapter will answer.

3.1 Liner Shipping

A branch of the shipping market[11] is the liner shipping. Liner shipping is the maritime transport service carried out between specific ports at regular intervals and predetermined rates. These services are performed by carriers (Merk et al., 2018). The itineraries operated by the ships are scheduled in advance and follow the published schedule. The program includes departure and arrival times for each port. The schedule frequency is weekly[12] or fortnightly and they make circular routes. Shipping line systems can cross the complete world or be limited to a certain geographical area, depending on each carrier's capacities and the necessities of the clients.

[11] The shipping market is divided, based on the type of transport, into three categories/sectors: liner shipping, bulk shipping and specialized shipping (Stopfrd, 2009).
[12] A weekly liner service employs ships equal to the number of weeks a ship requires to complete a single circular route.

3.2 The major shipping trade routes

The trade routes in the containership market are divided into three categories (Isalos, 2024).

- There are routes between Asia and Europe.
- Trans-Pacific routes, those that cross the Pacific Ocean and describe flows from Asia to North America, as well as,
- Trans-Atlantic routes cross the Atlantic Ocean and describe flows from Europe to North America.

The top trade routes with their trade volume for 2021, are depicted in the map below and mainly refer to:

- Asia - North America (Trans-Pacific): 21.9 million TEUs shipped.
- Asia - Mediterranean - North Europe: 15.3 million TEUs shipped.
- Far East - Indian Subcontinent (ISC): 12,3 million TEUs shipped.
- North Europe - Mediterranean - Asia: 8.5 million TEUs shipped.
- Asia - Mediterranean: 7.91 million TEUs shipped.
- North America - Asia: 7.3 million TEUs shipped.
- North Europe - North America (Trans-Atlantic): 6.5 million TEUs shipped.
- North America - North Europe: 4.1 million TEUs shipped.

Figure 4. The world shipping trade routes with trade volume. World Shipping Council (2021).

The difference in volume between each trade route can also be highlighted in the map below, which is a print screen of the interactive map showing container trading in live mode. The busiest trade routes are highlighted with yellow.

Figure 5. Print screen of an interactive map depicting the container trading routes (Shipmap, 2024).

The drivers that push the growing of container trade are the states of the Far East, and China in particular. "*Given that China is home to 70% of the world's top ports, it's no surprise that Asia leads the major commercial routes*[13]. *This fact only serves to highlight the country's significance in international trade and logistics. China has experienced significant growth, which has shifted the market in its favor*[14]*, and it is now the world's largest supplier*" (LianVisman, 2023).

Since the Far East states dominate container exports and imports, Asia's trade routes have developed into significant ones. The world's second most important trade route is the Far East – Europe route. This progress has had a major impact on Europe. In particular, the transshipment process, as well as the development of feeder traffic maritime transport networks, is experiencing particularly significant advance, so that to be able to assist on the entrances of vessels loaded with European Union imports from the East.

On the above shipping routes, various kinds of container ships are used to facilitate maritime transport. The container ships that are used are selected based on:

- the restrictions of the ports,
- the situation of the sea,
- the availability of the vessels and
- the shipping schedules of the carriers.

For mega container ships, due to their size, there are few ports that have the conditions and facilities to receive them, especially due to the restriction of draughts and shore cranes that can have the necessary height and reach to load and unload the ships. Large vessels are also limited in relationship of the routes that select, as they are exposed to bad meteorological conditions. The route that concentrates the largest number of mega container ships is between Asia and northern Europe via the Suez Canal, but also from Asia to Mediterranean

[13] Asia is primarily the starting point for commodities, with China, South Korea and Japan being the main exporters. On the other hand, the West, especially the USA and the countries of the European Union, are the top importers, those who drive a significant part of the demand for container shipping.
[14] Historically, the U.S. imported two loaded containers from Asia for every one loaded container shipped to Asia. Over the last year, the 2 to 1 imbalance has grown to 3 to 1, generating millions of vacant containers that must be transported backwards to Asia to meet its export demand. The Asia - Europe trade is also similarly imbalanced at 2 loaded containers moving from Asia to Europe for every 1 moving back.

Europe, Persian Gulf and India, East and West Coast of the USA. Mega container ships over 395m in length cover only Asia-Northern Europe traffic, due to transport volumes and they tend not to cross the Pacific, for example, because of severe storms. "*Medium-sized container ships sometimes lose hundreds of containers in the Pacific, that's why ultra-large ships come close to the shore, in order to avoid big waves. It's a question of stability*" (Karamperidis[15], 2022).

3.3 *Factors affecting line shipping*

Various factors affect line shipping. First, fuel costs significantly affect ships' operating costs and freight rates.

Also, technological innovations and developments in port infrastructure improve efficiency and reduce liner shipping costs (Isalos, 2024). "*The industry is moving towards a digitised data-driven world, with the challenge of finding the right long-term technologies and connecting them to ships at sea in an efficient way. Industries across the spectrum are coming to terms with the fundamental changes that technological advances in areas such as Artificial Intelligence (AI), Robotics, Automation, Smart Ships, Autonomous Ships, will have the opportunities they promote*" (UNCTAD, 2019).

An important element affecting shipping is also the regulatory framework for maritime decarbonization. the International Maritime Organization (IMO) implemented in 2018, an "*initial climate change strategy according to which international shipping must reduce greenhouse gas emissions by at least 50% by 2050*" (IMO, 2019). Thus, the IMO identifies four (4) main pillars for reducing emissions as follows (Angelopoulos et al. 2020):

- Energy efficiency,
- Energy sources,
- Low carbon fuels and
- New technologies.

[15] Stavros Karamperidis is the head of the Maritime Transport Research Group at the University of Plymouth.

In addition to the above, geopolitical developments and various other local crises can radically change the global map of sea flows. It is a fact that the shipping business has been hurt by several geopolitical hurdles.

The trade clash between the US and China is now apparent. Trade cannot remain unaffected by broader geopolitical developments, as conflicts spill over directly or indirectly into commodity flows. Increasing protectionism, linked to geopolitical changes, could contribute negatively to international trade and affect the shipping industry.

Also, Suez Crisis is another event that significantly affected liner shipping. It was a military and political confrontation between Egypt and a coalition of countries, including Britain, France, and Israel, in 1956. The crisis was triggered by Egypt's decision to nationalize the Suez Canal, a critical shipping canal connecting the Mediterranean Sea to the Red Sea and the Indian Ocean. The nationalization of Suez was seen as a threat to the interests of Western powers, as it cut off the flow of cargoes (Middle East to Europe). Overall, the economic impact of Suez crisis highlights the vital position of maritime transport in global trade and how vital it is in maintaining stable and safe shipping routes.

The Panama Crisis generally refers to the political and military conflict between the US and Panama, in the 1980s. The origins of the crisis can be traced back to the signing of the Panama Canal Treaty in 1977, which set a timetable for transferring control of the canal from the United States to Panama in late 1999. During Panama Crisis, when the Panama Canal was disrupted, alternative shipping routes were used to transport goods between the Atlantic and Pacific Oceans. It is understood that straits are inherently valuable for defensive and offensive military operations. By changing their geography, being owned by a power, and attracting attention to their territory, channels introduce a new power advantage and can trigger the use of force as well as be used to increase the use of force.

The Russian-Ukrainian conflict has had a considerable effect on the global freight activity, leading to the disruption of traditional trade routes and increased use of alternative routes. As tensions between the two countries have risen, worries about the security of vessels transiting the region increase, leading to ships being diverted to safer waters.

The ongoing Houthi attacks in the Red Sea exacerbate the situation as ships avoid Suez and circumnavigate Africa's Cape of Good Hope unloading and loading at ports in western Europe and north-west Africa (Tsamopoulos, 2024), causing financial and time burdens.

In addition, the grounding of the "Evergiven" in the Suez Canal in March 2021 had a great impact. The 20,388 TEUs Ever Given literally stuck in the Suez Canal, delaying a major artery of international trade. The ship remained trapped in the channel until March 29, when multiple rescue teams managed to detach it. At the same time, hundreds of ships had formed "queues", while others were changing routes, resulting in several additional travel days.

Moreover, the recent accident in the port of Baltimore, where the cargo ship Dali, with volume of 9,971 TEUs, packed up into Baltimore's Key Bridge in March 2024[16], impacted the maritime trade. As Muntean et al. (2024) mention "*the bridge's collapse also has strangled the regional infrastructure. The wreckage of the bridge has clogged the port, a major shipping channel for the sugar and automotive industries. In addition, the Key Bridge was a critical thoroughfare, with 30,000 commuters relying on it every day*".

Considering the presence of sea suffocation points around the world, such as Panama Canal, Suez Canal and Strait of Malacca, most of the trade flows around the world are served through of demanding Sea Lines of Communication (SLOCs), we can assume that there are a variety of factors that can negatively affect liner shipping and require foresight and capable risk management processes.

3.4 Global shipping alliances

3.4.1 The concept

Highly competitive markets require container shipping to offer high-quality services at a meager cost. Each shipping company wants and aims to be the largest in size and to have such ships in its fleet available to fully satisfy the demand of the highly competitive market. In order to achieve the above, shipping companies merge, acquire, and have horizontal or vertical consolidation. Through these corporate events, companies strengthen their fleet and financial figures with the possibility of further investment in constructing larger ships. In addition, vertical integration (cooperation between the shipping company and the terminal

[16] The images went around the world. The video is destined to go viral as the images are spectacular. The news received a "hot list" treatment in the general media as soon as the morning shows opened on 26th of March 2024. Baltimore's Francis Scott Key Bridge, a four-lane bridge, 2.6 km long and 350 m high, was incredibly pulverized in a few fragments of time like a straw fetus, without resistance, when one of its pillars was hit by the container ship Dali at around 1:35 a.m. on the night of March 25 to 26.

or the transport companies between them) that helps in the smooth operation of the ship is enhanced, if any. The above consolidations/agreements led to an increase in the capacity offered by large container ships.

In accordance with (Sarmmah & Munroe, 2024), "*A shipping alliance, often referred to as an ocean alliance, is a group of ocean carriers that create a cooperative agreement together. This agreement covers several trade routes through collaboration among its members on a global scale. These groups of carriers commit to vessel-sharing agreements to help cover as much of the shipping market as possible. This means they gain access to vessels owned by other carriers. Often, carriers also agree to move containers on behalf of one another*".

Global alliances or strategic alliances, as they are called, are collaboration agreements to a worldwide degree among liner shipping firms. These agreements, which emerged in the mid-1990s (particularly towards the end of 1995), involve maritime transporters working on the main worldwide trade routes, predominantly on the East-West trade roads (Asia-Europe, Asia-US, and US-Europe), which account for the principal portion of containerized freight flows. Strategic alliances were created and promoted by carriers operating in Asia, as opposed to consortia, which had a primarily regional goal and were controlled by European transporters between the 60s and 80s (Lu et al., 2006).

3.4.2 Major global shipping alliances

The 3 Major global shipping alliances for 2024 are as below:

Alliance	Members (Shipping Companies)
2M[17]	MSC & Maersk[18]
Ocean Alliance[19]	CMA-CGM, Cosco Group, OOCL and Evergreen

[17] "*The 2M Alliance was formed in 2015 between Maersk and Mediterranean Shipping Co (MSC). The cooperation covered the Asia-Europe, trans-Pacific and trans-Atlantic trade routes. The HMM also joined 2M in 2017 for a three-year partnership, but later teamed up with THE Alliance instead*" (Sarmmah & Munroe, 2024).

[18] Maersk will be leaving THE Alliance in 2025 and will form the new alliance Gemini Cooperation (Sarmmah & Munroe, 2024).

[19] "*The Ocean Alliance was launched in 2017 for an initial period of five years between COSCO Shipping, OOCL, CMA CGM, and Evergreen. In 2019, the companies confirmed an extension of the alliance to ten years (until 2027). In February, 2024, the alliance announced a further five year extension, starting from 2027. The Ocean Alliance includes 330 container ships and an estimated carrying capacity of 3.8m TEUs. Ocean*

THE Alliance[20]	Hapag Lloyd[21], NYK, Yang Ming, MOL, K-Line, HMM

Table 3.The three Major global shipping alliances for 2024.

Based on Alphaliner's (2022) statistics, the 3 major alliances collectively account for about 99% on route Asia (Far East) - Europe and about 89% on route Asia (Far East) – N. America, as shown in the graphs below.

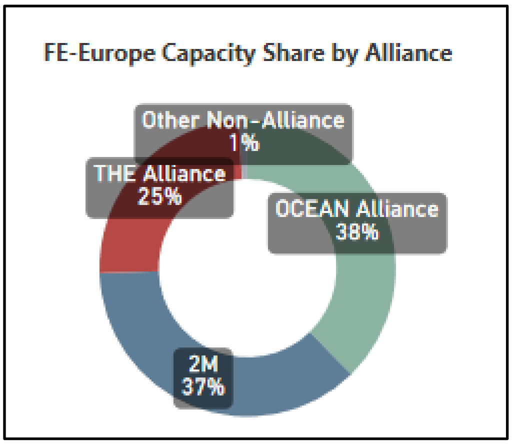
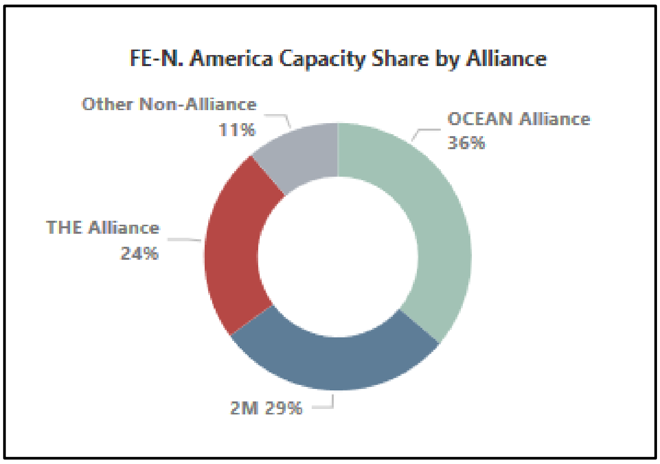


Figure 6. Percentage of service from Alliances on the route Asia (Far East) – Europe (Alphaliner, 2022).



Alliance offers 38 different services including 19 transpacific services, 11 services between Asia and Europe (and the Mediterranean), and 4 services between Asia and the Middle East. " (Sarmmah & Munroe, 2024).

[20] "*The Alliance was launched in 2017, THE Alliance combines 3.5 million TEUs. That's approximately 25% of the global container capacity. On top of that, THE Alliance has also revealed that it will deploy a fleet of 249 ships. They will connect 76 ports throughout Asia, North Europe, the Mediterranean, North America, Canada, Mexico, Central America, the Indian Subcontinent, and the Middle East. In 2019, they optimized port-pair connections to accommodate customers' needs for greater reliability and stability in service quality. In April 2020, HMM from South Korea joined THE Alliance and increased its total capacity by 519,000 TEUs. Thus, THE Alliance's global market share went from 25% to 30%*" (Sarmmah & Munroe, 2024).

[21] Hapag Lloyd will be leaving THE Alliance in 2025 and will form the new alliance Gemini Cooperation (Sarmmah & Munroe, 2024).

Figure 7. Percentage of service from Alliances on the route Asia (Far East) – N. America (Alphaliner, 2022).

Alliance members persist to battle on prices, whilst operating effectiveness and gains from volume utilization help preserve the low rates in terms of freight. By uniting services and founding alliances, shippers have reinforced their negotiating power against ports. It is important to note that large-scale shipbuilding and alliances in liner shipping have complicated the interaction between liner companies and ports and produced new dynamics whereby shipping companies have more clout and influence.

Although shipping systems appear to have profited by the increased efficacy brought about by alliance consolidation and reorganization, ports have not reaped the same rewards at the same rate. Due to alliance decisions, these tendencies intensified competition across container terminals. The standards they establish have to do with the available capacity, the selection of call ports, and the logistics network configurations. These factors can decide a container terminal's future (UNCTAD, 2018).

3.4.3 Impact of shipping alliances and benefits

The majority of shipping alliances operate largely in the same manner. The primary areas of information exchange and communication between corporations include scheduling, problem-solving, assigning vessels, and stowage plans. What sets alliances apart from other kinds of partnerships is that they do not include common pricing, marketing, sales, or asset ownership. They talk candidly about regulating engine problems, environmental concerns, fuel kinds, and operational efficiency. Each shipping alliance includes specific pay, carrier participation, and capacity planning. Carriers enter into a variety of arrangements[22] with one another in addition to shipping alliances.

The best method for shipping companies to cut these variable costs is to use common resources, such as networks, port facilities, and ships, along particular routes. It's a major factor in the formation of vessel-sharing and shipping alliances.

[22] "*A Slot Charter Agreement (SCA) is a contract between two partners/shipping lines who buy and sell a specified number of slots for a certain period of time, in order to widen their coverage*" (SAP, 2021).
"*Simply put, a Vessel Sharing Agreement is a contract or deal signed between partners of an alliance to run a liner service along specific routes. The space for each partner may vary from port to port, and depends on the individual input per company*" (Sarmmah & Munroe, 2024).

An ocean alliance's natural effect on carriers is another significant aspect; it allows them to purchase mega ships that they wouldn't otherwise be capable to afford. This enables shipping companies to have an impact on the world economy in addition to growing their business. Shipping lines also came to the realization that, particularly in the wake of the cargo ship disasters, they could not cover every route on their own. If they did this, they would have to leave certain ships unattended for weeks while tying up their ships on a particular route. And the whole shipping industry would be impacted by this. Forming agreements with other shipping companies allows big shipping lines to allocate their resources better. Smaller lines can also benefit from expanded service coverage without having to expand the size of their fleet. In the end, shipping alliances offer additional choices and may lower delivery expenses.

4. Maritime transport infrastructure

4.1 Ports

Historically, ports have been the hub of commercial activity. They have served as locations for loading and unloading cargo, tying together the hinterlands and maritime transit for various service providers, businesses, and trade. Additionally, they are seen as catalysts for regional and even national economic growth through jobs, salaries, rent, profits, and taxes (Meersman et al., 2009).

In any country where goods are transported using containers, the overall infrastructure related to their supply and receipt by carriers includes (Farthing, 1993):

- Ports and container terminals[23],
- domestic journeys carried out by lorry, rail, and/or interoperable transport, and
- appropriate legislation.

The ports with the highest service in TEUs for 2020 are depicted in the table below. In this list, we can observe the Piraeus harbor, which is in 26th place and the fourth European port in a row, after Rotterdam, Antwerp, and Hamburg. It is also impressive that there are 7 ports

[23] Regarding ports and container terminals, it is estimated that more than 200 countries have appropriate infrastructure that allows container ships to dock (World Population Review, 2024)

in China in the top ten. This list highlights the liner shipping industry's genuine global reach as well as the value of the port network in enabling the prompt and effective transfer of cargo and ships. China boasts numerous ports that are in the top fifty container ports worldwide, making it the greatest exporter of containerized products in the world.

	Port	**Volume 2021 (Million TEU)**
1	Shanghai, China	43.5
2	Singapore	36.6
3	Ningbo-Zhoushan, China	28.72
4	Shenzhen, China	26.55
5	Guangzhou Harbor, China	23.19
6	Busan, South Korea	22.00
7	Qingdao, China	21.59
8	Hong Kong, S.A.R, China	18.35
9	Tianjin, China	17.95
10	Rotterdam, The Netherlands	14.35
11	Jebel Ali, Dubai, United Arab Emirates	13.5
12	Port Klang, Malaysia	13.24
13	Antwerp, Belgium	12.04
14	Xiamen, China	11.41
15	Kaohsiung, Taiwan, China	9.62
16	Los Angeles, U.S.A	9.85
17	Hamburg, Germany	9.2
18	Tanjung Pelepas, Malaysia	8.7
19	Dalian, China	8.34
20	Laem Chabang, Thailand	7.55
21	Long Beach, U.S.A.	8.11
22	Tanjung Priok, Jakarta, Indonesia	7.82
23	New York-New Jersey, U.S.A.	7.59
24	Colombo, Sri Lanka	7.34
25	Ho Chi Minh City, Vietnam	7.20
26	Piraeus, Greece	5.44

Table 4. Ports with the highest volume of TEUs for 2020 (World Shipping Council, 2022).

4.2 Port Terminals

A large container ship, upon entering the fleet of a shipping company and/or shipowner, begins to be part of an organized service for the transfer of containers between a port terminal of origin and another of destination, fulfilling a defeat that crosses seas, oceans, canals and straits and that can have intermediate calls in different ports. This type of vessel, and especially the mega container ships, due to their size and the volume of containers they transport, require port terminals appropriate for their operation, artificial and/or narrow channels for its passage, and cargo transfer points for the handling of their cargo. All these elements are commonly referred to as maritime transport infrastructures, highlighting that among them are port terminals, which are multifunctional areas in which, among other activities, loading/unloading of goods from shipd, deposit, storaging and inspection of goods are carried out, formalizing the transfer between the modes of maritime and land transport.

Port terminals comprise an area of water and land in which constructions such as breakwaters, access channels, docks, births, piers, etc. constitute the port infrastructure. Works such as ships, buildings, etc., fixed and mobile apparatus, such as gantry cranes, vehicles, etc., elements that are considered port superstructure, are observed. The structure of the port terminal constitutes the link between the maritime transport infrastructure and the land transport infrastructure.

4.3 Containers Terminal

Beškovnik & Twrdy (2010) state that "*a container terminal can be defined as a set of facilities that allows containers to be transported on time, correctly and safely between various ways of transport*". A container terminal is the primary hub of the supply chain network, and consequently, all operations associated with the transportation of goods and containers must be coordinated and optimized, particularly for the large container vessels.

A container terminal serves as a location where containers are transferred between different modes of transportation. This process may include moving containers between ships and land vehicles such as trains and trucks, classifying the terminal as a maritime container terminal. Conversely, the transfer could occur between land vehicles, usually trains and trucks, thereby designating the terminal as an internal container terminal.

The cargo of a single ship unloaded at a container terminal is distributed to numerous trucks, barges, and trains for its onward transportation. Containers can be stored in inland and maritime terminals, both filled and empty. Full containers are temporarily kept before their next transport. Empty containers are usually saved in storage facilities for longer until they need to be reused. The containers for their storage are stacked, and the resulting structures are called container stacks. Container terminals are constantly evolving facilities[24] (Lewandowski, 2016).

Intermodal transportation is a recent development that emphasizes increased coordination, cooperation, and integration of the many parts of the transportation system. The aim of intermodality is to move cargo in an unceasing flow from the origin to the end point in the quickest and most economical manner possible, and port container terminals are now crucial to global trade. It is therefore acknowledged that the design and operation of a container port are becoming more and more complicated and that this complexity increases when the terminal is required to accommodate mega container ships. Comprehensive investigations that consider these qualities are necessary for every requirement involving the creation of a terminal (Angeloudis & Bell, 2011). Its design and development are the result of a multidisciplinary effort that includes experts in operations research, economics, and information technology.

In order to keep pace with global container volume growth, container terminals need to build new berths, expand equipment for loading and unloading processing, or improve their operating efficiency. At the same time, container terminals face challenges in providing better services so that the required turnaround time of a vessel is reduced. Thus, increasing operational efficiency at container terminals is one of the most crucial challenges (Qingcheng et al., 2011).

[24] Over the past 25 years, ownership of container ports has seen major changes due to growing awareness of their profitability through concessions to private operators. Despite several attempts to enter the market, only a small number of businesses—aside from liner shipping companies—have been successful (Theys et al., 2010). The increase in market share of privately controlled terminals is largely due to the divestment of public terminals.

4.4 Characteristics of ports and terminals

So, the maritime infrastructures intended for the operation of mega container ships have the following characteristics (James et al., 1997):

- Dimensions to operate vessels with certain length, beam and draught.
- Depth and manoeuvring radius.
- Auxiliary equipment.
- Operational efficiency.
- Logistical requirements.
- Protective works.
- Connection with the Hinterland[25].

On the basis of the above characteristics, the structures should be specially designed to operate large container ships and the volume of containers that they transport, in an efficient and economically profitable way, linked to other structures that allow a significant continuous flow of containers.

The main challenge of large infrastructures and superstructures for large container ships is to continuously adapt to the evolution of this type of large ship, or to anticipate such developments by considering the time required to work on these structures and the implications of capital investment in equipment and infrastructure and superstructure works.

The time and capital required for the execution of the project to expand a structure for large container ships becomes more relevant when the physical space to grow is limited or the hydrographic conditions are not suitable to increase the ease of passage and/or access, due to the need to carry out complementary works or have to face extensions to the original project.

At present, urban growth surrounding many port terminals makes it difficult for them to expand their infrastructure to have more physical space to operate with large volumes of containers (Munim & Schramm, 2018). Urban development also imposes restrictions on land communication routes with the terminal due to the density of vehicle traffic, which limits the continuous flow of cargo to and from the terminal.

[25] Hinderland is considered "*the land behind the coast or the banks of a river, or an area of a country that is far away from cities*" (Cambridge, 2024).

Projects for the expansion of port terminal infrastructure and land transport that links them with logistics centers in densely populated areas face in order to be viable, in addition to the solution to technical aspects of construction, compliance with the regulations which are in place to protect the environment, political agreements and attention to social situations, among other aspects. The evolution in the size of huge container ships is driving an upsurge in the size of the maritime transport infrastructure, which can be seen in the reforms carried out by large ports, for example, the port of Rotterdam (MARPRO, 2024).

The graph below shows the container capacity at ports worldwide over the last 22 years. It is obvious that there is an increasing trend every year, which seems to be continuous in the future.

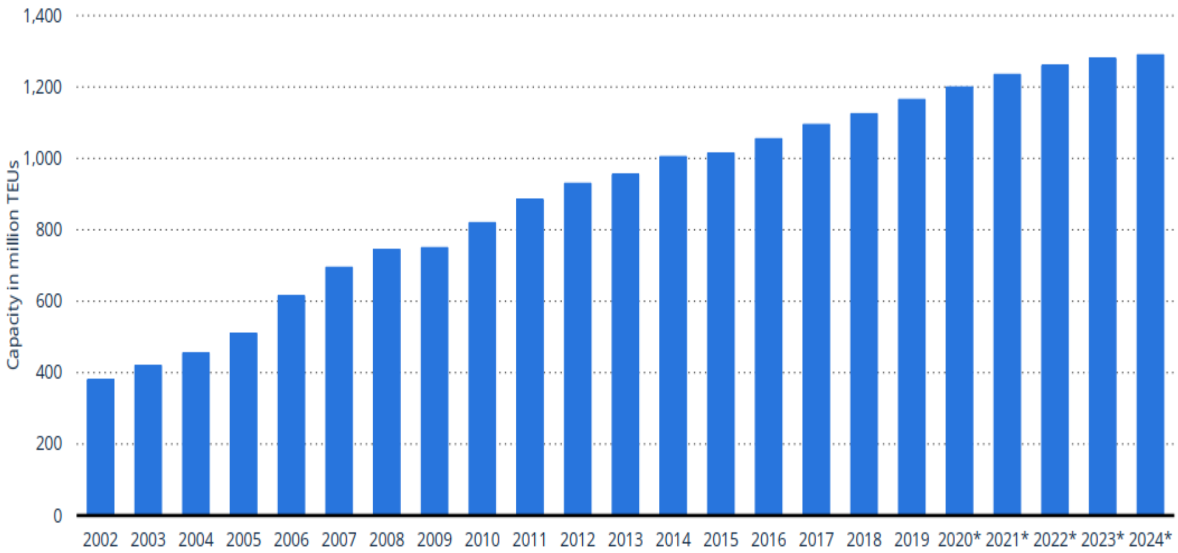


Figure 8. Container capacity at ports worldwide 2002-2024 (in million TEUs) (Statista, 2021).

4.5 Selection of ports and Terminals

When choosing a port, the primary criteria for a container carrier's selection are as follows:

- available hinterland networks,
- affordable cots, and
- customer access.

Apart from these norms, line firms also highly prioritize frequently disregarded elements including port portfolio, environmental concerns, and connection. The criteria for port selection and terminal choice differ, with the latter primarily considering:

- pace of processing,
- managing expenses and,
- credibility.

"*The selection decision is different per container carrier, per transaction and per port type, implying that a 'one size fits all' approach is not appropriate*" (Wiegmans et al., 2008). "*There are two main factors shipping companies consider when they decide to serve a port*:

- *The potential for attracting cargo (related to port throughput), and*
- *The port's operational performance*" (Monteiro, 2014).

Ports can enhance their control over the latter aspect, which is contingent upon the industrial and service strength of their hinterland. Both port owners and terminal operators are under burden to increase their port's productivity under this situation. This necessitates a constant assessment of the current state of affairs in conjunction with an endeavor to pinpoint and execute possible enhancements. Competition influences are also presumed, such as:

- Geographical location. The variations in distance between the port of departure and possible ports of destination, as well as the distance from the current trade route, are significant factors influencing the cost to the clients. Therefore, it goes without saying that a port's geographic position will have a significant influence on any customer's decision.
- Infrastructure. The effectiveness of a terminal depends on and is influenced by some main parameters. These are the dimensions of the platforms, the quantity of cranes, the natural depth, the number of other machines, the computer system, the number of personnel, etc.
- Pricing policy. The main cases of pricing policy followed by a port are divided into 2 categories: in the first the so-called economic criteria are used and in the second the so-called political criteria. In the first case, factors such as the elasticity of demand for services and production costs are taken into account. It states that similar tariffs apply in ports within the same nation and vary in ports outside of it. The case of the political criteria is based on the logic of pricing services below cost so that tariffs are likely to be lower than those of competitors in order to attract the largest proportion of customers.

From the above, it is understood that in order for a port to be selected as an investment by a private individual or as a stop on an itinerary, the existence of an interest or necessity and the consent of the carriers are required.

4.6 Key performance Indicators

Bigger and bigger ships are being built. The strongest ships of today are capable of carrying up to 24,000 TEU. The goal of this rapid development is to lower operational expenses because it is more profitable to transport more containers per trip. Conversely, this tendency, as already has been highlighted, puts terminals under pressure to operate well because shipping lines have to adhere to schedules in order to satisfy their clients. Remarriage expenses have the potential to reduce earnings, and when making up for lost time, more fuel is needed to destroy the remainder. Being late will probably have worse effects since mega-ships take longer to dock and make it more difficult to find berth windows, which will force the already delayed vessel to arrive much later than expected.

Efficient utilization of docks is crucial for enhancing the productivity of container terminals. The quay allocation problem in a terminal refers to the viable assignment of quays for ships at berth, aiming to minimize the total duration between ship arrival and departure from ports. Ship waiting time for docking and ship handling time are key indicators of a container terminal's efficiency. Decreasing these durations individually contributes to improving terminal productivity. Therefore, efficient allocation of docks of incoming ships at berth is an effective way to manage container terminals (Arabshahi et al., 2010).

Increasing productivity per berth[26] and, eventually, port terminal operations[27] is another tactic to deal with the emergence of mega ships and the declining timetable trustworthiness. The average quantity of containers a crane moves in an 60 minutes period while a ship is

[26] Berth productivity is a notion that dates back many millennia. Berth productivity can be defined as the amount of goods transported via a specific berth in a specific amount of time. This metric can be used to evaluate the general effectiveness of container terminals and ports. The British created the notion of "berth productivity" in the 1700s in order to gauge and maximize the speed at which ships were loaded and emptied at ports. (Buzinkay, 2022).

[27] Several methods have been used over time to gauge the productivity of container ports. The most popular method involves measuring operational key performance indicators (KPIs) to determine productivity at each of the port's functional elements. For instance, productivity at the berth is measured in TEUs per meter, productivity at the crane is measured in TEUs per crane, and productivity at the terminal area is measured in TEUs per terminal unit area. (Monteiro, 2014).

berthed is known as: "berth productivity". A high berth productivity indicates the number of containers that are moved per hour by a single crane. It is unclear how many workers have been employed, how many cranes have been in use, or what other factors—such as available space and RTGs—have been involved. Nevertheless, a terminal's ability to manage a ship while it is berthed is a crucial performance metric. It is an essential performance metric at the port, along with berthing capacity, storage capacity, loading/unloading equipment, floor area, and the number of gate lanes. This metric assesses efficiency.

Moreover, the productivity of a port or terminal is usually measured by calculating the container movements that a container terminal is able to carry out per ship and per hour, on all ship sizes. Looking at the area of productivity in ports, someone is able to notice the dominance of China's harbors related to the rest ports of the world, as shown in the map below.

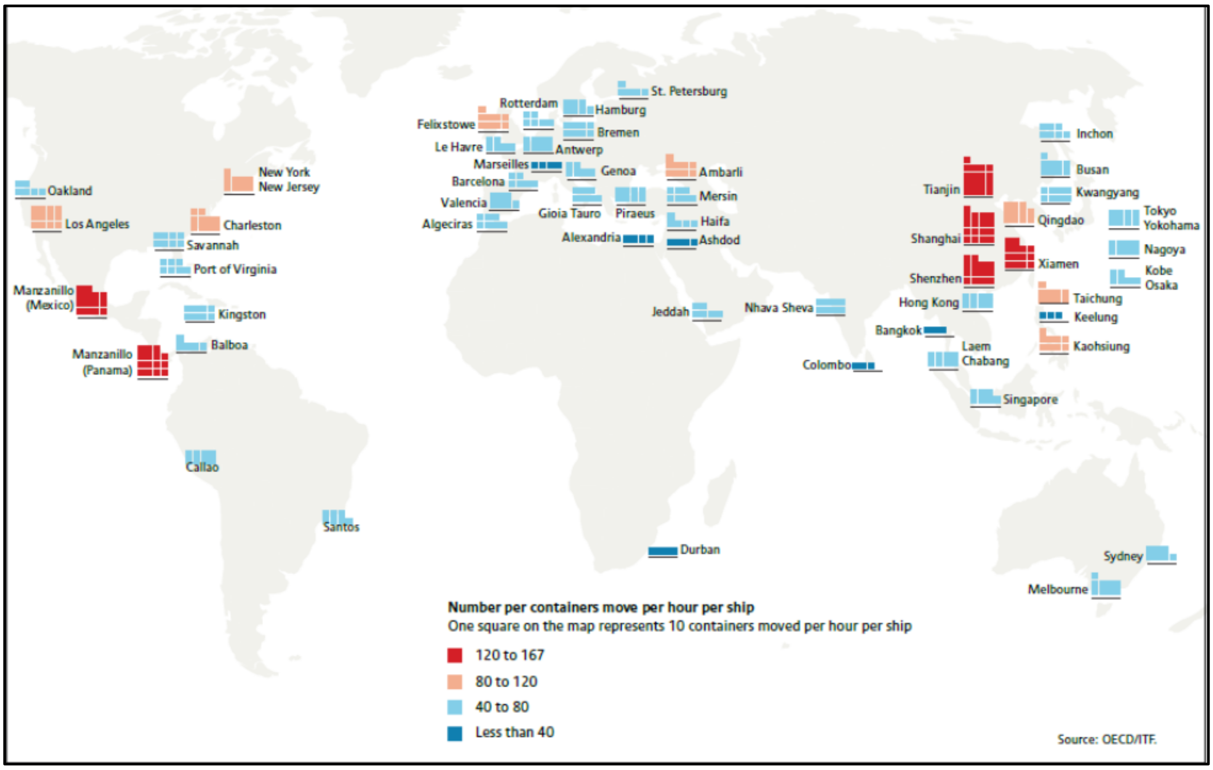


Figure 9. Berth productivity in main ports, in 2014 (OECD, 2015).

Of all the usual service performance criteria, "turnaround time" -that is, the average time a ship spends in a terminal- is the most significant. The majority of terminals view the time spent loading and unloading containers from quay cranes (QCs) as a crucial component of the terminal completion time of the ship. A number of cranes in a typical container port serve a number of ships tied to the dock, loading and unloading cargo (Ng & Mak, 2006). In addition, Shangyao, et al. (2009) argue that good short-term scheduling of vessel itineraries along with proper container shipping planning are very important factors for shipping businesses.

Companies' investment strategy might change in terms of their geographic orientation due to business cycles and shifting economic geography. This establishes a pattern that illustrates the emergence of commercial geography in the business container terminal, bringing concerns about the sameness or disparity between terminal location, the procedures that lead to these terminals' growth, and the relationships they uphold as central hubs in the worldwide distribution network.

In (2007) Medda and Carbonaro, studying container traffic in the Mediterranean basin, reported that: "*The introduction of the largest vessels has created the need for shipping companies to look at ports from different operational points of view, such as the physical characteristics of the ports, such as draught, length and area available for containers, logistics systems, and their distance from the main sea route from the Suez Canal to Gibraltar*". Some ports have developed differently than others, and their unique features have been discovered by the combination of these factors working in tandem with shipping corporations' strategy. A container port's capacity to absorb goods and offer shipping companies excellent service is what essentially drives the development in traffic through this channel. Ports that manage to provide these will attract calls from shipping companies, thus increasing their traffic volume.

5. Mega container ships

5.1 Statistics

As mentioned in the 2nd chapter, there are 202 mega container ships (already built or ordered to be built), with capacity above 18,000 TEUs. The graphic below shows these mega container ships by year of delivery. We can notice that everything started after 2013 and since then there is an annual κατασκευή of 10 to 29 such ships. Moreover, we can notice that the last 2 years maritime industry insists on the construction of numerous container ships with capacity of 12,500 to 15,199 TEUs and the last 7 years no container ships with a capacity of 7,500 to 9,999 were constructed.

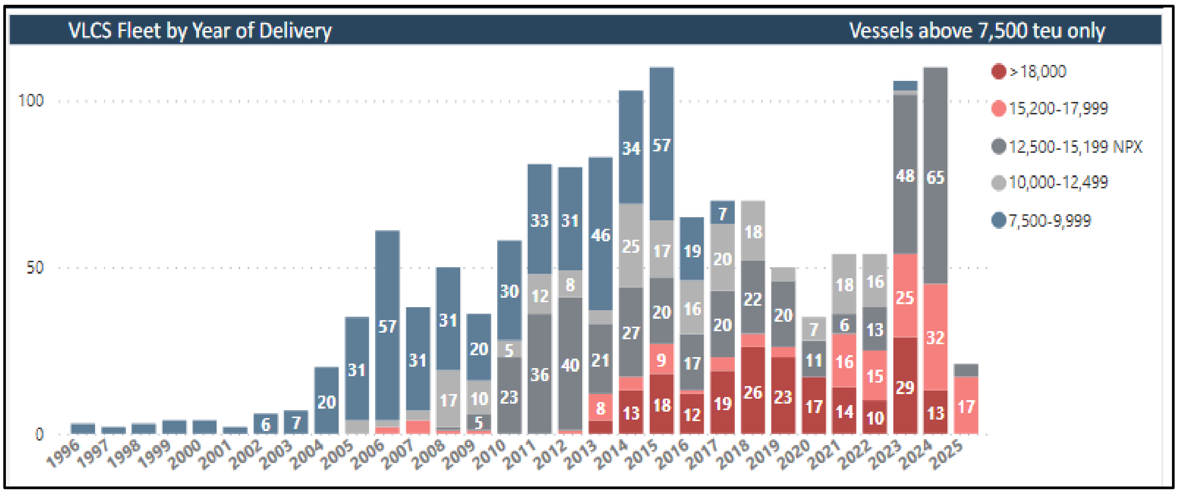


Figure 10. Container fleet by year of delivery (Alphaliner, 2022).

In regard to each maritime carrier, the table below depicts that MSC has the most mega container ships, 36 vessels, with APM-Maersk in the second place with 31 vessels.

Main Carriers - Breakdown of units operated by TEU size range

Carrier	18,000-24,000	15,200-17,999	12,500-15,199	10,000-12,499	7,500-9,999	5,100-7,499	4,000-5,099	3,000-3,999	2,000-2,999	1,500-1,999	1,000-1,499	500-999	100-499	Total
MSC	36	6	61	22	125	56	76	38	99	46	58	32		655
APM-Maersk	31	19	14	32	96	107	125	72	145	48	34	9		732
CMA CGM Group	12	27	25	48	56	49	60	38	67	52	69	62	4	569
COSCO Group	28		47	17	60	37	115	9	31	54	53	23		474
Hapag-Lloyd	6		34	16	49	28	39	22	33	10	5	8		250
ONE	6		29	15	40	34	37	2	29	6	10			208
Evergreen	15		20	18	30	29	6	1	35	44	6	1		205
HMM	12	8	10	8	4	11	15		1	7	1			77
Yang Ming			25	5	9	15	6		10	20	1			91
Zim				3	7	10	36	5	19	6	24	1		111
Wan Hai Lines						17	22	10	34	38	23	1		145
PIL				4		7	10	19	6	13	10	14	1	84
KMTC					1	5	7	1	13	19	15	3	5	69
X-Press Feeders							4		17	21	19	37		98
IRISL Group			4			9		2	10		4	3	1	33
SITC									21	23	33	20		97
UniFeeder						1	5	2	6	20	32	27		93
Zhonggu Logistics							3	2	14	12	13	38	18	100
Sinokor							5		8	13	27	18	5	76
TS Lines						3	5		5	18	19	4		54
Top 20 Total	146	60	269	188	477	418	576	223	603	470	456	301	34	4221

Table 5. Container ships by TEU size range ad by owner carrier (Alphaliner, 2022).

The table below depicts the assigned container ships by capacity to each trade route. We can notice that the 146 mega container ships that existed in 2022 were assigned at the Far East

(FE) – Europe trade route and the other 4 vessels were assigned at the Middle East (ME) - Indian Subcontinent (ISC) trade route. The biggest container ships are mostly located in the far East-Europe trade lane, for two main reasons in addition to the arguments presented on page 21. On the one hand, because more exportable cargo is transported and it is one of the longest trade routes translated into nautical miles, and on the other hand, because following this route, the ships can travel close to the shore, avoiding big waves and the extreme conditions when crossing the Pacific or the Atlantic Ocean.

Global Capacity Deployment Breakdown by Trade (by Vessel count)

Trade area	100-999	1,000-1,999	2,000-2,999	3,000-3,999	4,000-5,099	5,100-7,499	7,500-9,999	10,000-12,499	12,500-15,199	15,200-17,999	>18,000	Total Cellular Units	Non-Cellular	Total Liner Units	%
Eur-N.Am		4	15	17	61	32	30	11				170		170	3%
FE-N.Am	1	26	41	13	120	106	151	94	136	4		692	5	697	13%
FE-Eur	3	3	6	3	12	10	18	7	89	52	142	345	3	348	6%
ME/ISC	36	129	83	31	82	105	90	11	23	4	4	598	35	633	11%
Africa	16	68	90	60	108	39	31	2	5			419	23	442	8%
LatAm	38	102	104	52	54	56	115	64	14			599	34	633	11%
ANZ/Oceania	13	48	39	22	46	48	26					242	19	261	4%
Intra FE	551	685	281	31	108	17		1				1,674	320	1994	30%
Intra-Europe	217	240	69	23	21	15	6					591	49	640	11%
In repair yard (RY)	19	37	15	5	11	7	8		2			104		104	2%
Idle	10	15	7	2	2	3	3					42		42	1%
Other/Unas.	34	7	7	2								50	14	64	1%
Total	938	1,364	757	261	625	438	478	190	269	60	146	5,526	502	6028	100%

Table 6. Container ships by TEU assigned by trade route (Alphaliner, 2022).

The ten mega container ships with the greatest capacity in TEUs are the ones below (Nilson, 2024):

- MSC Irina Class with capacity of 24,346 TEUs is operated by MSC on the route Europe - East Asia.
- OOCL G Class (“Spain” and “Piraeus”) with capacity if 24,188 TEUs built for the Hong Kong-based Orient Overseas Container Line (OOCL) is operated on the route FE - Europe - FE.
- ONE I Class with capacity of 24,136 TEUs operated by the Singaporean shipping company ONE and is currently used on the route FE - Europe - FE.
- MSC Tessa Class with capacity of 24,116 TEUs is operated by MSC carrier on the route FE - Europe - FE.
- Evergreen A Class with a capacity of 24,004 TEUs was built by the China State Shipbuilding Corporation (CSSC) in 2022 and is operated by Evergreen,

- Evergreen A Class with a capacity of 23,992 TEUs was delivered in 2021 and is operated by Evergreen.
- HMM Algeciras Class with a capacity of 23,820 TEUs was built by Samsung Heavy Industries for Korean operator HMM and is deployed on the route between FE - Europe - FE.
- MSC Gülsün Class with a capacity of 23,756 TEUs is operated by MSC.
- Hapag Lloyd Berlin Express Class is built in 2023, with a capacity of 23,664 TEUs, belongs to the operator Hapag-Lloyd's fleet and is deployed on the route between FE - Europe - FE.
- COSCO Shipping Universe with a capacity of 21,237 TEUs, belongs to COSTCO carrier company. It is deployed on the route between FE - Europe - FE.

Shipbuilders continue working on creating even bigger container ships, and there is slight indication that this tendency will ever halt. Some experts predict that ships that can carry cargoes 50 percent larger than those of the Ever Given will sail the high seas by 2030. In other words, the container remains more popular than ever (Nagurney, 2021).

Based on the free edition of the website www.vesselfinder.com, a custom fleet was created with the above mentioned ten mega container ships, see table 7 below, and a query to track these vessels was developed[28].

[28] More or less the same capabilities were available in the free edition of the site www.marinetraffic.com

Vessel	Speed (kn)	Last Port	Current Location	Next Port
COSCO UNIVERSE Container Ship			China Coast	Singapore ETA: Jun 09, 09:15
EVER ACE Container Ship	0.0		Rotterdam Maasvlakte ATA: Jun 05, 11:44 UTC	Rotterdam
EVER ALOT Container Ship	0.0		Indian Coast	Tanjung Pelepas ETA: Jun 10, 22:00
HMM ALGECIRAS Container Ship			Indian Ocean	Singapore ETA: Jun 09, 15:00
HMM OSLO Container Ship			East Asia	Yantian ETA: Jun 09, 10:00
MSC GULSUN Container Ship	7.7		East Asia	Busan ETA: Jun 07, 08:50
MSC IRINA Container Ship	10.8		China Coast	Yantian ETA: Jun 07, 06:00
MSC MINA Container Ship			Indian Ocean	Singapore ETA: Jun 10, 10:00
MSC TESSA Container Ship			Indian Ocean	Singapore ETA: Jun 12, 08:00
OOCL SPAIN Container Ship	19.2		Baltic Sea	Wilhelmshaven ETA: Jun 09, 15:00

Table 7. Container ships by TEU assigned by trade route (Vesselfinder, 2024).

So, the map below (figure 10) was generated on 07 June 2024, depicting the positions of these vessels around Asia and around Europe, confirming the statistics developed by Alphaliner and projected above.

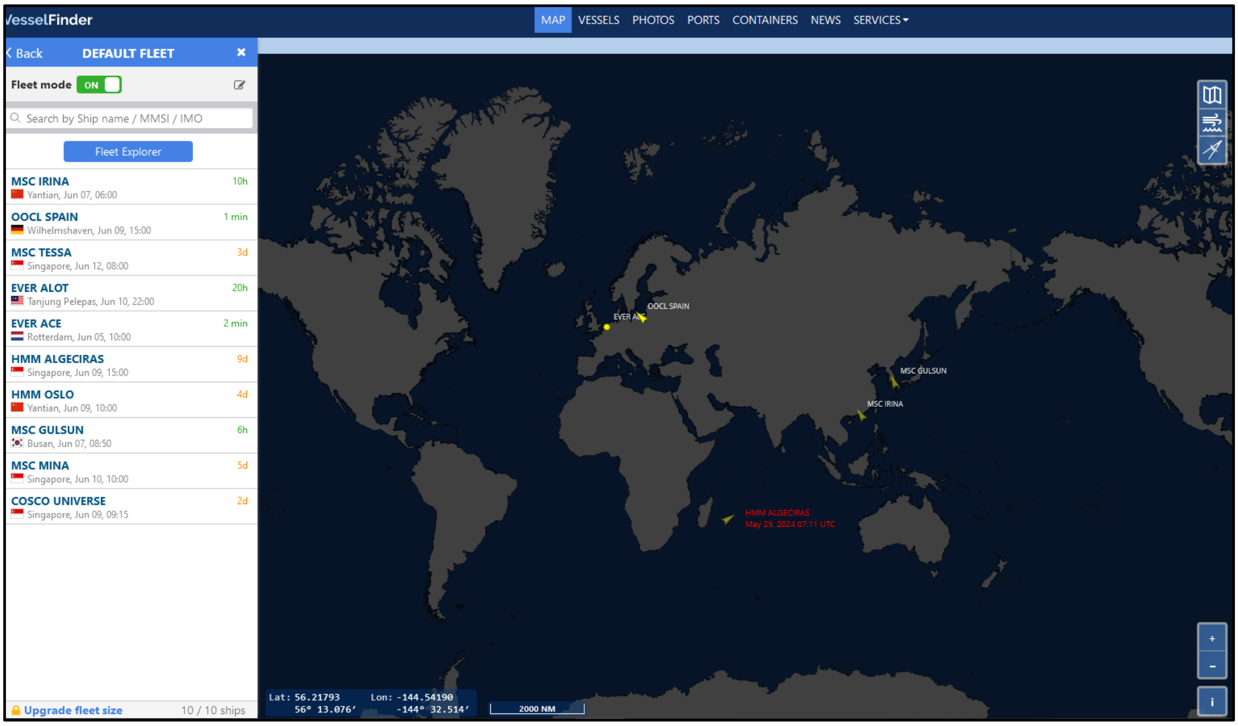


Figure 11. Mega container ships position on the map on the 7th June 2024 (Vesselfinder, 2022).

5.2 Challenges

The pursuit of economies of scale is a defining feature of container transportation (Merk, 2018). Since the creation and launch of the containership, the size of these vessels has been steadily growing in order to reduce the unit costs that come with larger ships and so generate cost savings. These savings were significant and impacted to lower maritime transport costs. But growth towards ever larger container ships is having a big impact on the port system (in terminals) and dynamics (in the supply chain) between ports and cities (hinterland).

The arrival of large ships in ports affects three main points. First, ports designed with lesser ship dimensions must be modified to accommodate larger ships. Second, bigger ships equate to larger sizes, which includes handling bigger loads of cargo each time a ship docks. Thus, peak and through effects of ports increases. Thirdly, the increase in ship size has furthered the partnership among shipping companies.

Ports must modify their equipment, infrastructure, maritime access, and logistics with the hinterland in order to prepare for big container ships. Larger ships require broader and deeper access points since they are wider and have a larger draft. Longer piers and larger maneuvering areas are required because larger ships are also longer. Ships require container cranes with a longer range since they are broader. Stronger docks are required since larger ships pull harder when moored. Most port modernization investments[29] usually take long periods of time and any form of upgrading a port is generally a costly investment that usually requires a political decision by the country concerned.

For a terminal to have the ability to meet the needs of modern container ships and be competitive in the market, it must follow technological developments and be equipped with modern container handling equipment. Also, the terminal must have sufficient ability to manage an adequate quantity of containers and accordingly be able to accept many large ships.

Another particularly important parameter for ports is to ensure the minimum possible percentage of damage that may occur during the various processes in which containers are involved in terminals. That is, ensuring that cargo will be delivered in excellent condition is a very important parameter that the administration of a port must take care of.

Seaports in the world, and particularly in developed countries, are constantly involved in a fierce competition to increase their market share and one of the strategies used to survive this competition is to increase the quality, efficiency and quantity of services, in addition to staying up to date in relation to being able to operate with the latest ship designs. Building new terminals, extending docks, and improving rail and road connecting ports and hinterland are a few possible implementations of this plan. Therefore, in order for the various ports to grow, they need to draw in different types of investors. Growth of the land container network has a direct impact on port growth as well. As a result, a number of onshore infrastructure projects are being implemented concurrently in the contemporary sections of major ports that handle containers, supporting the more effective transportation of containers by road or rail. Thus, major highways and railway networks are built, which communicate with the railway networks from one region of the world to another and serve

[29] The terminals to serve the mega container ships will have to occupy a greater number of Ship to Shore (STS) cranes per ship stay to maintain a fast transfer performance, this has led the terminals to invest in more equipment to move containers, STS cranes, Rubber Tyred gantry (RTG) cranes, truck tractors, implementation of systems that help the dispatch and reception of cargo, improvements in access, etc. All the times that allow improving performance, a more significant number of cranes operating the same warehouse, and a greater number of personnel carrying out the lashing and unlashing of containers, will help to compensate for the time spent by the ship at the dock since the more cargo transported, the longer the time it will take the terminal to load and unload.

the transport of containers. In addition, in order for terminals to provide a set of sophisticated services, the continuous development of logistics in general is required.

Modern container transport has seen a rapid increase in economies of scale as combined transport is increasingly used. Because of this, the state's assistance in building the necessary road and rail networks that connect to ports is necessary for the many businesses providing logistics services to operate satisfactorily (Boile et al., 2006).

The distances that commodities must travel increase along with trade. Longer wait times as ships travel the world as a result have put more burden on container terminals to operate further effectively. Upon appearance of mega container ships at a terminal, overcrowding is created in the port, at the various stages of handling TEUs, in the stowage area and in their movements to the mainland. There is also an increase in the stage of transhipment to feeders, trucks and trains. Ports must load and unload ships as quickly as possible (port productivity/berth productivity) in order to minimize the impact of larger ships. They must also increase the speed at which trucks and trains load and unload in order to lessen the amount of time that containers devote in the stowage area (container dwell time). To accomplish all this, more cranes[30] and stowage yard equipment, larger stowage space and flexible docking capacity may be needed (Merk, 2018).

Over time, the difficulties presented by the existing constraints on berth production have grown more intricate. Container terminals need to identify strategies to maximize output despite a variety of external factors, including shifting traffic patterns, global trade, and meteorological conditions like fog or stormy seas. The productivity of berths is significantly impacted by weather conditions. Container terminals have to consider the impact of weather on their operations, from daily variations in wind and wave patterns to seasonal unknowns like monsoons. Weather-related delays can cause expensive backlogs and impede the movement of goods and services. Both manual and computerized approaches are still used to measure berth productivity today. Modern technology has, however, made it possible for ports to measure and enhance berth productivity more successfully. Ports may now improve their systems for more efficiency thanks to cutting-edge technologies such as artificial intelligence (AI), automated systems, and Internet of Things (IoT) sensors. Moreover, port

[30] The largest ships can only be worked by a maximum of eight cranes at once. Therefore, increasing crane productivity is the only method to increase the total number of moves and therefore reduce the number of hours at berth (Buzinkay, 2022).

officials are now able to detect areas for improvement speedily because of the use of data analytics, which has given them better insights into their operations.

Increase in container size, in terms of TEUs capacity, is in a continuous evolution and existing market vessels are used on the Europe-FE trade route. They replaced the ships that had previously made this route and these in turn were placed on another shorter route. With the advent of other ships, even larger, the latter will once again be moved to another even shorter route and later removed from any other. Older ships will either be sold to smaller shipping companies or scrap shipyard. All other trade routes are impacted by the gradual transition on one trade route from older, smaller ships to newer, larger ones. No commerce route on the planet can escape this dynamic, and unless all ports choose not to make the required changes to their reception, which never occurs, its effects are usually hard to reverse.

The cost savings of larger ships depend largely on their loading rate. Between ships of different sizes, there is not much of a variation in utilization, which translates to the cost of reception per seat of a container. Grimstad and Neumann-Larsen (2013) state that the cost benefit of a larger ship (the next in tonnage) will be neutralized if the filling rate is lowered by only 3-5%. For example, an 18,000 TEUs vessel should have a filling rate of about 91%., to achieve cost savings, however, liner shipping companies face difficulties in achieving such high fill rates. (OEDC, 2015).

Large businesses and industries are becoming more prevalent in the maritime sector, at the sacrifice of growing ship sizes (Jankowski, 2003). This has had negative consequences for smaller companies, whose ships are no longer in particular demand, since they cannot build oversized ships. In future, maritime trade between Europe and Asia may belong entirely to the largest corporate alliances.

All ships, especially the larger ones, have increased difficulties in insurance, with high premiums due to increased risk exposure mainly for two reasons. First of all, the lack of suitable technology and rescue gear, which are necessary to remove a shipwreck of this size, will raise the expense of rescuing such a vessel in the event of an accident. Moreover, not many shipyards in the world have the sufficient specifications, because of the size, to repair these ships. Even more difficult, the journey to these shipyards if the site of the accident is far away. Insurance companies are unable to accurately define the costs of such scenarios.

Secondly, cargo safety, risk exposure for shippers also increases linearly depending on the tonnage of their ships. We can assume that the cost of total loss, in case of sinking, would double for a ship 20,000 TEUs, compared to a 10,000 TEUs.

As future prospects, the trends for the future of the container industry can be summarized in the following key points:

It is not expected that larger ship designs—which have the potential to carry between 27,000 and 30,000 TEU—will be constructed until there is sufficient demand for cargo on the few routes that these ships can now service (Hossain, 2023). In order to manage the higher bunker fuel prices that arise during market spikes and overcapacity, many shipping lines have opted to use slow steaming, which results in more ships operating at a slower speed. Currently, the average speed of a container ship is between 20 and 25 knots, and it is unlikely that this will increase due to energy consumption. Since the speed advantages of fast containerships would not be sufficient to offset the much higher transportation costs, this type of ship has not yet been put into operation.

Regarding the optimization of the ship network, transport companies have the ability to optimize the route of containers, choosing a smaller number of ports. This leads to cost reduction, maximization of profitability and efficiency. Companies will have to design an optimal network of ports and ships, which is not an easy task. Also as part of network optimization, many more ships can be used to transport containers. In this way, capacity is maximized and transport costs are minimized. In this context, the technology of new ships, which is based on more efficient use of fuels, should be added. The long-term goal is not to keep ships in ports too long, which leads to minimizing the cost of keeping ships in ports. Finally, the creation of strategic agreements: it is a standard practice of many companies, which are involved in the transport of cargoes. Typically, the creation of alliances can drive to even more resourceful usage of the fleet of ships, as well as more feasible optimization of the network.

In summary, the number of harbors that can accommodate larger containership generations is decreasing, which puts strain on port infrastructure and machinery. Because they offer economies of scale, maritime transport companies are heartened to engage the prime containerships available on their routes. However, in order to handle larger containerships, ports and interior transportation networks will need to make significant capital investments.

Consequently, commercial characteristics rather than technical limitations significantly more restrict the potential for economies of scale in container shipping (Rodrigue, 2024). As the shipping sector continues to face challenges from a dynamic environment, changes in technology, international trade and travel, and weather patterns, terminals must find ways to increase berth efficiency. Among the most crucial strategies that terminals may employ to boost berth efficiency include assigning staff specific tasks, leveraging state-of-the-art technology, and streamlining cargo handling protocols.

6. The case of Piraeus port

6.1 Geography and infrastructure of Piraeus port

Because ports in the Mediterranean region largely service their own local hinterlands and there is little competition amongst them, the region has not traditionally been seen as a homogenous range in the port industry. However, the importance of the Mediterranean in international maritime freight transit has increased due to globalization.

There are essentially two types of Mediterranean container ports (Lloyd, 2022).

- Gateway ports that connect to a rural area. For instance, the main use of Genoa and Barcelona has been as entry ports for domestic trade.
- Transhipment hubs: these are locations where lines move containers from east-west services to local feeder services.

In order for a port to be able to serve as a transhipment centre, it must have certain characteristics. Initially, the mooring positions of ships must have a great depth under the sea, for the approach of large ships. Then it should be close to the main sea routes. In addition, a container handling terminal equipped with the necessary systems for container transport procedures should be made available from the port. The port should also have sufficient land that can be used to transform the port into a transhipment centre. Finally, land transport should have easy access to this port (Steenken et al., 2004).

Greece's largest port, Piraeus, is one of the biggest in the Mediterranean and is essential to both the local and national economies as well as global trade. Greece's main seaport is located at the intersection of three continents: Europe, Africa, and Asia. It functions as a central point for ferry services connecting the islands to mainland Greece, an international hub for cruise ships, and a transit trade center for the broader Mediterranean region, accommodating vessels of all kinds and sizes. Its strategic location near the northern entrance of the Suez Canal makes it an ideal distribution hub in the Mediterranean for both Southern and Northern Europe. Moreover, it offers an advantageous transshipment location for goods with emerging production networks in the Balkans and Eastern Europe, potentially saving four to ten days of travel compared to alternative ports like Hamburg, Rotterdam, and Antwerp. Piraeus has evolved into a significant transshipment center for goods (Splash, 2022).

The following categories apply to the port of Piraeus's amenities:

- Port for passenger traffic.
- Port for commercial traffic. The Piraeus Port Authority (PPA) has 3 piers (I, II, III) as depicted on the figure below.
- Port of shipbuilding service.

Figure 12. Piraeus Port Authority (PPA) infrastructure (Pallis, 2024).

Comparatively speaking, the port of Piraeus enjoys an advantage over other ports in Europe (PPA, 2024):

- Due to its strategic location at the meeting point of Asia, Africa, and Europe, as well as its natural depths and infrastructure, it can accommodate even the biggest contemporary cargo ships.

- It also runs 365 days a year, 24 hours a day. The port's acquisition of catering services is linked to nearly all major Mediterranean ports, international norms govern security and operational standards, and the tariff scale is also determined by the volume of containers and transhipment cars.

- The affordable storage prices as well as the operating and safety requirements that comply with international regulations are, finally, significant advantages.

Piraeus Container Terminal (PCT) (Piers II and III) has high quality infrastructure and equipment and has the capacity to provide cutting-edge services for loading and unloading containers. Its infrastructure includes two piers with naturally deep drafts that can accommodate large vessels. The terminal can handle about 6.2 million TEUs annually and has state-of-the-art equipment including 30 quay cranes and 22 rail-mounted gantry RMG cranes (PCT, 2024) that can handle the largest container ships currently in use.

The Hellenic Railways Organization's new port terminal, whose primary railway line connects the freight port with the new Attica Multimodal Freight Terminal at the Thriasio Pedio in Elefsina, is operational next to the container terminal. Through a Rail Ramp that it owns, the Piraeus Container Terminal is connected to the European Rail Network. Because of its capabilities, which can accommodate up to 10 trains per day, it is able to provide dependable rail transit options between Piraeus Port, the Balkans and Central Europe. In addition, Piraeus Port has the ability to operate 4 mega container ships, up to 25,000 TEUs each, at the same time and has an expanded feeder network to facilitate the loading, unloading and dissemination of the cargo (Vamvakidis, 2021).

6.2 Privatisation and investment

Initially, the various carriers using the ports demand the optimal operation of the ports, mainly in operational matters related to the various time delays, but also in terms of infrastructure and facilities. Eliminating time delays in a port requires improving the delivery of port services as well as reforms in administrative and operational matters. In order for a port to meet the requirements of carriers, a special business plan is required, which will take care of all the above. Improving infrastructure also requires investment by private actors (Baird, 2002). Thus, in modern times, the need for privatization of container terminals has appeared. The components of a port concern that can be privatized the ownership of facilities, the production of services and the definition of the operating conditions of the port (Tzortzakis & Tzortzaki, 2002).

More specifically for the port of Piraeus, since 2010, COSCO has taken over the container piers II and III and since 2016 it has taken over the overall management of the port, through PCT S.A[31], a subsidiary company of COSCO[32]. Today, PCT S.A, a 100% subsidiary of COSCO, manages piers II and III. The PPA, of which now 67% is also owned by COSCO, manages the port logistics of Pier I. PCT Pier II and Pier III, are under concession for 35 years and Pier I is under Management agreement. One significant turning point in the privatization initiative was the agreement reached by the Greek State and COSCO for the latter to purchase a 67% share in the Piraeus Port Authority (PPA). The total value of the investment was estimated at €1.5 billion by the end of the concession in 2052 (PPA, 2016).

In addition, there is the signing of two important MoUs at PPA's facilities, between Shanghai International Port Group (SIPG) which manages 25.7% of the international trade volume in China, handling approximately 35 million containers annually with 2,700 vessel calls per month, which signed separate MoUs with COSCO and PPA. The first agreement concerns the cooperation of the PPA with the port of Shanghai, the movement and increase of containers from China to the EU, as well as the transfer of know-how and staff training to Greece. The second agreement between COSCO and SIPG concerns issues of international cooperation (HuffPost Greece, 2017).

The thinking behind the privatization of the port and its sale to a Chinese-owned company is based on the following statements of the then Greek Prime Minister, who had pointed out that Greece may serve as a pillar of China's economic, commercial, and cultural operations as well as the promotion of China on the European continent because of its geographic

[31] Founded in Greece, Piraeus Container port Single Member S.A. is one of the best container terminals in the Mediterranean and a fully owned subsidiary of COSCO SHIPPING Ports Limited, the third-ranked container port operator globally. PCT S.A.'s main activities include loading/unloading and storage services for imported and exported containers traveling through the Port of Piraeus, including cargoes that use Piraeus simply as a transit station (transshipment cargoes).
[32] COSCO paid €293.7 million. to acquire a 51% stake in August 2016, while it had deposited €88 million to acquire an additional 16%. euros from the year 2016 in an escrow account (escrow account) (Bellos, 2021).

location and, of course, its membership in the EU. "*Our goal is to serve as a bridge between the East and the West, and I think this arrangement will help you cut the renowned Silk Road even shorter. Transportation of goods from China to the Mediterranean and Central Europe can be accelerated and made more efficient through cooperation*". He also stated that "*the agreement with COSCO is mutually beneficial and paves the way for strengthening the strategic cooperation between Greece and China. Greece, he said, is in a strategic position and this coincides with the strategy of the Chinese Belt and Road Initiative (BRI). It [33]is important for Greece to become a gateway for the import of goods, a cultural gateway and seeks to import know-how and innovation, and promote maritime cooperation*" (News 24/7, 2016). In the same vein, the statements of the Chinese authorities, hoping that cooperation with Greece will transform the port of Piraeus into the largest container transhipment port in the Mediterranean.

Moreover, to the already mentioned, Greece, which was at the beginning of the financial crisis of 2008, needed investments and revenues and the exploitation of the port of Piraeus could bring them back. The reason why such a large project was awarded to a private and international company is the high cost of such an investment, which would be impossible for the Greek state to carry out.

The port of Piraeus after the Cooperation with COSCO, is now a strategic position for Europe-China trade. With Chinese involvement in Europe, Piraeus has the potential to serve as the conduit between the maritime Silk Road and the Eurasian supply zone, supplying current and upcoming industrial complexes. Greece is very important to China's economic interests because it is the easternmost point of Europe. The following are the main elements that support the port of Piraeus (Vamvakidis, 2021):

- The connection between the terminal operator and COSCO's main shipping line, which will increase its capacity to meet performance guarantees;
- The port of Piraeus's dominant position in the Greek and Mediterranean container market; and

[33] The belt Road Initiative, or else Modern Silk Road, is a strategic move by China with significant implications for strengthening its position as a maritime power, optimizing its international trade capabilities, developing geo-economic advantage, securing important supply chains and achieving energy security. As Follath (2016) describes, OBOR is a gigantic project, involving over 70 countries, that is, about half of humanity. Chinese firms have invested a total of $40 billion in countries along the route and created about 60,000 jobs. According to an OBOR assessment by consultancy PwC, over 66 countries are now part of the initiative (Wong et al., 2017).

COSCO's strong financial position, which enables it to absorb losses for up to several years if needed.

Being a significant maritime firm on the China-Europe route, COSCO is also a significant provider of services and clients for the Piraeus terminal. COSCO, CMA-CGM, OOCL, and Evergreen are members of the Ocean Alliance. Since these businesses focus their shipping on the Asia-Europe route, COSCO's partner ships also travel through Piraeus. Furthermore, the port of Piraeus provides "*facilities to the majority of major shipping companies, including Maersk Line, Mediterranean Shipping Company (MSC), French Transportation Company, China Shipping Container Lines, and Evergreen Line*" (Van der Putten, 2014).

The large liner shipping company COSCO, based in China, has focused on capitalizing on the port of Piraeus to expand its operations in the Mediterranean and Europe and to gain access to the wider region. This move will enable China to establish a direct trade route to Europe, making it easier to market its products in these regions. COSCO's investment in the port is expected to bring significant benefits and profits in the long term. By utilizing Piraeus as a hub, COSCO will be able to bypass congested Northern European ports like Rotterdam or Hamburg, reducing the transit time for cargo to reach Europe by almost a week. Additionally, as the owner of the port authority, COSCO will have influence over the port fees its own ships are required to pay (Saeedy, 2018).

COSCO's engrossment in the Piraeus port, initially through the contract for piers II and III and later through the acquisition of PPA shares, has resulted in significant improvements to the port. COSCO leverages experienced and well-trained human resources, new technologies such as digitalization, and the necessary equipment and facilities. The company has made various investments to promote the port in international markets, both as required by the contract and to enhance productivity and profits. An important partnership was formed between COSCO, Hewlett Packard, and Hellenic Railways (Tsantila, 2013) for importing products into Europe from the port of Piraeus and then transporting them via the railway network to Southeastern Europe.

The port of Piraeus has already been significantly upgraded, reaching 26th place in the world in 2020, according to Table 4. of this research. COSCO's management and China are pressuring the Greek government to launch the plan for the development of Pier IV[34], as with its assistance the port will acquire an annual capacity of 10 million containers (StarGr, 2019). The amount of this investment is estimated at 350 million euros (ypodomes, 2020). Additionally, the concession agreement's conclusion resulted in higher earnings for the Greek economy. The sales of state-owned shares, the yearly concession fee from the PPA, dividends on the company's profits, the income from taxes on the company's profits and employee remuneration, and social security contributions are their main sources of income.

In conclusion, Piraeus' strategic location at the intersection of three continents—Asia, Africa, and Europe—has helped to develop the port into a desirable investment destination. At the same time, after its upgrade, it can accommodate large cruise ships and a reliable system of transportation and transportation of vehicles to and from Piraeus is created, thus promoting the supply chain [35]management industry and the maritime transport industry. After the investments are completed, COSCO and the Greek government hope to build a contemporary port that can compete with other major European ports and serve as a center for freight transportation between Greece, the Mediterranean region, and the rest of Europe.

Of course, COSCO's entry into the port of Piraeus and the signing of the concession contract also brought turmoil to Greece. Strikes, demonstrations and protests played out daily for months. The workers argued that working conditions were exhausting, that the majority of them worked under contract and had to be available 24/7, 365 days a year. Labor unions supported a variety of demands regarding wages, employment, social security and arrears due to laid-off workers.

Municipal and other authorities have pointed out from time to time that the contract has negative effects either on the quality of life, the environment or working conditions. Mobilizations began raising issues of air pollution coming from specific projects with

[34] In July 2022, the revised PPA master plan was approved by the Port Planning and Development Committee, paving the way for the implementation of COSCO's projects in the port of Piraeus.
[35] In this context, the development of a "green" Business Park on a property of approximately 450 acres, in the Municipality of Fyli, has been planned and the provision of financial incentives totaling € 21 million. euros, to the freight forwarders established in the area of Eleonas/Votanikos, for their relocation to the new park of Fyli. In fact, according to the information, about 200 businesses have already agreed to relocate to the new business park. The property that has been selected to develop the Fyli Business Park is in a privileged position in terms of proximity to the urban fabric -Athens and Piraeus. Also, the businesses that will be transferred to the new park will have access to key networks: railway network, Athens-Lamia and Athens-Corinth National Road interchange with Attiki Odos, Port of Piraeus, Port of Elefsina, Port of Lavrio, as well as the Thriasio Logistic Park (Vegiazi, 2024).

COSCO, as well as issues related to heavy pollution, oil installations and the city's exits to the sea. Concerns were expressed that the contract leads to the reduction of the development prospects of the greater Piraeus area and works to the detriment of local communities as there has been an exacerbation of chronic burdens produced by the port. Among others, traffic problems, air pollutant emissions from ships and vehicles, sea pollution, noise pollution, light pollution and many others were also mentioned.

Aside from potential issues arising from the Greek government's agreement with COSCO, the benefits to date are deemed noteworthy: New jobs were created at the port of Piraeus, and combined transport was encouraged, strengthening the port's geostrategic importance and elevating it to a highly competitive center in Northern Europe. It evolved into a Global Transit Center as well.

6.3 Piraeus port statistics

In 2020 and despite the pandemic and the significant downturn in economic activity caused worldwide, container throughput at the Port of Piraeus fell close to 5 million TEUs from 5.16 million in 2019[36]. The situation would have been even better if there had been Pier IV, which the Chinese group had already asked to build and which is still awaited by the Greek government. In total, 4.7 million TEUs were transported from the two piers in 2021 (NewMoney, 2020) as shown in the graph below. In 2023, 4.58 million TEUs (Ports Europe, 2024) were transported from piers II and III PCT operated by PCT S.A. Adding the figures of the pier, controlled by PPA (COSCO is the main shareholder with 67%), with 600,000 containers, the total traffic in the six-month period exceeds 5 million TEUs. Based on these figures, the Piraeus container port overtakes Valencia. The port of Piraeus with continuous investments has managed to reach the fourth place in Europe (Banks, 2023)

[36] Data refer only to piers II and III, i.e. PCT and not to the entire PPA.

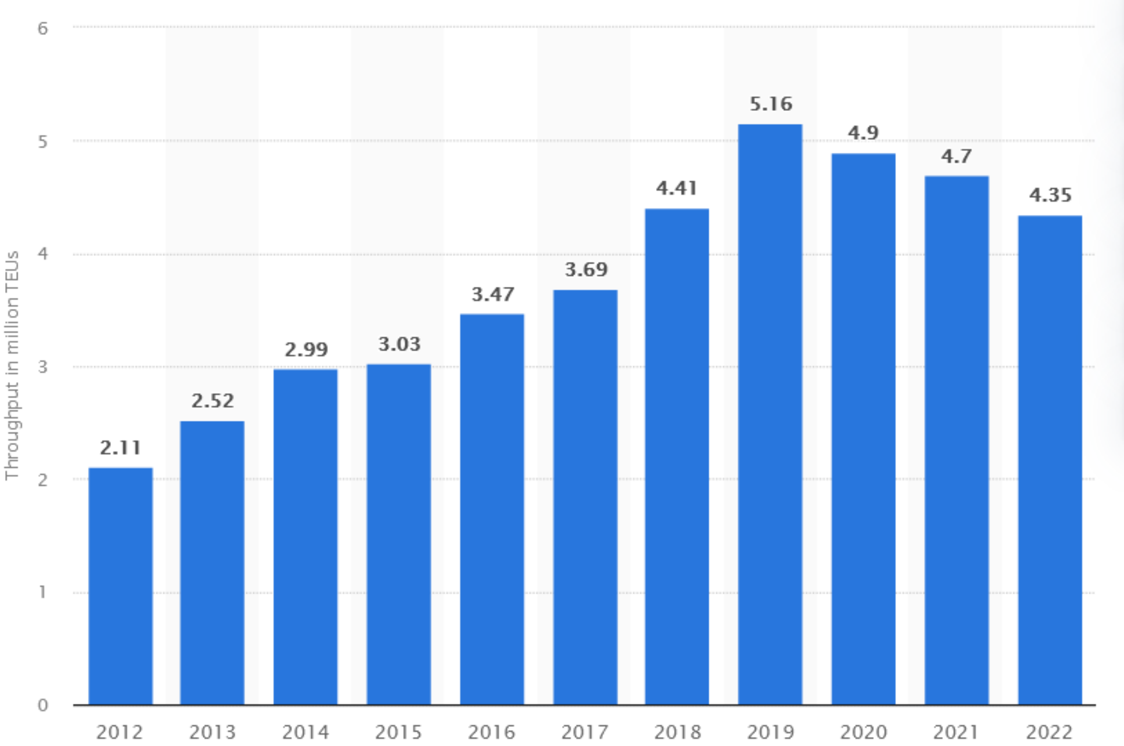


Figure 13. Volume of containers handled in the Port of Piraeus (Statista, 2023A).

Piraeus was the fifth port in Europe for 2022, in terms of total container service, as shown in the graph below, with a small difference behind Valencia Port, while in 2020 it was in fourth place according to Table 4. of this paper.

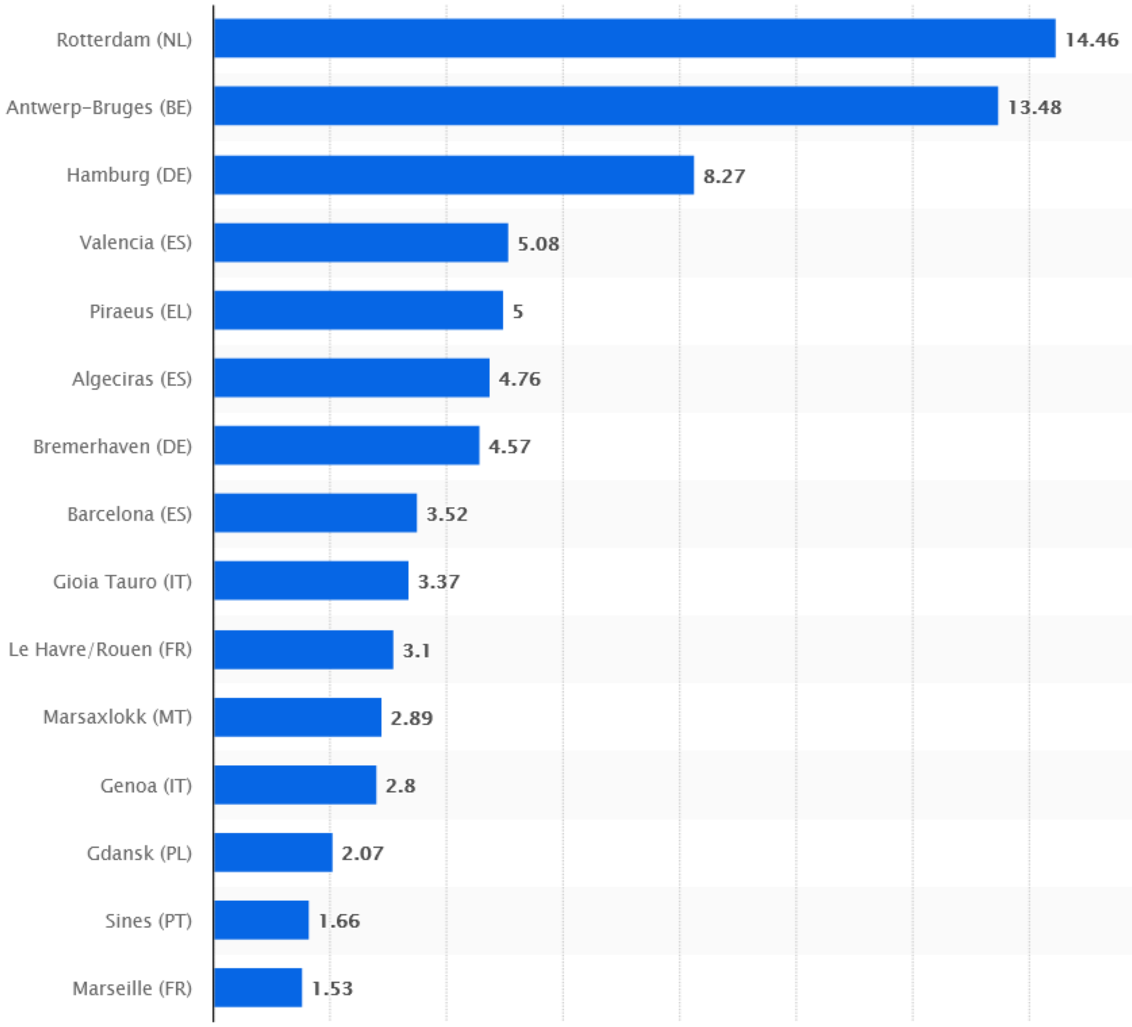


Figure 14. Largest container ports in the European Union (EU) in 2022 (Statista, 2023B).

The "OOCL Spain," one of the biggest mega boats in the world and the first of its kind to approach the station's facilities, arrived in Piraeus on April 17, 2023, for its inaugural voyage. This vessel will henceforth be a regular stop on its itinerary. The 84-day "OOCL Spain" itinerary makes port visits at 13 distinct locations from Southeast Asia and China to Northwest Europe. The main reasons for selecting Piraeus as an intermediate transport station are the excellent services that PCT offers in terms of ship and transit cargo turnaround times, the technological superiority of those services, and Piraeus's advantageous location as a major hub for maritime freight flows to and from Southeast Asia as well as many other regions of the world (NewMoney, 2023).

The huge container ship "OOCL Piraeus", which has a capacity of 24,188 TEUs, called the Port of Piraeus on July 10, 2023, as part of a special event. One of the most giant container ships in the world, "OOCL Piraeus" is said to have gotten its name in honor of the Greek container port's significant contribution to the global freight transport sector. Since June 2023, OOCL Piraeus" has been a part of OOCL's Europe-Asia route (OOCL, 2024), which connects South East Asia and North West Europe via 13 ports on an 84-day round trip. The following port rotation is followed by the ship: Shanghai, Xiamen, Nansha, Hong Kong, Yantian, and Cai Mep are the cities in China. - Singapore - Greece's Piraeus Germany's Hamburg and the Netherlands' Rotterdam - Belgium's Zeebrugge - Valencia, Spain - Piraeus - Abu Dhabi (UAE) - Singapore – Shanghai (Container-news, 2023). Following "OOCL Spain", "OOCL Piraeus" is the second mega container ship to call at Piraeus.

Regretfully, no publicly accessible AIS data could be found on any electronic platform on the web for the arrival of mega container ships at PCT; to research which other huge container ships had docked at the port, how often they arrived, what hours they were in service, etc.

The Piraeus port is currently the fourth largest multipurpose port in Europe and the largest in the Mediterranean. It has also become one of the container ports with the greatest rate of growth worldwide. Along with directly contributing over €1.4 billion to the local economy and increasing Greece's GDP by 0.8%, Piraeus has also generated over 3,000 direct and 10,000 indirect jobs (BusinessNews, 2023). At the 3rd Forum "Belt and Road for International Cooperation," China's Ambassador to Greece, Xiao Juncheng, also praised the cooperation between China and Greece and mentioned that the China-Europe Land-Sea Express line[37], which starts at the port of Piraeus and reduces transport times by at least 7 to 10 days, is a third important channel for trade between China and Europe. It reaches Central and Eastern European countries and supplements traditional sea routes[38] (Euro2day, 2023), highlighting the port's significant role even for mega container ships.

[37] One crucial route that connects land and sea is the China-Europe Land-Sea Express Line. It originates in the southern port of Piraeus, travels via Skopje in North Macedonia, Belgrade in Serbia, and Budapest in Hungary (China Pictorial, 2023).
[38] In 2022, a total of 181,000 TEUs were transported via this land-sea express line, an increase of 18.4% year-on-year (Euro2day, 2023).

7. Conclusions

Shipping has been a fundamental gear of trade and development since ancient times, and nowadays, sea transport is the most efficient, advantageous, and safe solution for transporting a large mass of cargo. Global container traffic has roughly doubled in the last 40 years, and the total cost of maritime transport nowadays is the lowest because large quantities are transported, reducing the individual cost of cargo.

Developments in ship construction have steered the production of innovative types of ships to convey transportation of any cargo in an economical way. In addition, liberalization in-laws on rules of trade has allowed firms to grow their businesses to inexperienced places and move their finished goods to any marketplace worldwide. The container will continue to be the main unit of cargo for unitized cargo. Moreover, technological developments have been the driving force behind further expanded vessel constructions, with the goal of progressing economies of scale and encountering the exact freight and trade course necessities.

Since the early 1960s, when the first container vessel (a modified tanker) was used, we have entered the fifth generation of container ships, reaching vessels that can carry a volume of over 24,000 TEUs. These ships (that have a capacity over 18,000 TEUs) are called mega container ships. The main characteristic of these ships is the Triple “E” (Economy of scale, Energy efficient and Environmentally improved).

The increase in demand for containerized transport and the interest in controlling the costs led to an increase in demand for larger vessel sizes. By using these increasingly large ships, shipping companies have taken advantage of these economies of scale, which have allowed for continuous reductions in costs per TEU transported. Studies show that vessels of up to 25,000 TEU keep producing economies of scale, with a regular volume utilization of 90%. Moreover, these new mega container ships have the ability to control better fuel consumption in relation to their speed. In addition, the emergence of revolutionary techniques does make it possible to build new oversized ships at relatively low prices. However, mega container ships have increased difficulties in insurance, with high premiums due to increased risk exposure mainly for two reasons. First of all, the lack of suitable technology and rescue gear, which are necessary to remove a shipwreck of this size, will raise the expense of rescuing such a vessel in the event of an accident. Moreover, not many shipyards in the world have the sufficient specifications, because of the size, to repair these ships. Even more difficult, the journey to these shipyards if the site of the accident is far away. Insurance companies are unable to accurately define the costs of such scenarios. Secondly, cargo safety, risk exposure for shippers also increases linearly depending on the tonnage of their ships.

The top two trade routes in terms of trade volume, due to China's dominant position concerning the exports, are FE-North America (Trans-Pacific) and FE-Mediterranean-Europe through the Suez Canal. These two trade routes serve the liner shipping market, but shipping companies deploy mega container ships only to the second one. More specifically, 146 mega container ships that existed in 2022 were assigned to the Far East (FE) – Europe trade route, and 4 vessels were assigned to the ME - ISC trade route. The biggest container ships are mostly located in the far East-Europe trade lane, because more exportable cargo is transported, it is one of the longest trade routes translated into nautical miles and ships travel close to the shore, avoiding big waves and the extreme conditions when crossing the Pacific or the Atlantic Ocean.

Mega container ships are affected by various factors such as fuel costs, the limitations in the ports in regard to the existing infrastructure, or the capacities to serve the logistic procedures through the reception, unloading, handling, and support of intermodal transport. Straits and channels in maritime routes, and access channels, manoeuvring basins and docking basins in ports present natural limits. Moreover, the IMO orders for reducing emissions act restrictive on these ships. In addition, various geopolitical incidents such as crises on the SLOCs (Suez, Panama crisis in the past), local wars (Ukraine), piracy (Houthi attacks), and accidents (Baltimore Bridge collapse and “Evergiven” grounding in the Suez Canal) limit the accessibility and the freedom of movement of mega container ships.

Shipping companies merge, acquire, and have horizontal or vertical consolidation to satisfy demand at any time by having a functional and appropriate fleet available. So, shipping alliances are created through cooperative agreements among companies, enabling access to various vessels. An ocean alliance's natural effect on carriers is another significant aspect; it allows them to purchase megaships that they might not otherwise be able to afford. This enables shipping companies to have an impact on the world economy in addition to growing their business. Forming agreements with other shipping companies allows big shipping lines to allocate their resources better.

Regarding the optimization of the ship network, transport companies have the ability to optimize the route of containers, choosing a smaller number of ports. This leads to cost reduction, maximization of profitability and efficiency. Companies will have to design an optimal network of ports and ships, which is not an easy task. Also as part of network optimization, many more ships can be used to transport containers. In this way, capacity is maximized and transport costs are minimized.

The 3 major alliances collectively account for about 99% of route FE – Europe. Carriers have improved their negotiation position with ports when it comes to port of calls and terminal port services by banding together and forming alliances. Ports have not benefited equally from alliance consolidation and reorganization, even though liner shipping networks appear to have benefited from enhanced efficiency. Due to alliance decisions, these tendencies intensified competition across container terminals. The standards they establish have to do with the available capacity, the selection of call ports, and the logistics network configurations. These factors have the power to decide a container terminal's future.

The mega container ships, due to their size and the volume of containers they transport, require port terminals appropriate for their operation, artificial and/or narrow channels for their passage, and cargo transfer points for the handling of their cargo. All these elements are commonly referred to as maritime transport infrastructures, highlighting that among them are port terminals, which are multifunctional areas in which, among other activities, the loading/unloading of goods from ships, deposit, storaging and inspection of goods are carried out, formalizing the transfer between the modes of maritime and land transport. Nowadays, the ports that can serve mega container ships are limited worldwide. Additionally, their geographic position will significantly influence any customer's decision to use a specific port as a stop in any route.

Container terminals, as the primary hubs of the supply chain network, deal with the movement of goods and containers and must be able to coordinate and optimize all the processes and have the capacity to apply intermodal transportation systems efficiently, particularly for the mega container vessels. The structures should be specially designed to operate large container ships, and the volume of containers that they transport, in an efficient and economically profitable way, should be linked to other structures that allow a significant continuous flow of containers. Moreover, efficient utilization of docks is crucial for enhancing the productivity of container terminals. The quay allocation problem in a terminal refers to the viable assignment of quays for ships at berth, aiming to minimize the total duration between ship arrival and departure from ports. Ship waiting time for docking and ship handling time are key indicators of a container terminal's efficiency. Decreasing these durations individually contributes to improving terminal productivity. Therefore, efficient allocation of docks of incoming ships at berth is an effective way to manage container terminals and increasing the productivity per berth.

The main challenge of large infrastructures and superstructures for large container ships is to continuously adapt to the evolution of this type of large ship or to anticipate such developments by considering the time required to work on these structures and the implications of capital investment in equipment and infrastructure and superstructure works. The time and capital required for the execution of the project to expand a structure for large container ships becomes more relevant when the physical space to grow is limited or the hydrographic conditions are not suitable to increase the ease of passage and/or access due to the need to carry out complementary works or have to face extensions to the original project.

Most of the ports and terminals are limited in their operation by the logistical development in the hinterland, which is slower than the progress of the port terminal due to the complexity of the problems to be solved. The ports and their corresponding container terminals should continue to be developed to achieve greater efficiency by adapting their facilities and equipment to the growth in size of the new ships, not foreseeing the development of works that would allow them to exceed the current limits currently set by nature and the urban development with which they interact.

Based on the Alphaliner statistics (page 37), we can notice that the maritime industry has insisted on the construction of numerous container ships with a capacity of 12,500 to 15,199 TEUs for the last two years, and no container ships with a capacity of 7,500 to 9,999 have been constructed for the last seven years. So, it is clear enough that the average volume has increased and that the number of mega container ships will continue to grow in the next few years.

Piraeus port has developed into a transshipment center for goods. Its geographic location near the northern entrance of the Suez Canal allows it to be part of the FE - Europe maritime shipping route. The political will to permit the development of Piraeus port and the investments that took place in the last decade through its privatization, turned Piraeus into a modern port, able to operate four mega container ships, up to 25,000 TEUs each, simultaneously. The logistic network connecting the port with the hinterland has also been upgraded, incorporating a railway terminal, facilitating the TEUs reaching the Central and Eastern European countries. In addition, there are plans to build another pier (number IV), in order to be able to acquire an annual capacity of 10 million TEUs. At the moment, Piraeus port competes with the biggest ports in Europe and has reached the 4th port in terms of annual container service in 2020. In 2023, Piraeus port welcomed two of the largest mega container ships in the world as part of their itinerary from Southeast Asia and China to Northwest Europe.

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