



**Master's Degree Programme
in Supply Chain Management**

**Slot coordination process applied for port congestion
confrontation and the contribution on multimodal transport
operations: A critical analysis.**

By Efstathia Rouchitsa

Supervisor: Stratos Papadimitriou

Co-supervisor: Theodoros Tsekeris

Piraeus, Greece, June 2024

Theses / Dissertations remain the intellectual property of students, but in the context of open access policy they grant to the HOU a non-exclusive license to use the right of reproduction, customisation, public lending, presentation to an audience and digital dissemination thereof internationally, in electronic form and by any means for teaching and research purposes, for no fee and throughout the duration of intellectual property rights. Free access to the full text for studying and reading does not in any way mean that the author/creator shall allocate his/her intellectual property rights, nor shall he/she allow the reproduction, republication, copy, storage, sale, commercial use, transmission, distribution, publication, execution, downloading, uploading, translating, modifying in any way, of any part or summary of the dissertation, without the explicit prior written consent of the author/creator. Creators retain all their moral and property rights.

*"This paper is dedicated to Thanos, my brother
Marianna, my sister in-law and my beloved nephews"*

Abstract

Ports' operational efficiency is the result of effective management policies that require cooperation among different sections of the public and private sectors. Ports constitute supply chain nodes, where considerable freight is borne to the final destination, augmenting local, regional, national, and international wealth levels. A combination of modalities operations is imported, mainly train and road networks, connecting maritime transportation with the hinterland. Congestion rises after economic, social, and geopolitical events and the sanitary restrictions imposed during the COVID-19 pandemic. Demand rises and falls, and route alterations cause inconvenience in maritime transportation and the global market. The queuing of vessels outside the ports and the increased waiting times affect global trade and prosperity, while multimodal transit, environment, labor conditions, and markets are vulnerable to significant implications. Sufficient capacity, robust automated equipment, human resources expertise, and effective collaboration lead to decent port performance. One step further, slot distribution is implemented to manage the movement of vessels towards ports and terminals. Slot coordination is implemented in ports of high importance for the international supply chain and other modes of transportation and information systems, exploiting its essential benefits. Utilizing data provided by AI tools and devices established onboard and at ports' operational centres, slots are applied to administer time and capacity efficiently. However, planning port operations according to slot allocation systems is sensitive to factors affecting global society. The shipping industry faces essential disruptions preventing vessels' routes and timelines from conforming to the slots. Since the smooth operation of the maritime is disturbed by unprojected incidents, immediate information flow is crucial to the competent departments. Interrelating with land modes is supported by high-technology innovations applied through all the functioning stages, contributing to operational optimization. Both road and train modalities present advantages and disadvantages in commodities distribution while constantly evolving simultaneously with maritime trade. The augmentation of the demand for goods is due to transportation demand. Inland and seaborne transportation are derived simultaneously, possessing their share in the global supply chain. On the one hand, high speed combined with a large volume of railways and on the other hand, truck flexibility constitute multimodal transportation options for commodities distribution worldwide. This paper eventually inserts the perspective of a multiple-slot coordination system implemented in multimodal transportation, updated continuously under changes happening in every mode.

Keywords

Slot allocation, port operations, coordination, multimodal transportation

Table of Contents

Abstract	iv
Table of Contents	vi
List of Figures	vi
List of Tables.....	viii
List of Abbreviations & Acronyms.....	ix
Chapter 1. Introduction.....	1
1.1 Background	1
1.2 Aims and Research Objectives	2
1.3 Importance of the Research.....	3
1.4 Dissertation Outline	3
Chapter 2. Port's Operations Management: Congestion issue	7
2.1 Port's operations significance for global trade	7
2.2 Congestion factors	9
2.3 Impacts of Congestion.....	19
2.4 Resolving congestion.....	24
Chapter 3. Slot coordination system.....	27
3.1 Description of slot coordination system	27
3.1.1 Slot Coordination in Air Traffic Management	27
3.1.2 Slot Coordination process	28
3.2 Slot coordination system in maritime transportation	31
3.2.1 Pros and cons: consequences analysis.....	35
3.2.2 Threats and unpredicted factors downgrading slot coordination's efficiency.....	40
Chapter 4: The effect of Slot port's coordination in multimodal transport operations	49
4.1 Multimodal transportation and the land modes' share in global trade	49
4.2 Dependence of multimodality on port's operations.	51
4.4 Potential system's extension	58
Bibliography	60

List of Figures

1. Display of an indicative terminal space distribution

2. Annual Average time at the anchorage (%)	8
3. Time spent at the anchorage in average per type of vessel	9
4. General configuration of port operations for container handling	10
5. Containerships' size evolution	12
6. Tankerships size evolution	13
7. Bulkcarriers' size evolution	14
8. Moneuvring display outside the Port of Rotterdam	19
9. Slot allocation process	28
10. Port call timetamps	31
11. Port Call Process	32
12. Port of Rotterdam	36
13. JIT Process	37
14. Vessel's position display	38
15. Sealand Express grounding close to Cape Town in 2003	40
16. What does the Polar Code mean for ship safety?	43
17. Recorded water levels at Gatun Lake	48

18. Impact of the four factors on the market share	51
19. Container Terminal display	52
20. Cargo handling equipment	53
21. Impact of a call of a 20000 TEU vessel on inland transport	53

List of Tables

1. Percentage classification of vessels that stay on the anchor at the Port of Rotterdam	8
2. SWOT Analysis for Slot allocation system	57

List of Abbreviations & Acronyms

ACT	Automated Container Terminals
AGVs	Automated Guided Vehicles
AI	Artificial Intelligence
AIS	Automatic Identification System
ATA	Actual Time of Arrival
dwt	dead weight tones
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
GHGs	Greenhouse Gases
GIA	Global Industry Alliance
IATA	International Airport Transport Association
ILO	International Labour Organization
IMO	International Maritime Organization
IoT	Internet of Things
JIT	Just-in-Time
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MGX-24	Megamax-24
MLC	Maritime Labour Convention
MMSI	Maritime Mobile Service Identity
PCS	Port Community System
PPP	Public-Private Partnership
RTA	Requested Time of Arrival
RTD	Requested Time of Departure
SC	Supply Chain
SCM	Supply Chain Management
SSIM	Standard Schedules Information Manual
TEN-T	Trans-European Transport Network
TEU	Twenty-foot Equivalent Unit
TOS	Terminal Operating System
TSMS	Time Slot Management System
ULCS	Ultra Large Containership

WAGS Worldwide Airport Slot Guidelines

Chapter 1. Introduction

1.1 Background

Surging product's demand has contributed to the increase in transporting operations and maritime trade since 2021. Social, environmental, and political issues have modified global maritime operations. Shipbuilding development concerning trade needs, environmental obligations, and route alterations due to the Russian invasion of Ukraine, especially for tanker shipping, characterize the current situation for global maritime trade. Significant ports where international trade is transmitted to the mainland or change shipping routes face congestion issues. The average waiting time for a ship to enter one of the twenty most essential ports in 2023 was approximately six days, significantly decreasing from sixty-one days for the corresponding period in 2021.¹ Still, waiting time should be eliminated, and port operations should be able to support trade's transition. Multimodal transport operations are based on ports' efficiency, let alone in cases where other transport modalities are established in port extension. Land transport modes are combined directly with maritime transport to transfer commodities to the mainland. Railway terminals and motorways are constructed or upgraded to make communication with port infrastructure efficient.

Therefore, port operations must support maritime trade effectively since they constitute transition hubs for multimodal transportation. Potential applications are examined, one of which has already been implemented in air transportation and airport organization. Slot coordination, implemented efficiently many decades into airports presenting congestion, consists of a system by which aircraft's estimated time of arrival (ETA) and estimated time of departure (ETD) are pre-signed among competent stakeholders. Airlines companies apply landing and take-off calculated hours, considering ground handling time. The right to land/take off at a specific time of the day is called "slot", and airlines must keep up with the agreed ones. If not, repercussions, such as charges, are imposed. Thus, aircraft landing and take off at a pre-scheduled time, eliminate waiting time. Slots requested individually or in total are estimated according to historical data. Maritime trade

¹ UNCTAD Handbook of Statistics 2023. (2023). Manuel de statistiques de la CNUCED/UNCTAD handbook of statistics/Handbook of international trade and development statistics - United Nations. <https://doi.org/10.18356/9789213585535>

is by nature vulnerable to parameters of uncertainty. Weather and socio-political continuous alterations significantly affect transportation. Scheduling ETA and ETD is constrained by variables that are difficult to forecast. The slot coordination system contributes to information exchange feasibility and route scheduling. Berth, loading/unloading time is defined, considering factors that may cause delays. Cargo handling demands good infrastructure exploitation. Consequently, port operations have to be concluded within a specific time period, and the parking area must be free for the next arriving vessel. Congestion issues do exist and need resolution.

1.2 Aims and Research Objectives

This research aims to provide a critical analysis of the advantages and disadvantages of slot implementation on ports and the effect of this implementation on multimodal transport operations. All congestion variables will be introduced and combined with potential solutions. In a broader context, this dissertation will critically analyze and distinguish the factors and constraints that a slot coordination system should be designed with. Simultaneously, the impact of slot systems on multimodal transport operations will be examined and assessed. Furthermore, this paper will move one step further by suggesting technology applications for port operations concerning sharing time-cycle information following digitalization needs. Indicatively, the dissertation will compile not exclusively the output of the “Global Environment Facility (GEF) - the United Nations Development Programme (UNDP) - IMO GloMEEP Project and members of the GIA, 2020: Just in Time Arrival Guide – Barriers and Potential Solutions” paper. This analysis is based on the deductive procedure and findings on purely quantitative data from online databases combined with exploiting the existing academic literature and shipping practitioners’ published knowledge.

Moreover, historical data drawn –if not published- by port authorities in collaboration with maritime monitoring application firms will be displayed to justify the reason for a slot coordination practice to be undertaken. This cross-sectional study of the existing knowledge and data analysis aims to determine the efficiency of the port slot coordination method. Given the abovementioned analysis, the research is essential to state that there is a notable correlation between congestion port issues and the connection with the mainland.

1.3 Importance of the Research

Spiking ships' volume, in combination with limited port capacities, require efficient port operations management. Waiting time and potential delays cause economic losses for the maritime industry. Multimodal transportation rises by renewing modes' fleets, constructing new highways/railways, or upgrading existing ones. Routing is vital for all types of transportation, let alone when combined operations occur. National and local economies are developing due to the infrastructure established to serve trade transportation. Routes change under the scope of cost minimization. Terminals are based in regions of geographical importance that are beneficial for investments. Under the scope of digitalization, port management should implement a slot coordination system to provide on-time information exchange regarding arrival, departure, and time on the berth. Keeping up with schedule, in combination with information provided to other means of transport, increases transportation's efficiency.

1.4 Dissertation Outline

The research for this paper has determined that the slot allocation system is an efficient method for organizing vessels' arrival, departure, and the meantime services. Congestion interacts with the port capacity, living conditions, market cycles, multimodal commerce operations, and climate change. Vessels' waiting outside the port burdens maritime trade that executes the majority of goods conveyance globally sustainably, even though new decarbonization goals have been set. Time spent on the anchorage provokes an increase in operational costs and depreciation of sensitive freight. Multimodality is affected directly since it is difficult to conform to the schedule. Berthing delays pass on to other modes of transportation acting within or adjacent to the port's establishments. Delays make the supply chain ineffective, limiting the market's growth, which depends on the timely distribution of goods. Local society bears the cost of environmental implications. Air quality downgrades the living level, causing severe health issues for habitants. Labor legislation compliance for shipping and port personnel is crucial because maritime activities present a decreasing trend in seafarers' occupation. The nautical profession has become less attractive than it was due to the nature of maritime operations. It is a further concern when congestion demands personnel to occupy time expansions and incur

additional working costs. The rest of seafarers is a significant part of regulatory provisions implemented worldwide.

Slot allocations have been effectively implemented for many decades in airline transportation and are now gaining ground in maritime and rail modalities. Ports, where a significant percentage of global trade is transferred to the final destination, use time slots to coordinate loading/unloading, transshipment, and port activities. The use of smart technology systems and devices, already established on vessels and ports, is revolutionizing the field. These systems calculate ships' coordinates and travel time towards the port of destination and berthing, and the following functions are planned. Shipping lines apply for time slots either individually or for a series of slots, having evaluated the data kept from the previous period. The efficiency of slot allocation is supported by the resilience of networks and databases, making it a demanding application that requires remastering data inputs, exporting outcomes, and saving historical data to be assessed for the next period.

However, maritime circulation is not without its challenges. It is vulnerable to factors that can disrupt the smoothness of supply chain operations. Environmental changes, sociopolitical issues, cyber threats, industry powers, and communication burdens all play a critical role in maintaining maritime trade normalcy. A characteristic example is the strategic cross point of the Panama Canal, which has been significantly impacted by climate change. Even with the use of slot allocation for ships' navigation through the canal, the corresponding authority was forced to decrease the number of available slots, leading to delays. The alternative routes remained comparatively ineffective, given the increase in time spent and expenditures.

The operational transport combination within the terminals' extent is mandatory and thoroughly interrelated with slot allocation. Rail modality services cargo distribution in the hinterland, exploiting high-speed means of conveying large quantities. Moreover, road mode reaches remote areas, contributing to transportation flexibility. Land modes' facilities inside or nearby ports function with timetables planned according to vessels' time of arrival and loading/unloading operations. The management of the available capacity achieves traffic avoidance. Space configuration is important for warehousing and vehicle circulation. Automated equipment is used for freight transshipment at the rail and road networks establishments.

Figure 1 displays an indicative configuration of automated container terminals (ACTs), where the seaborne transition is combined with a road connection.

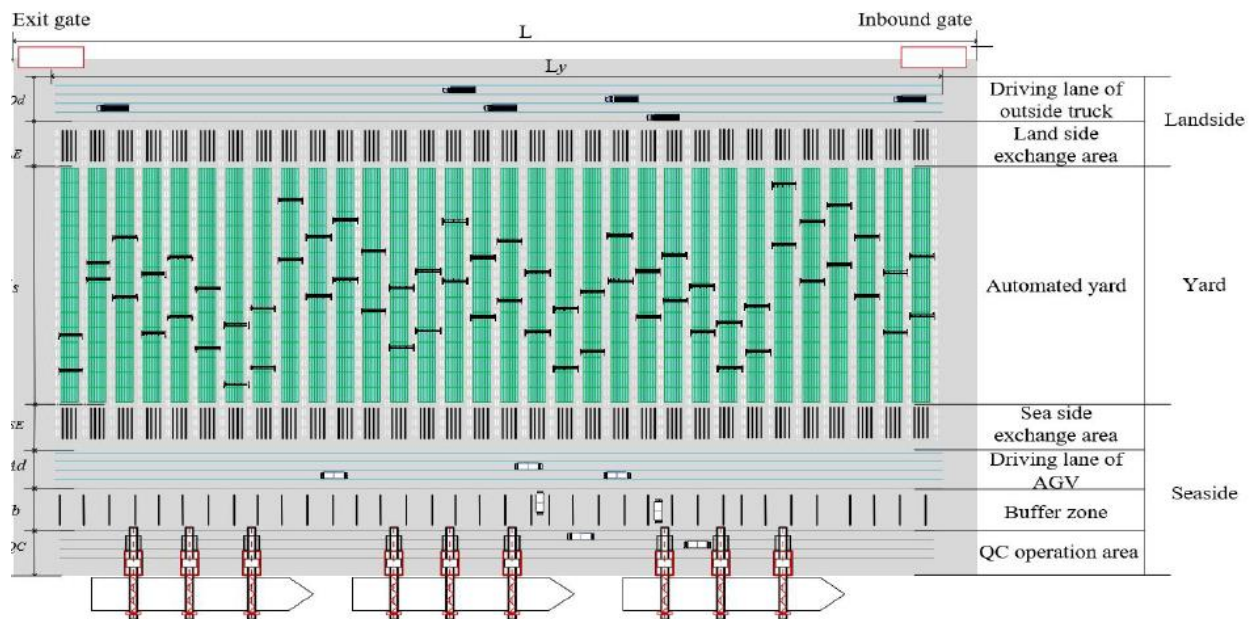


Figure 1: Indicative Terminal's space distribution: Source: Analysis and Design of Typical Automated Container Terminals Layout Considering Carbon Emissions article by Nanxi Wang, Daofang Chang, Xiaowei Shi, Jun Yuan and Yinping Gao, 24 May 2019

The above image shows the case in which three vessels are berthed and serviced by the port's handling equipment, while Automated Guided Vehicles (AGVs) simultaneously reach their destination point through the designated lane. Modernized equipment selects cargo to be loaded or drops off the containers taken by the ships. In the land-side exchange area, trucks are loaded/unloaded and start/finish their trip through the driving lane. The extent of each part is based on quantitative calculations for the optimization of multimodality's efficiency. With the flexibility provided, the multimodal operations should be performed within a specific timeframe. Slot allocation depends not only on the time of arrival but also on the time of departure for the previous vessel.

Having clarified the importance of facilities adequacy, slot distribution enables the productive usage of port handling equipment, yard, and route planning. Not all ports require slot application systems since slot application systems are recommended as a congestion confrontation strategy. Time slots utilize the already implemented smart technology on ships and ports activities. Shipping lines' estimation for time travel based on predictions gives, as a result, the estimated time of arrival, ETA that is. Depending on the port operations planning, the time of completion is calculated (ETC), and the estimation of departure time follows, provided that port operators have notified for the Requested Time of Completion (RTC). Eventually, Requested Time of Departure (RTD) is announced, given that shipping operators have submitted the Estimated Time of Departure (ETD).

Nevertheless, slot coordination will not eliminate the vessels' waiting times or gathering since, in many cases, they remain on the anchorage without port calls. Recording sea crossing time, holding inspections, preparation for port operations, maintenance, or commodity price level alterations are reasons that will preserve shipping backlog and parking at the ports' exterior sea area.

The implementation of a robust integrated slot system for terminal and multimodal transport operations can be examined in the future. Separated into segments for each modality, a common slot allocation system should be tested, which will adjust timestamps for the information provided on time without the intervention of different platforms and databases. Therefore, delays happen in seaborne transportation and affect the time of arrival, which will modify the time for the truck or train loading/unloading procedure. Just-In-Time (JIT) policy will maximize its performance, presenting essential impacts on the supply chain management (SCM), global market, and environmental policy.

Chapter 2. Port's Operations Management: Congestion issue

2.1 Port's operations significance for global trade

The maritime industry's share of the global trade is estimated approximately 90% (OECD), tremendously higher than the rest of the modes of transportation. Thus, it is essential to maintain operational smoothness in the supply chain worldwide. A significant part of the supply chain is port efficiency, which faces today's considerable challenges in serving the augmenting demand for goods. Ports constitute trading hubs, where commodities are transmitted to the mainland or another vessel to reach their final destination. One of the definitions for port operations efficiency is the performance of port operations and the optimization of the produced result under the constraints of the resources or, given the produced result the limitation of resources provided.²

Socio-political – economic disruptions, such as pandemic Covid-19 restrictions, the Russian invasion in Ukraine, and Houthi's attacks in the Red Sea against commercial vessels, result in alterations in oil prices, time of arrival, time of departure, duration of journey, route mapping among others and interject the effectiveness of global supply chain. Port management departments should face new risks and apply new methods to confront new circumstances.

Notably, during COVID-19 restrictions, erratic demand fluctuations were noted, especially for the containerized commodities, when finally, in 2021, demand stabilized at a high level. Thus, vessels' capacity is augmented and port congestion is maintained high. Moreover, socio-political events, such as the Russian invasion of Ukraine, conducted route modifications for tanker shipping, creating new trade relations among vendors and customers. Having been affected by the evolutions, the global supply chain has taken a new shape, requesting port management as a transition part to develop new strategies for operations efficiency. It is essential to mention that the waiting time of vessels outside the ports has decreased in recent years after the COVID-19 period. However, it remains a crucial matter for global trade effectiveness (OECD).³

² Theo Notteboom, Athanasios Pallis and Jean-Paul Rodrigue (2022) [Port Economics, Management and Policy](#), New York: Routledge, 690 pages / 218 illustrations. ISBN 9780367331559.

³ UNCTAD Handbook of Statistics 2023. (2023). Manuel de statistiques de la CNUCED/UNCTAD handbook of statistics/Handbook of international trade and development statistics - United Nations. <https://doi.org/10.18356/9789213585535>

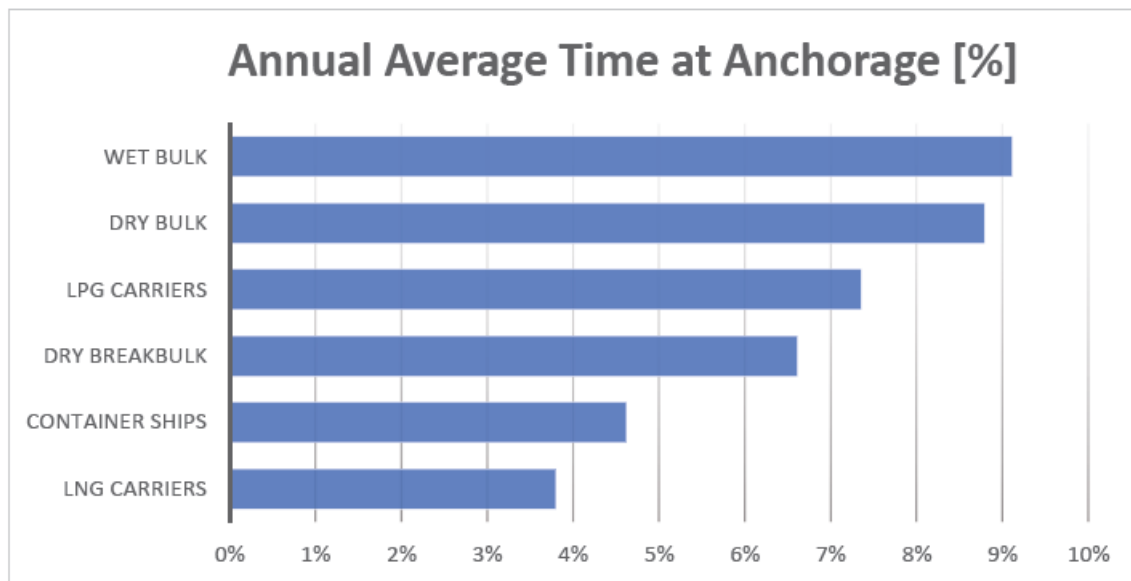


Figure 2: Annual Average time at the anchorage (%) Source: GEF-UNDP-IMO GloMEEP Project and members of the GIA, 2020: Just In Time Arrival Guide – Barriers and Potential Solutions.

Figure 2 shows the waiting times in 2018, classified by the type of vessel as a percentage of the total waiting time for all the vessel types. Bulk carriers possess the first two places, while container ships, which transport huge quantities of cargo, obtain the penultimate place. LPG carriers note a significant percentage of waiting time, followed by dry breakbulk, and the last place is for LNG carriers.

Moreover, according to Matti Masovic's research⁴, it is indicated that in Port of Rotterdam, one of the most highly technologically evolved terminals globally, the percentage waiting time for containers is kept at low levels, thanks to JIT policy, implemented in containerized shipping (Table 1).

Vessel category	Percentage to anchorage
Liquid bulk	46.96%
Breakbulk	8.35%
Dry bulk	43.13%
Container	18.15%
Large container	23.04%
Passenger	0.07%

⁴ Master Thesis, Port Call Efficiency Optimization, Using Data Analysis, Process Mining and Discrete Event Simulation, MSc Programme Engineering and Policy Analysis – TU Delft, Matti Masovic 2019

Table 1: Percentage classification of vessels that stay on the anchor at the Port of Rotterdam: Source: Master Thesis, Port Call Efficiency Optimization, Using Data Analysis, Process Mining and Discrete Event Simulation, MSc Programme Engineering and Policy Analysis – TU Delft, Matti Masovic 2019

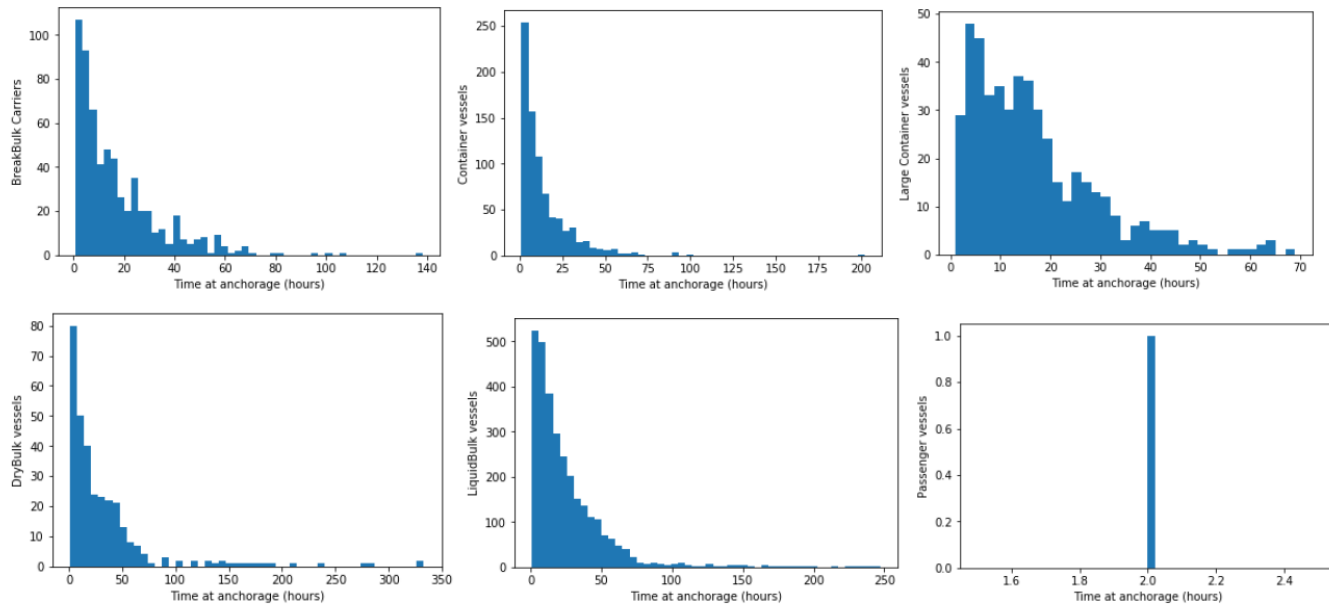


Figure 3: Time spent at the Rotterdam's port anchorage in average per type of vessel. Source: Master Thesis, Port Call Efficiency Optimization, Using Data Analysis, Process Mining and Discrete Event Simulation, MSc Programme Engineering and Policy Analysis – TU Delft, Matti Masovic 2019

Implementing quantitative methods and data analysis, Matti Masovic extracted the above results for 2018 in Figure 3. Outliers in the waiting time distribution per type of ship are intense, especially for large containers. The fact that most containerships remain on the anchor for no more than 20 hours is optimistic for supply chain operations. Likewise, breakbulk, dry bulk, and liquid bulk stayed at the anchorage for similar times, while only one passenger ship was recorded to wait for two hours.

2.2 Congestion factors

Congestion interacts with land procedures, port operations, and modalities connectivity. It is critical that port activities are developed to support the maritime industry and commodities transshipment to other modes of transportation. In this section, factors related to port functions are to be discussed, emphasizing the significance of the working elements individually and combined. Facilities, equipment, human resources, and technology sufficiency are interrelated and finally result in the port performance increase or decrease, respectively.

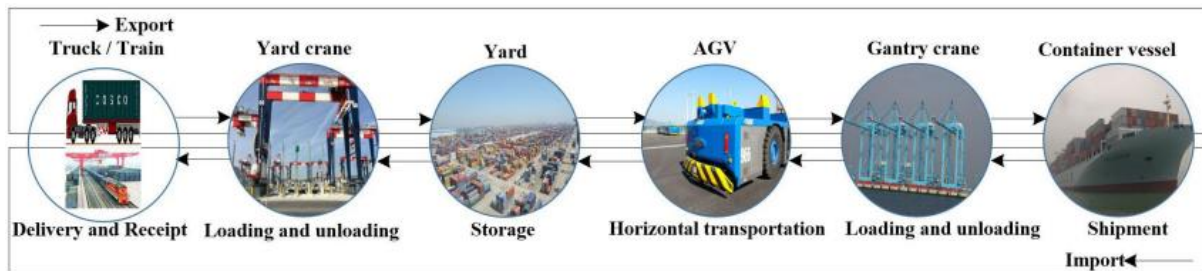


Figure 4: General configuration of port operations for container handling. Source: System Dynamics Analysis for the Governance Measures Against Container Port Congestion, Bowei Xu, Xunjun Li, Xiaoyan Liu, and Yongsheng Yang (2021)

The image above indicates a general scheme of container port operations, showing the interdependence that multiple sections present within the marine environment. Both sides consist of procedures origin. The transshipment process starts with the arrival of a containership, a truck, or a train. Robust cranes, automated in many cases, are scheduled to pick up/ drop off containerized cargo. Intelligent vehicles enable the horizontal transition from and to the yard, the expansion of which must be adequate for safe warehousing. This chapter analyses the main factors provoking global trade ineffectiveness, let alone shipping trade malfunctions.

First and foremost, the quality of port infrastructure is a pivotal element in ensuring the sufficiency of port services. Its condition directly influences the level of congestion, underscoring the urgency of its maintenance and continuous improvement. Terminals, berths, storage facilities, and handling equipment are structured to facilitate vessel mooring, loading/ unloading, etc. If insufficient, delays occur, and the vessels stay outside the port, figuring queues. Analytically, berth availability is essential for ships docking and moving on to cargo loading/unloading. The capacity of berths determines the number and capacity of ships to be on the dock simultaneously, which is significant enough, especially for the high demand period. Moreover, efficient port capacity accommodates a variety of sizes and types of ships.⁵ Containerships, tanker and bulk ships of different sizes arrive and depart from ports worldwide, transporting goods such as food and energy, contributing to the global wealth.

The following images show the evolution of the global fleet, categorized by the type of vessel. Starting from containerships, since 2013 there are the Ultra Large ships (ULCS),

⁵ Theo Notteboom, Athanasios Pallis and Jean-Paul Rodrigue (2022) [Port Economics, Management and Policy](#), New York: Routledge, 690 pages / 218 illustrations. ISBN 9780367331559.

measured in meters, and Twenty-foot Equivalent Unit (TEU) for calculating their capacity. In 2019, an expansion formed the Megamax-24 (MGX-24), hosting 24 containers across and 24 bays. However, it is a type of vessel that can be serviced in specific ports, reaching the constraints of moving into the Suez Canal.⁶ Regarding the tanker ships, it is essential to mention that the largest ever-built vessel, the Knock Nevis (1979), was too large to be serviced by any port. As a result, loading and unloading operations happened while the ship was moored outside the port. Since 2010, there have been twelve operating tankers, over 320,00 dwt, and two of approximately 430,000. Last but not least, bulk carriers, constructed to transfer bulk goods such as iron ore, coal, and grains, have overcome 400,00 dwt and 360 m. Since 2020, there have been 68 Valemax ships (VLOC) operating, some of them in the Chinese maritime market.⁷

⁶ Vessels moving into Suez Canal have no length limitation but should have up to 68 m. airdraught, 70.1 m. beam and 17.07 m. draught. Sphinx Shipping Agency
[The Geography of Transport Systems](#) Sixth Edition Jean-Paul Rodrigue (2024), New York: Routledge, 402 pages. ISBN 9781032380407

⁷ Theo Notteboom, Athanasios Pallis and Jean-Paul Rodrigue (2022) [Port Economics, Management and Policy](#), New York: Routledge

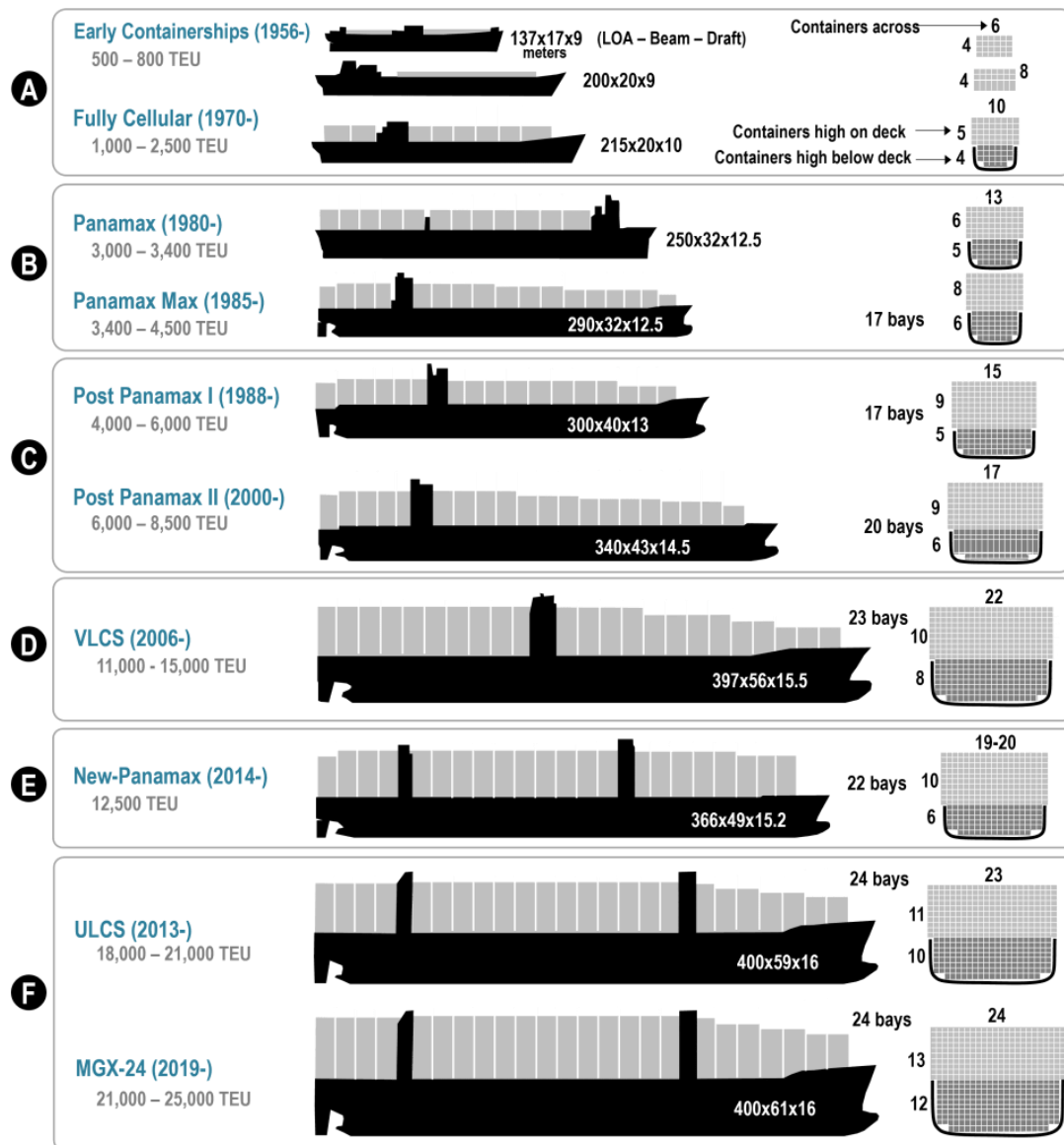


Figure 5: Containerships' size evolution. Source: The Geography of Transport Systems Sixth Edition Jean-Paul Rodrigue (2024), New York: Routledge

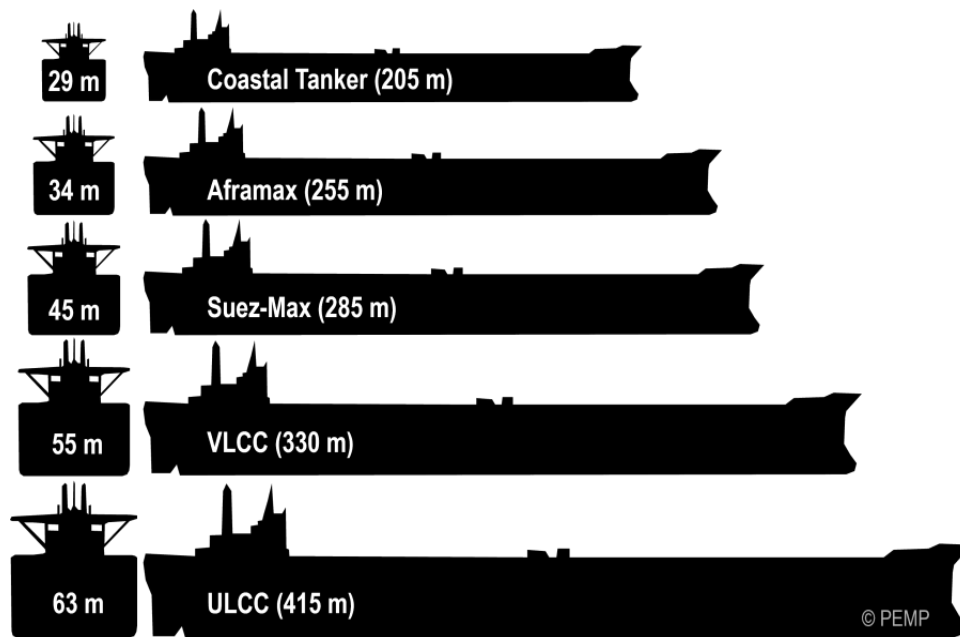


Figure 6: Tankers' size evolution Source: Theo Notteboom, Athanasios Pallis and Jean-Paul Rodrigue (2022) Port Economics, Management and Policy, New York: Routledge

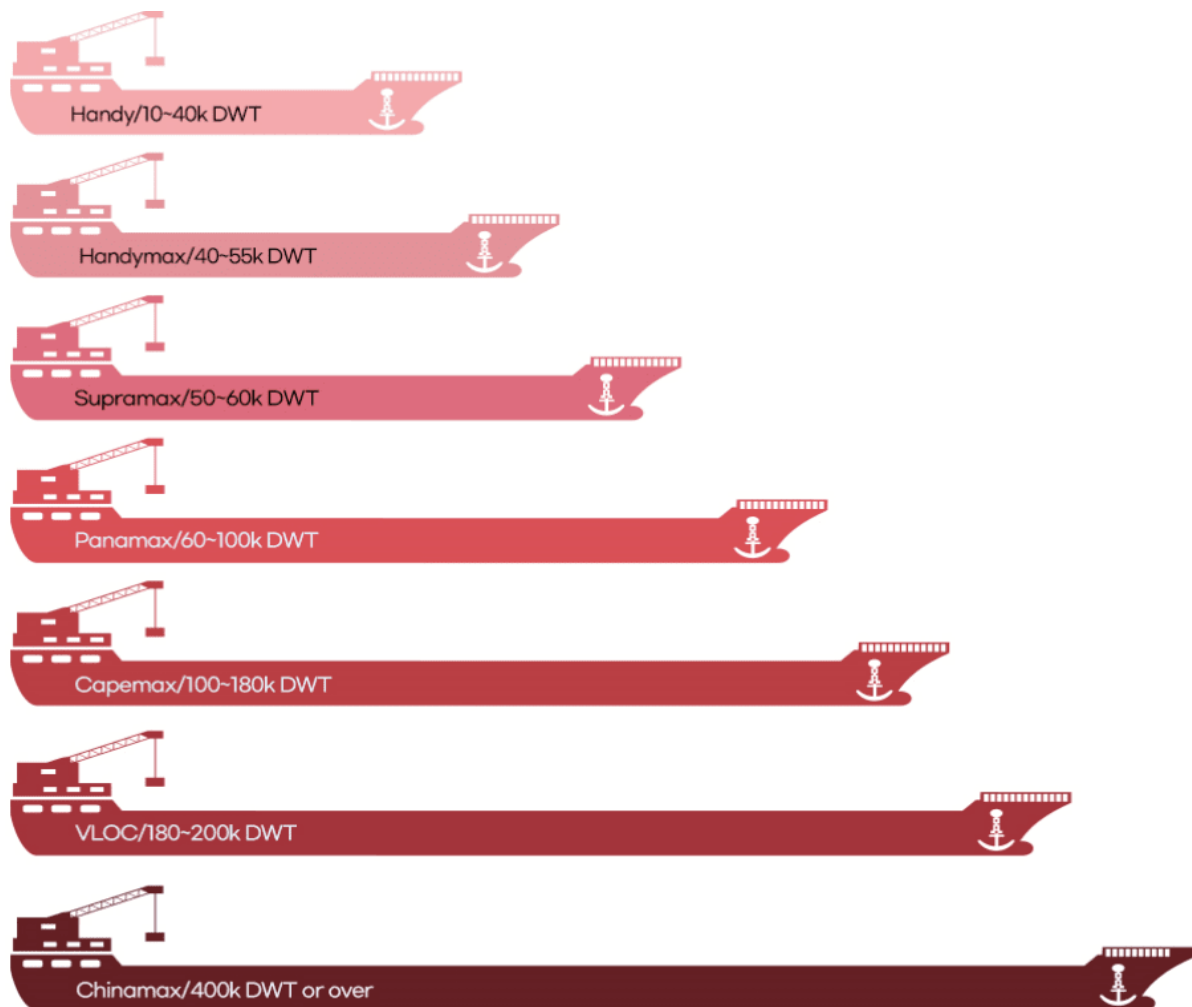


Figure 7: Bulkcarriers' size evolution Source: Logistics Terms Types of Container Ships and Bulk Carriers Registration date NOV 02, 2021

In a nutshell, the surge in shipping volume, driven by the escalating transportation demand, is a pressing issue. The hubs must be equipped to handle this increasing capacity, where goods are loaded/unloaded, stored, and transmitted to their final destinations.

Cargo handling equipment is also a crucial factor that directly affects port congestion; it should be well-serviced or renewed and capable of exploiting the economies of scale in maritime trade. The rising ships' capacity provides significant economies of scale in transportation, while port equipment should conform to these. Modern equipment, using automated systems, cranes, and container handling systems, contribute to immediate and accurate cargo movement, mitigating the time needed for specific actions and, as a result, vessels' on-dock time. Therefore, investing in up-to-date equipment facilitates handling large cargo volumes, in contrast with old and poorly-serviced equipment. Automating equipment's elements overcomes human resources reliance since they operate 24/7,

occupying less or even no personnel. AGVs and automated cranes accelerate actions, eliminating the human factor and possible failures.⁸ Applying a Terminal Operating System (TOS) integrates technology at cargo handling procedures, allowing real-time management, contributing to the optimization of the flows and port performance improvement.⁹ Modern equipment provides sustainability by utilizing electric vehicles and machinery with low Greenhouse Gases (GHGs).

Maintenance of the equipment is equally important. Tactical and on-time maintenance prevents potential malfunctions which will cause unexpected retardations. Moreover, as already mentioned, sufficient equipment capacity is mandatory to handle vast quantities of cargo for loading/ unloading operations. In the opposite case, significant delays are provoked, and ships figure queues outside the ports. Regarding economies of scale, equipment's ability to be adjusted according to the cargo volume is essential. Scalability of equipment takes advantage of only the necessary elements and quantities, which accelerates the actions.

Furthermore, transshipments consist of an already known practice: cargo is transferred directly from ship to ship, annihilating the time of cargo in the yard. In 2007, Singapore's busiest container port exploited this equipment capability on 80% of cargo transmitted. Efficient practices diminish the use of land for terminals and ports, eliminating time cycles for berthed ship operations.¹⁰

Human resources expertise in handling equipment is critical when advanced technology is applied. Furthermore, upskilling and reskilling update working skills so machinery is used appropriately and casualties and downtimes are avoided. Coordinating all available resources, including gear and personnel, involves planning daily operations, implementing practices, and evaluating results and indicators used for port performance. These constitute necessary processes working to eliminate time cycles and congestion. Weather conditions play a significant role in the equipment's operational condition, highlighting the need for

⁸ Advanced Material Handling: Automated Guided Vehicles in Agile Ports, for the Center for Commercial Deployment of Transportation Technologies, P.A. Ioannou, H. Julia, C.-I. Liu, K. Vukadinovic and H. Pourmohammadi University of Southern California, Edmond Dougherty, Jr (2001)

⁹ Improving the Performance of Dry and Maritime Ports by Increasing Knowledge about the Most Relevant Functionalities of the Terminal Operating System (TOS), Miguel Hervás-Peralta, Sara Poveda-Reyes , Gemma Dolores Molero, Francisco Enrique Santarremigia and Juan-Pascual Pastor-Ferrando (2019)

¹⁰ Mindur, M. (2020) SIGNIFICANCE OF THE PORT OF SINGAPORE AGAINST THE COUNTRY'S ECONOMIC GROWTH. *Zeszyty Naukowe - Politechnika Śląska. Transport/Scientific Journal of Silesian University of Technology. Series Transport*, 106, 107–121. <https://doi.org/10.20858/sjsutst.2020.106.9>

machinery robustness and operational projection containing possibilities of weather alterations.

It is crucial to understand that the impact of cargo handling equipment is not just significant; it's directly affecting port congestion. Time cycles are modified accordingly, and the quality, quantity, and type of handling by human resources or automated systems influence operational efficiency, time of ships on the berth, the number of ships to be in parallel serviced, yard's exploitation, cargo over-stowage and therefore waiting times outside the port for ships reached their port of destination.

Consequently, although it constitutes a high-level cost, investing in handling equipment offers long-term profits and creates economies of scale that conform with the rising volume of maritime transportation. The port of Rotterdam utilizes advanced technology systems and port management, making long steps towards the digitalization of procedures in total, aiming to create a "green" port having the least possible carbon footprint.¹¹ Implementation of the Internet of Things (IoT), blockchain, and Artificial Intelligence (AI) provides on-time information exchange, which speeds up operations and minimizes costs. To continue with cargo treatment, storage facilities should be able to hospitalize the amount to be transferred. Allocation of storage is constrained by port capacity and is affected by the time of arrival and departure of the ships, the duration of the cargo's stay at the port, etc. First of all, limited yard space provokes cargo congestion and retardation of the unloading procedure. Ships remain on the anchorage till space is available for cargo storage. Regarding container storage, the organization is required in a way that containers to be loaded first are accessible. Inefficient way of storage burdens actions related to cargo handling, causing severe disruption of the supply chain.

Moreover, allocating berths and scheduling play a significant role, too, and an ineffective way of managing spaces leads to delays. Port operations include vessel berthing, loading/unloading, transporting cargo to the yard, piling, storing, and even ship fueling, which requires a specific time and ought to be coordinated appropriately for port performance optimization.¹² Seasonal reasons affect the volume of the cargo transported due to the augmentation of demand for specific commodities, while some external elements influence the ports' performance. Those are weather conditions, potential strikes,

¹¹ <https://www.portofrotterdam.com/en/to-do-port/futureland/the-digital-port>

¹² Chen, P., Fu, Z., Lim, A., & Rodrigues, B. (2004). Port yard storage Optimization. IEEE Transactions on Automation Science and Engineering, 1(1), 26–37. <https://doi.org/10.1109/tase.2004.829412>

and global disruptions such as socio-political issues as mentioned above. Maritime trade is vulnerable to weather conditions, and time intervals cannot be foreseen. Ships travel in the sea which afflicts the construction of a vessel, the cargo, and of course, the crew employed on the ship. Furthermore, bad sea conditions hinder the process of both travel time and port operations.

Connectivity with other existing modes of transportation is crucial for the port operations' performance since terminals and ports constitute hubs of different modalities. Sufficient and adequate connectivity should exist to transport goods to the mainland and their final destinations. Road and rail networks established in the ports or connected in some way relieve the port facilities from cargo storage. The malfunction of intermodal connectivity provokes cargo gathering in constrained space, which leads to port operations delays. Technology is applied to the majority of the stages described. Since time is valuable, outdated software or hardware cannot effectively support maritime and marine operations. Port facilities exploit technology innovations that apply in many sectors. Administrative procedures, equipment automation, and communication are domains in technology systems work. Corresponding tasks depend on the constant use of technology systems. Communication is thoroughly connected with technology and information flows. The information must reach the relevant entities on time. Customs are also part of the entities occupied at the clearance of the importing goods. Clearance procedures are responsible at a high level for dwell time augmentation. Blockchain software is applied in maritime trade; in many cases, customs are included among the participants in transactions. There is a global discussion for further expansion of the entities participating in a blockchain environment, with regards to maritime transactions, exploiting the potentials of the compound of information flow with technology, given the safety of a digital environment. The analysis is expanded to the introduction of other national authorities into the platform, because, in many cases, they appear as a reason behind the marine operations delays and congestions happening not only outside the port.¹³

Among other external elements, political stability is essential for the smoothness of port performance. Governmental consistency assures policy maintenance and regulation. Lawmaking is acted upon under a stable scope that conforms with economic policy.

¹³ Blockchain technology in maritime supply chains: applications, architecture and challenges, Jiaguo Liu, Huimin Zhang & Lu Zhen (2021), <https://doi.org/10.1080/00207543.2021.1930239>

Socio-political stability creates an appealing environment for both short—and long-term investments. Financial growth comes from the development of the national market.

Conversely, political instability and regulatory and policy modifications create a negative economic disposition and social turbulences. The implementation of legislation changes continuously conducts in volatile situations where investment and market indicators are difficult to project. As an expansion of an unstable legislation environment, strikes discontinue production and distribution cycles. Port activities are affected by strikes directly, even in cases where the cause and the region of the strike are irrelevant.¹⁴ Transportation of important for living products becomes ineffective and the quality of transmitted commodities differs due to the long stay in repositories. Risk analysis using models which include the estimation of strike possibility, is implemented for ports of huge significance for the global supply chain, such as Cochin Port in India, in which strikes took place due to political issues during 2007-2010.¹⁵ Research made for the evaluation of the political situations impact on supply chain management showed that the Government of Libya had to confront with internal conflicts caused by organized armed teams which had the total control the essential energy sources. Taking note in Libya are established ports of huge significance for the universal supply chain. Thus, it was impossible to construct effective road and rail networks which in conjunction with port activities would contribute to national and regional transporting operations.¹⁶

Not to mention that transparency and lack of bureaucracy are encouraged by political consistency. Administrative burdens are time-consuming and often identical to the absence of productivity. Stamps, signatures, and the use of hardcopy exclusively belong to previous eras where technology had not evolved. Currently, circumstances demand time-interval reduction and minimization of bureaucracy, which contributes to the supply chain's efficiency. As mentioned, in some cases, customs have joined the blockchain platform, first applying for the transaction's direct participants. This shift to digital platforms will require a redefinition of roles and responsibilities, with stakeholders needing to adapt to new ways of working. Digitalization is a continuous evolution applied

¹⁴ DISRUPTION RISKS AND MITIGATION STRATEGIES: AN ANALYSIS OF ASIAN PORTS, Jasmine Siu Lee Lam, Shiling Su, Maritime Policy & Management, 2015

¹⁵ DISRUPTION RISKS AND MITIGATION STRATEGIES: AN ANALYSIS OF ASIAN PORTS, Jasmine Siu Lee Lam, Shiling Su, Maritime Policy & Management, 2015

¹⁶ Supply chain risk management and the role of organisation culture: evidence from libyan ports, Mohamed Atig Ahmed PH.d. THESIS 2020

to maritime and port operations. New technologies implemented on ships demand corresponding port technological evolutions. Involving stakeholders should safely access information required for the smoothness of continuous procedures. In this way, bureaucracy will be minimized as productivity will be increased, and time cycles will be eliminated, contributing to the decrease of port congestion.¹⁷

Generally, funding for physical infrastructure and technological applications might be repellent, let alone for ports presenting lower traffic. Moreover, regulations settle the frame of the market's operations, yet law-making departments should conform to the market's expectations to diminish the massive load of paperwork and unnecessary procedures. Flexibility is essential when technology assists daily activities and minimizes time and workload. Resistance to new practices and implementations from an older mentality exacerbates processes in every transportation step. Competent and involved participants should keep pace with new challenges and trends and enhance communication to avoid complexities.

2.3 Impacts of Congestion

The implications of port congestion on the global supply chain are direct because it prolongs time intervals and delays cargo distribution. In particular, commodities shipping to their final destination requires a longer time since vessels stay anchored outside the port. Supply chain management efficiency relies on implementing practices providing just-in-time goods distribution, including transportation and warehousing. Ports are hubs where cargo is transmitted and stored and should operate efficiently, contributing to the smooth continuation of global trade. Warehousing is also important for port operations in order to avoid product obsolescence. Warehousing consists of the conditions and the organization of storage as well as the time that products are kept. Consequently, it is crucial that cargo be safely saved and transmitted timely.

¹⁷ Research in Transportation Business & Management, Blockchain applications and architectures for port operations and logistics management, Raja Wasim Ahmad, Haya Hasan, Raja Jayaraman, Khaled Aalah, Mohammed Omar (2021) www.elsevier.com/locate/rtbm

Moreover, regarding the analysis by GIA¹⁸, some ships do not use the anchor while waiting outside the port but prefer to operate manoeuvres to prevent anchoring-related incidents. Bad weather, sea conditions, or unsuitable seabed formations might lure the anchors for the positions dropped and cause collisions. Due to this tactic, there have been many incidents concerning anchor loss and retrieval incapability, leading to further delays. Added actions such as buoyancy, safety, and operational certification by the inspectors and the correspondent organizations prevent the continuation of transition.

Figure 8 illustrates an indicative example: a containership moved outside the port of Rotterdam for the last 12 hours of its journey, increasing its fuel consumption by 15%.

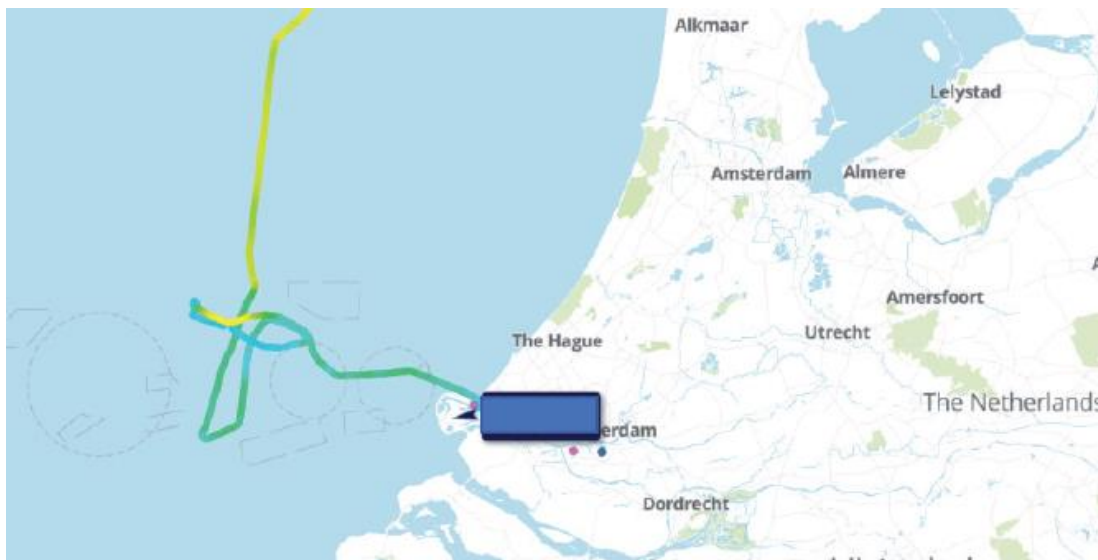


Figure 8: Moneuvring outside the Port of Rotterdam display. Source: GEF-UNDP-IMO GloMEEP Project and members of the GIA, 2020: Just In Time Arrival Guide – Barriers and Potential Solutions.

Additionally, an analysis undertaken by GIA for the period 02/2019-03/2019 showed that of the 61 containerships that submitted a port call, 11 remained at the anchorage, 19 operated circles while approaching, and 31 arrived and berthed on time.

Intermodal Transportation impact

¹⁸ Global Environment Facility [GEF], United Nations Development Programme [UNDP], & IMO. (n.d.). Just in Time Arrival Guide – Barriers and Potential Solutions

Intermodality's efficiency depends on port performance. For instance, if a port experiences frequent equipment breakdowns or lacks sufficient storage space, it can lead to congestion and increase dwell times, delaying the transshipment and uploading processes. This can result in carriages and vehicles remaining in the port's expansion for much longer than necessary, while route planning should be reviewed. In particular, vessels' higher waiting time corresponds to the higher waiting time of trucks stacked in the port's yard till they get loaded. Longer waiting truck waiting time means a smaller number of routes. The rail carriages are used respectively, and so goes on. Such congestion drives inefficient use of transportation facilities and modes. Combined modes of transportation benefit local, regional, and international economies. Networks are designed to help goods reach even remote areas, not only transportation hubs and metropolitan cities. Besides, the trade aims to satisfy customers' needs and augment wealth worldwide. It is clear that since international networks are connected with maritime nodes, consequences will be wider, reaching the regional level. The smoothness of international goods exchange is highly affected by loading/unloading, transshipment, uploading, and general operations. When disturbed by halts, it takes time to recover. Thus, exacerbation of port performance downscales intermodality's effectiveness.

Market impact

Retailers and vendors have to adjust inventory management due to projecting inadequacy of the arrival of goods. Customers are disappointed by the delays in delivery. Lower levels of inventory and increase in operational costs raised by unproductive procedures cause price levels to boost to specific commodities at the beginning and afterwards to the majority of goods and services. Traders have to deal with cargo obsolescence and financial losses. Moreover, ships remaining outside the port conducts to the increase of operations' cost, such as fuel consumption. Therefore, customers must finally pay added costs when purchasing products and services. Inventory presents either deficits or surpluses, while the supply chain cannot meet customers' needs.

Consequently, producers and suppliers get unreliable feedback concerning the actual demand, leading to false production levels. Market uncertainty provokes unstable financial conditions and is relocated in the society like a loop. People's disappointment with the general increase in price levels or inflation and lack of goods available leads to social turbulence. Repercussions roll to local and regional economic evolution, decreasing

financial operations, leading to recession, and mitigating competitiveness, especially for economies based on imports and exports.

Environmental Impact

Queuing ships raises GHG emissions and produces general pollution at sea and in the air environment. Cities' atmosphere is burdened with pollutants, which is downscaling the standard of living. Increased waiting times lead to the augmentation of air environment pollutants which harm the local and broader atmosphere. Air quality is degraded in areas where industrial and maritime operations are developed. Stacked trucks and trains create traffic situations, possessing space until they get loaded and depart; hence, added pollution results from intermodality's inefficient operations.

GIA's research, carried out by the Port of Rotterdam Authority in cooperation with national authorities, showed that if the total of containerships had provided information for Requested Time of Arrival (RTA) 12 hours before, fuel consumption and, thus, gas emissions would have been decreased for those hours up to 4%. Even earlier notification of the ETA, prior to 12 hours, would contribute to even less gas emissions since the vessel's speed is adjusted with respect to the data provided by the port authority. In particular, an experiment's results showed a 23% reduction in fuel consumption for a vessel that notified of her ETA and received back the RTA or the corresponding information disposed.¹⁹ Significantly, approximately 9% of the total journey, including wet, dry and dry breakbulk, containerships, LNG and LPG carriers with a volume equal to or more than 5,000 GT, is spent on the anchorage. This is a key area where waiting times and the associated environmental burden can be minimized.

The global maritime industry has set specific goals regarding decarbonization, focusing on fleet standards even though maritime trade produces only 2-3% of the total GHG emission. Shipbuilding, fuel consumption, digitalization, and planning routes are all planned to fulfill decarbonization aims. Specifically, the International Maritime Organization (IMO) has set the first goal of a 40% decrease in GHG emissions by 2030 and 50% by 2050, compared with the emissions of the base year 2008. Recently, in 2023, the Marine Environment Protection Committee (MEPC 80) of IMO revised the targets, aiming for net-zero GHG emissions by 2050, setting gradual targets throughout the

¹⁹ GEF-UNDP-IMO GloMEEP Project and members of the GIA, 2020: Just In Time Arrival Guide – Barriers and Potential Solutions

decades. Mainly, by 2030, global shipping is aimed to manage a 40% reduction, exploiting new technologies and alternative or dual fuel consumption.²⁰ With regards to the European Union, measures have been implemented, such as the Emissions Trading System and FuelEU Maritime initiative, promoting alternative fuel and new technologies use.²¹

Labour issues

Transportation's labor domain is directly influenced by port congestion. Overload drives to more working hours, less rest, and more fatigue. Operators, drivers, and managers, among others, should rest in order to produce effectively. Moreover, in occupations requiring human actions, confusion leads to inappropriate equipment handling, and accidents happen due to the lack of rest. Not to mention, especially in seafarers' occupations where labor law restrictions are imposed, every delay in a ship's operation causes an expansion of working hours for personnel. Such overtime in transportation professions leads to violations of restrictions imposed and results in penalties for the competent companies. National authorities whose countries are members of the International Labour Organization (ILO) have implemented the Maritime Labour Convention (MLC – 2006). MLC 2006, which issues since 2013, defines the lowest level of working and living on-board conditions for seafarers of seagoing ships and aims to ensure the maintenance of the appropriate wage level, the maximum working hours, and relative employment issues.²² In this case, additional costs are produced due to overtime payments and equipment services. A suitable case study is Los Angeles and Long Beach ports, where 40% of national goods are imported. During the COVID-19 restrictions implementation, ships had to stay at the anchorage for several days or even weeks for their berthing turn to come, which in a row disrupted conveyances via rail and road modes. Rail and road transportation management had to be flexible and re-organized. Bottlenecks were not avoided, and delivery times were significantly affected. Intermodal transportation became unreliable because of the

²⁰ RESOLUTION MEPC.377(80) (adopted on 7 July 2023) 2023 IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS
<https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf>

²¹ Reducing emissions from the shipping sector, Official EU website, Energy, Climate change, Environment
https://climate.ec.europa.eu/eu-action/transport/reducing-emissions-shipping-sector_en

²² ILO <https://www.ilo.org/international-labour-standards/maritime-labour-convention-2006>

expansion of transit times, while trucks and drivers remained stuck at port and trains could not depart as scheduled.²³ Costs were raised by the increase in the time transit that passes to carriers. Trucking costs also increased due to vehicles staying longer while simultaneously exacerbating congestion. Eventually, the total additional costs passed to the customers. It is essential to note the environmental implications. Air presented higher levels of pollution, degrading the quality of living.

2.4 Resolving congestion

Resolving port congestion is crucial for maintaining the efficiency of global supply chains, reducing environmental impact, and minimizing shipping delays and costs. Port congestion can result from analyzed factors, including increased trade volumes, labor shortages, inadequate infrastructure, and external disruptions such as pandemics or geopolitical events. Here's an analysis of ways to address and resolve port congestion.

Port facility expansion and automation integration are necessary to handle the huge cargo volume transferred. Enlarging yards for container storage, building more berths, and renewing handling equipment like cranes are also required. AGVs are an efficient solution integrating modernization in port operations regarding infrastructure.

As mentioned, vessel volume has significantly increased to satisfy the augmentation of transportation demand. Vessel dimensions are consequently larger, and port facilities should be adjusted to service. Deepening port depth is significant for higher vessel volume service. Higher volume shipbuilding leads to fewer vessels traveling, eliminating queues outside the port. Respectively, cargo equipment should be sufficient to service larger ships in order to avoid dis-economies of scale.

Constructing specific freight corridors for rail and road networks could facilitate intermodality. Thus, goods' direct transition to other modes of transportation inside the port's extent is applicable and contributes to direct and faster conveyance to their final destination. Communication systems applied for cooperating modes of transportation work efficiently with regards to information exchange, that is, estimated time of arrival, departure, on berth, loading/unloading, and thus rail and road trips can be re-arranged according to new circumstances. A digital platform where timetables can be used,

²³ Acute port congestion and emissions exceedances as an impact of COVID-19 outcome: the case of San Pedro Bay ports, Vukić and Lai Journal of Shipping and Trade (2022) 7:25 <https://doi.org/10.1186/s41072-022-00126-5>

constantly updated if any changes happen, accessible for involved transporting companies. Port operating hours are suggested to be broadened, accompanied by a shift program to ensure equal working time for employees and maintenance conditions for the equipment. Smoother cargo improvement is supported by new or upgraded rail and road infrastructure. Investing in land networks contributes to the effectiveness of mainland transportation. Vehicle and carriage movement is undisrupted, facilitating cargo direct transitions.

Constant working demands efficient collaboration with firms and competent authorities. Port authorities are responsible for port exploitation, safety and security issues, operational management, infrastructure sufficiency and conditions, environmental policy implemented, port regulations' implementation, management of financial resources, gains or losses, and cooperation with relevant stakeholders. Coordinating all corresponding task targets to ensure a continuous, sustainable, and safe operating situation, contributing to local, regional, and international economic growth.

In many cases, this is the critical point where the public and private sectors collaborate. Regulatory departments and law enforcement authorities play significant roles in local and national competitiveness and market figuration. It is essential that law-making authorities work under the scope of lessening procedures and bureaucracy burdens as well as figuring market competition status. Furthermore, public-private partnerships (PPP) encourage investment in facilities and equipment, inserting technological innovations. Tax exemptions might apply for investments in port infrastructure as a bride for operational financing. Customs, on their side, can support procedures by being flexible and exploiting digitalization, utilizing technology potentials. It is clear that collaboration among companies, ports, and national authorities is highly required for transportation efficiency.

Incentives can be developed for vessel allocation in more ports, such as dynamic pricing for ports and seasons when high ship trafficking is presented or, conversely, financial benefits for ports and periods where available infrastructure is not used to the maximum level. It is important to note that this policy can be applicable and route planning departments should consider advantages and drawbacks when re-arranging. Time and distances needed to arrive at or depart from a port are crucial for figuring maritime corridors, given that all port options provide similar operational levels.

Port operations management departments integrate e-platforms and digital systems, offering on-time information flow among users and automated activities exploitation. Port Community Systems (PCS), the IoT, and AI applications optimize port performance,

providing a remarkable level of independence from human resources and bureaucracy. Stakeholders involved in commodities transportation participate in PCS, a digital community that assists employees of terminals, customs, and freight operators in being notified on time and coordinated effectively. As already mentioned in the previous chapter, IoT and AI provide, through device use, real-time information regarding equipment usage according to activities taking place, making maintenance planning and logistics work easier. Last but not least, blockchain is an expanding technology applied to platforms used for on-time information exchange among transactions' members, ensuring data security and reliance. Promotes documentation mitigations and reduces retardations caused by administrative procedures.

Slot coordination, introduced as congestion-resolving modus, inserts in the port organization the idea of providing specific arrival and departure times for each ship, requesting port calls. Slots have been implemented for decades for air transportation and in ports with congestion issues. It constitutes a system characterized by strict timelines and penalties when airline companies fail to comply with the timetable agreed upon. A slot coordination system analysis follows, and the potential to be implemented for port congestion confrontation is examined.

Chapter 3. Slot coordination system

3.1 Description of slot coordination system

Slot coordination is a critical concept in various fields, notably in transportation systems like airports and in telecommunications and computing. This analysis aims to focus on slot coordination primarily within the context of air traffic management, which is one of its most significant applications, and then examine whether it is applicable to sea transportation and port management

3.1.1 Slot Coordination in Air Traffic Management

Slot coordination refers to the process of allocating specific time slots for aircraft to take off, land, or use a particular corridor of airspace.²⁴ This is essential in managing airport and airspace capacity, ensuring safety, and optimizing air traffic flow to mitigate delays. International Air Transport Association (IATA) and national aviation authorities are competent organizations that establish slot coordination regulations. Notably, a "slot" constitutes a right that an airline company has acquired by the slot coordinator to use the necessary airspace and land at a pre-decided time for the arrival departure for a specific flight, taking into consideration the time required for ground handling services, such as embarkation/disembarkation, loading/unloading, fueling, etc. It is widely used in order to prevent disruptions and congestion. According to WAGS²⁵ the slot coordination system is implemented with regard to the airport's category. Airports classification is addressed by analysis taken, including transportation demand level and expectations, airports' capacity for each season that slot coordination is to be implemented, and at least every time that essential change occurred to operational policy, infrastructure, etc. A brief description follows concerning categories which are defined by the mentioned factors.

- In level 1, classified airports possess sufficient infrastructure to meet the needs. Airports are characterized as level 2 with regards to coordination, the management of whose is capable of confronting augmenting traffic circumstances on peak-periods during the season, week, or day by arranging schedules appropriately. For

²⁴ Worldwide Airport Slot Guidelines (WAGS), Edition 3, A Worldwide Airport Slot Guidelines © 2023 Airports Council International, International Air Transport Association, Worldwide Airport Coordinators Group All rights reserved. Montreal – Geneva,
<https://www.iata.org/contentassets/4ede2aabfcc14a55919e468054d714fe/wasg-edition-3-english-version.pdf>

²⁵ Worldwide Airport Slot Guidelines (April 2024)

this reason, a facilitator cooperates with airline companies to facilitate the utilization of the airport. Level 3 is where the slot coordination system applies. Capacity needs to be improved in comparison with traffic and transportation demand. Therefore, as advised by the Coordination Committee, a coordinator is employed to allocate slots requested by the airlines or aircraft users, aiming to optimize yard and airspace exploitation.

- The implementation of slots at level 3 airports lies on specific principles for the coordination's efficiency. The most significant and potentially relevant to this analysis should be referred to.
- Operating at a level 3 airport requires obtaining a slot, which is essentially permission to land, take off, etc., at a specific time. It's important to note that for certain types of flights, such as governmental or humanitarian, slot obligations may not apply, or specific procedures may need to be followed. It's crucial for airlines and operators to understand that they must adhere to the times provided by the coordinator. This clarity on the rules and procedures is essential for the audience to feel informed and prepared. A series of slots can be utilized for a specific period and regularly distributed. Moreover, since an airline operates at 80% of the time that slots were allocated, it maintains the series for the upcoming period, the so-called "historical precedence". Slots can be exchanged among airlines or commonly used with regards to the guidelines and regulations imposed.
- The slot allocation process is designed to be impartial and transparent. The coordinator, who operates independently both financially and operationally, ensures non-discrimination and transparency. They also monitor the use of the allocated slots to maintain the agreed schedule. This commitment to fairness and transparency is vital to building trust and confidence in the slot coordination process. Communication between the concerned parties is conducted according to the IATA Standard Schedules Information Manual (SSIM), and the requested times are projections of arrival (on-block) and departure (off-block), all expressed in UTC.

3.1.2 Slot Coordination process

The slot allocation will be discussed in this chapter, presenting the existing prioritization procedure. First of all, airlines or aircraft operators apply their suggested time of arrival

and departure given the time interval for land services provided. The coordinator receives the submission and, considering the Coordination Committee's recommendations and the available infrastructure, allocates the slots. Should slot distribution based on historical data be completed, new participants will obtain slots from the established slot pool, where new slots will be included. Airlines acquiring slots based on historical precedence, when requesting time modification, should notify of their flexibility with regards to time-table adjustment. It is coordination work to examine whether the suggested changes are applicable and allocate or reallocate correspondingly.

Consequently, as already mentioned, a pool is created with the remaining and new slots. According to WAGS, 50% of slot allocation should be addressed to new participants except in case this percentage is not reachable due to the lack of requests. Equal allocation abides by the terms imposed for transparent and fair slot policy, using necessary additional parameters and always complying with guidelines. New participants and older should share the slot allocation equally, and in case this is not achieved by the coordinator for a specific period, it is an obligation to be corrected to the next one.

Flexibility is a key aspect of the slot allocation process. Slots exchange among the airlines is a possibility, subject to negotiation, which can significantly assist in the operational optimization of their flight schedules. Once slots are allocated, the coordinator's role doesn't end. Continuous monitoring by the coordinator ensures the implementation of the agreed program, contributing to the creation of the historical precedence and the operational evaluation. This ongoing monitoring and potential slot exchanges underscore the dynamic nature of the slot allocation system, designed to adapt to the changing needs of the airlines and aircraft operators.

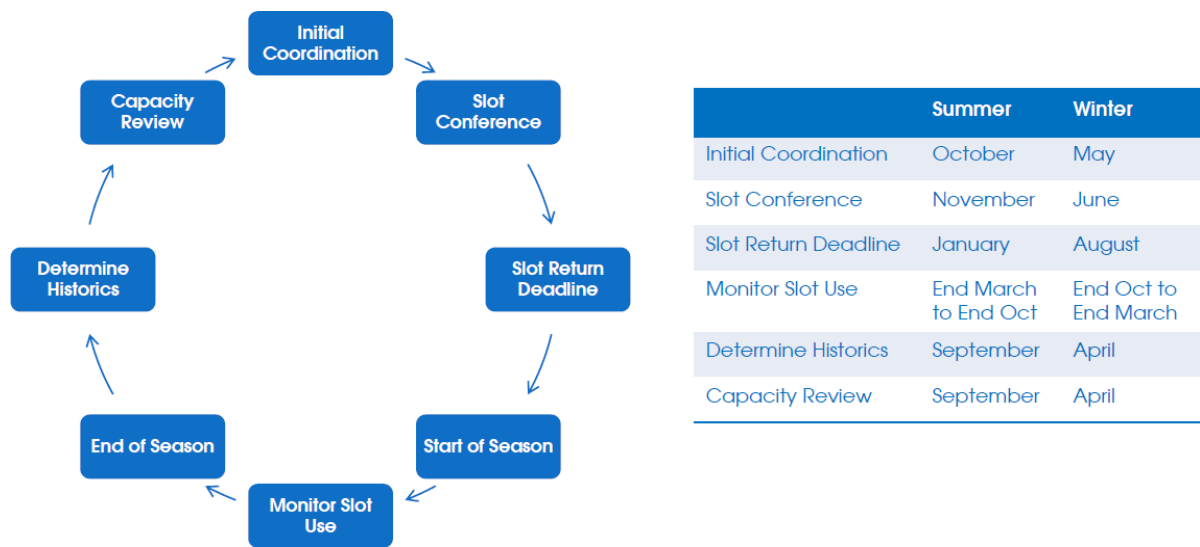


Figure 9: Slot allocation process Source: Airport slots, By Andrew Haylen Louise Butcher, BRIEFING PAPER Number CBP 488, 12 June 2017

Although the slot system is a mechanism designed to manage the allocation of limited resources such as airport runways or telecommunication channels, was developed to address congestion issues, considering the airport's capacity constraints that eliminate coordination efficiency. Furthermore, colossal slot demand in peak periods surpasses supply, which contributes to increasing competitiveness. The market's competitiveness conditions, and route alterations provoke disruptions in operating according to the issued slot allocations. Slot coordination demands specific procedures to be acted by the total number of stakeholders; however, additional complexity derives from the obligation of air transport companies to comply with different national regulations. Nonetheless, besides the challenges, the slot coordination system presents significant advantages for resolving congestion. It optimizes airplanes' exploitation of airspace and corridors while minimizing collision and other incident risks. Also, airlines are provided with specific schedules when slots are allocated for an entire season, acknowledging that if 80% of slots are serviced as agreed, their next submission will be prioritized. Additionally, regulations protect new entrants at an airport's slot system by distributing fairly the remaining slots.

Slot coordination applies in internet communications and computing as well to manage time counters for data transmission, optimizing network efficiency. It is crucial for systems such as time-division multiple access (TDMA) and computer systems planning algorithms.

Slot coordination assumes a pivotal role in the management of limited resources in both air traffic management and telecommunications. It entails meticulous planning and

allocation of time slots to ensure efficient, safe, and predictable operations. While the specific challenges and benefits may vary across segments, the fundamental principles of optimizing resource use and managing demand remain unwavering. This underscores the critical importance of slot coordination in port operations, highlighting the significant role that each segment plays in this process.

3.2 Slot coordination system in maritime transportation

Slot allocation in maritime transportation works similarly with the airline modality, constrained by factors discussed in the next chapter. Such constraints permit slot submissions in a short time frame, compared to airlines, where operators can submit for a series of slots for the next period. Time slots are tightly related to port calls since shipping lines and port functions operate with respect to the ETA, ETC, and ETD.

It is significant that worldwide guidelines for a slot coordination system in maritime transportation should be established. Such guidelines can be considered and created with the cooperation of stakeholders representing different transportation sectors. In this way, global instructions will be accepted and implemented in ports where a large amount of the trade is transferred. Shipping operators will have to deal with specific provisions and requirements worldwide.

Information flows among port operators and shipping lines to communicate the specific functions undertaken in particular periods. Operational optimization is managed with timestamps designated while implementing slot allocation and JIT strategies. Shipping operators have to notify the port/terminal operators of the ETA twenty-four hours before arriving, and then the RTA is defined. RTA is the time point at which the port operator asks the vessel to sail to the Pilot Boarding Place. It is mandatory that the JIT strategy demands the acknowledgment of the facility's availability, berth, handling equipment, and warehousing capacity that is. It is estimated that 80% of containership entries into port planning is based on the time point that berths are set free from previous vessels.²⁶ Hence, RTA is decided regarding the on-berth ship's ETD, and the so-called ETD Berth is estimated according to the time required to fulfill functions like fueling and transshipment. Particularly, the Estimated Time of Completion includes the ETC Terminal, which indicates the time for cargo operations, and the ETC Bunkers, which is for fueling time.

²⁶ GEF-UNDP-IMO GloMEEP Project and members of the GIA, 2020: Just In Time Arrival Guide – Barriers and Potential Solutions.

Should the mentioned operations and the customs clearance be completed, the on-berth ship is free to depart.

The RTD is a crucial element in the process, provided by the Port Authority. It takes into account the ship operator's information for the Estimated Time of Departure (ETD) out of the berth. The RTD Berth is calculated based on the ship's type and dimensions, the availability of port services, and the involvement of clearance and other authorities. The RTA of the incoming ship is then determined in relation to the RTD of the departing one. It's essential that the incoming ship adheres to the given timestamp, underscoring the importance of compliance in this process.

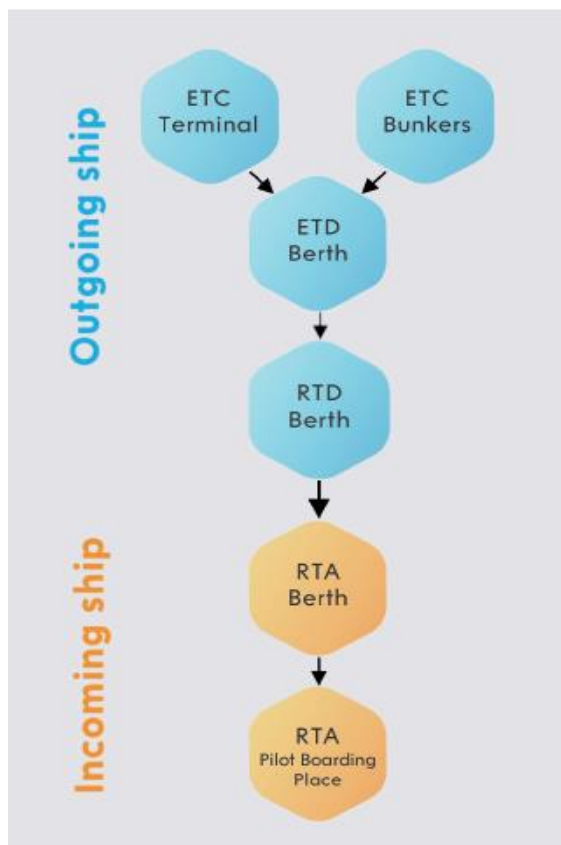


Figure 10: Port call timestamps Source: GEF-UNDP-IMO GloMEEP Project and members of the GIA, 2020: Just In Time Arrival Guide – Barriers and Potential Solutions.

An effective berth schedule, planned by the terminal, is crucial when requesting the vessel to come ashore at a specific time (RTA). This schedule, influenced by the number of vessels and the number of berths of the terminal, is a delicate balance of reliability and accuracy, with customs clearance demanding time flexibility. In this process, the Port Authority relies on the shipping line for the ETD. It's of utmost importance that shipping

operators, as key stakeholders, act promptly to declare and notify other involved parties, such as customs and nautical services, in advance, within a specific timeframe, and conclude all the mandatory functions. Timely notification is the key to enabling the availability of services and the prevention of surcharges. Once notified, the Port Authority submits the RTD, advising the ship to depart at a specific time.

On-board systems work for data transition towards a global network and consequently to port e-platforms. Acknowledge the vessel's type, size, destination, origin, ETA, berth needs, tugboat assistance required, and ownership status, which are significant information for decision-making regarding the port services. The duration of berthing and potential waiting time outside the port are estimated based on these elements. Furthermore, all services' phases are planned, and sufficient handling equipment, cranes, vehicles, warehouse capacity, and human resources are coordinated regarding the network's notification. Each procedure must be accomplished within a specific time, given potential malfunctions that lead to going off the schedule. Flexibility is an essential part of time cycle management that contributes to constantly adapting operations.

Currently, the system that offers communication are the Automatic Identification System (AIS), which sends out information concerning the ETA, using the timely position, the size, type, the IMO number, the Maritime Mobile Service Identity (MMSI), the type, and quantity of cargo, constructive characteristics of a ship, etc. It presents the potential to be further developed, assisting the efficient information flow and port operations planning, taking into consideration that AIS emissions are continuous, dependent on the ships' speed.²⁷ The timeline of information flowing is shown in the figure below.

²⁷ International Standard, Maritime navigation and radiocommunication equipment and systems Automatic identification systems (AIS), IEC 61993-2, First edition 2001-12

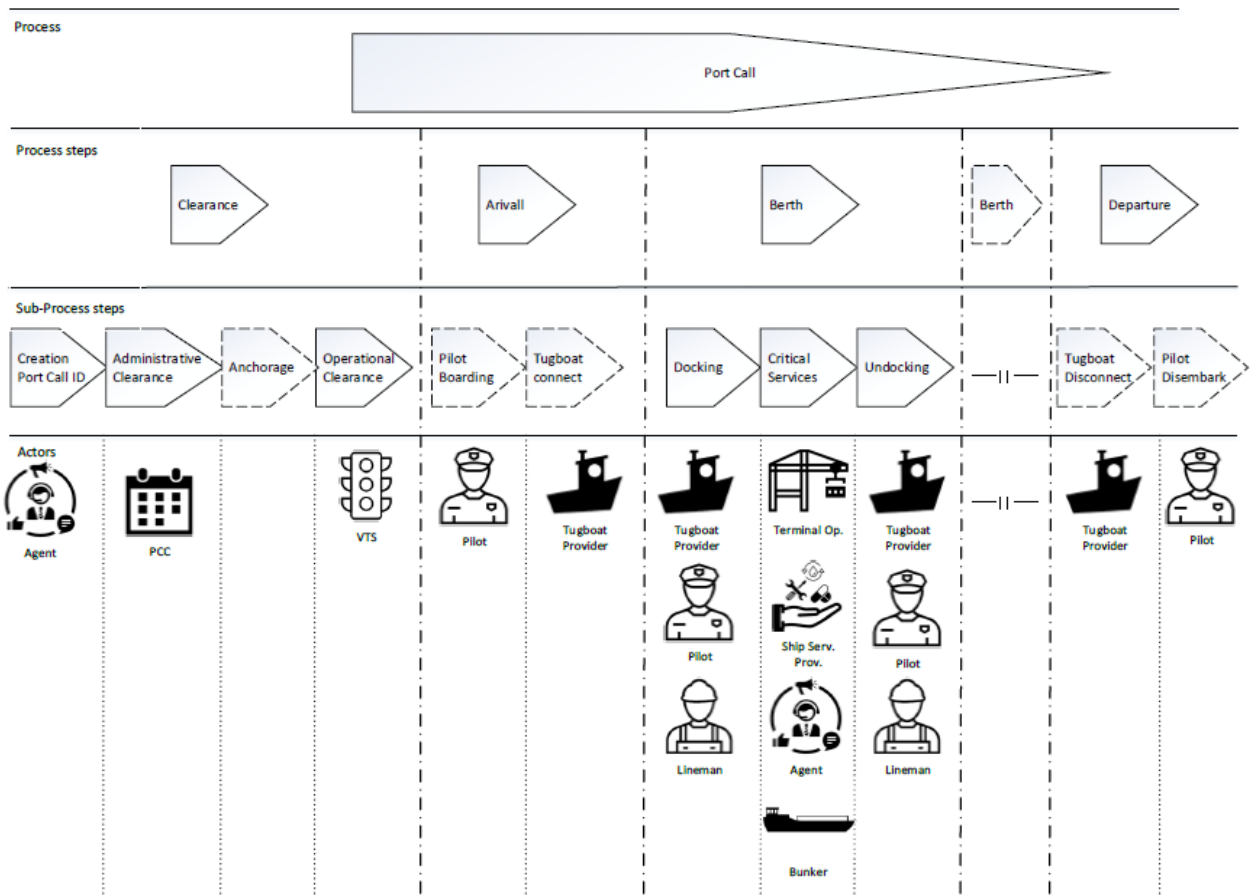


Figure 11: Port Call Process Source: International Standard, Maritime navigation and radiocommunication equipment and systems Automatic identification systems (AIS), IEC 61993-2, First edition 2001-12

Slot allocation is a time management policy correlated with the processes shown in Figure 11. Time slots formerly distributed are based on the time cycles required for navigation within the port sea area, docking procedure, ship's and terminals' operations, customs clearance, preparation for departure, and departure. Given the information provided to the terminal, AI tools and databases configure the timetable, exploiting interrelating inputs and outputs. Hence, terminal operators provide the RTA when, upon timestamps, they are figured, and any other necessary data concerning the vessel's and port's performance is saved in the databases. Historical data contribute to efficiency evaluation, assisting in operational planning.

Moreover, it is ensured that platforms providing essential outcome for port operations are accessible for entities involved, security for granted. Reliance on effective communication and data transmitted through satellite systems is crucial for slot distribution and potential modification. The slot allocation system is assessed with respect to the information

provided. The initial planning should be compared with the eventual in order to assess whether time slots were appropriately distributed, and if not, the disruption factors should be detected and analyzed.

3.2.1 Pros and cons: consequences analysis

Port congestion constitutes a crucial issue for global maritime and multimodal transportation. Slot coordination in port management is a critical policy to improve efficiency by improving port infrastructure exploitation. It combines continuous planning and allocating time slots for arrivals, departures, and port operations such as loading/unloading. It is implemented to decrease vessels' queueing outside the ports, optimize capacity and functional potentials, and improve port performance.

The slot system is vital for port performance since it coordinates all involved participants, starting with the operations department of shipping companies, which submits the time of arrival/ departure, given the time required on the dock that a vessel needs. Such submission is applied through e-platforms, integrated with terminal operating systems (TOS), which enhances the timely communication among stakeholders and improves the short and long-term schedule figuration. It is essential to mention that if updates are applied, the port's operations will be rescheduled accordingly. Real-time information flows assist necessary program adjustments, limiting the impact of unprojected disruptions.

According to guidelines implemented correspondingly to port operational requirements, it is crucial that ships comply with the slots allocated for the system's effectiveness. Operational functions depend on schedule compliance. Time-demanding port activities, e.g., berthing, loading/unloading, transshipping, and fueling, are planned based on the schedule formed. Physical capacities, technology systems, and personnel are all coordinated to maximize port performance. Terminal operators manage berthing and cargo handling procedures with regard to slots provided. Port authorities monitor the process by accessing the slot information system and ensuring its smoothness. The evaluation of data gained determines whether the maintenance of the ongoing strategies or significant modifications need to be made.

It is for granted that the digitalization of procedures and communication plays one of the most significant roles in operational efficiency. TOS, IoT, AGVs, networks, and platforms work under the scope of digital development, using information flows on time, remote equipment handling, automated procedures, reducing human resource overreliance, and

mitigating the time intervals and the possibility of incidents. Moreover, the slots system assists in massive data analysis that is applied to forecasting and strategy assessment.

Slot coordination systems implementation aims to eliminate port congestion by reducing the waiting time of vessels. Given the port's capacity, berths, cranes, and labor conditions, slots analysis results in slot formation for a specific period allocated to shipping operators pursuant to their submissions and historical precedence. When keeping up with slots, fuel consumption is decreased, crew labor planning is feasible, and no surcharges are imposed. Vessels' maintenance expenditures are mitigated, and the operational lifespan of machines, engines, and port equipment is expanded. Therefore, operational cost is minimized and preserved to predicted levels. Port performance is improving, and the local market's competitiveness is expected to rise, resulting in regional and national economic growth. Efficiently organized ports consist of ports of preference for transportation companies operating in land and sea transportation. Customers', vendors', and carriers' satisfaction creates a new level of demand and augmented deriving transportation demand.

Nonetheless, slot allocation is subject to challenges originating from the coordination complexity, integration of technology systems, and law enforcement. Guidelines and national regulatory frameworks impose certified documentation and procedures. However, complying with national regulations based on which slot allocation is acted is challenging due to the various regulatory frameworks implemented in ports' operations worldwide. Therefore, it is significant that a common framework for maritime trade facilitation be established, flexible enough to be adjusted to national requirements. Many different obligations arising from national regulations provoke confusion in maritime operations management, which may cause disruptions. Ships may only be permitted to insert port expansion once national requirements are complied with; hence, delays may occur due to administrative burdens.

Software use also carries administrative burdens, preventing operations consistency. AI applications exchange huge amounts of information simultaneously when permissions are requested. E-platforms and systems should sufficiently serve the corresponding data space and transfer. The slot coordination system contributes to scalability, based on the information received for vessels' capacity. The system's complexity also includes stakeholders' effective collaboration under the scope of transportation efficiency, requiring familiarization with technology innovations and compliance with international and national regulations.

Moving towards the decarbonization and digitalization of the maritime industry, shipping companies prefer port facilities that can support operations sustainably and innovatively. Direct and specific information flows concerning services' availability facilitate vessels to enter the port JIT, decreasing expenditures and maintaining transportation costs at a low level. Ports' standing in global trade is raised since they are preferred among others due to the high quality of services provided. A competitive goal is gained by conducting trade cycle development and larger profit margins. Procedures transparency and elimination of paper workload render the estimation of resources' quantity and kind of deciding effective. Short- and medium-term projections are more reliable by using technology systems that exploit as input updated data, adjusting timely the services' elements such as berths positioning and sufficient handling equipment.

Should the shipping lines go astray following the slots allocated, repercussions should be imposed and classified according to the frequency of falling foul of time slots. Alerts, notices, demurrage, and temporary or permanent vessels' exclusion from the ports' services are consequences when slots allocated are not complied with.

Slot allocation relies significantly on the network's robustness. A large amount of data is imported, edited, exported, and exchanged through AI devices and systems, aiming to coordinate different functioning sections efficiently. Communications and information flows should be accurate and on time; thus, connectivity turbulences and systems' vulnerability to potential cyber-attacks should be excluded. Updating software and servicing hardware are crucial for constant function.

As one of the busiest ports in the world, the Port of Singapore relies strongly on efficient slot coordination to maintain its competitive position. Tuas Mega port is constructed as the biggest port for containers, aiming to integrate all operations involved from the rest of the terminals, leveraging high automation systems. Port Community System (PCS) is implemented, a digital platform centralized that accommodates information exchange among shipping companies, port operators, and port authorities.²⁸ Integration automation facilitates berth allocation according to data reaching on time with regard to the type, size of vessel, and cargo information. Singapore port management exploits IoT devices and

²⁸ Port Community System Implementation: Lessons Learned from International Scan, F. Jordan Srour, Marcel van Oosterhout, Peter J. Van Baalen, Rob Zuidwijk, Transportation Research Board 87th Annual Meeting, January 2008

sensors to update data flowing among port operations participants. Dynamic changes, such as adjusting the schedule and the capacity's re-distribution, are applicable. As an outcome of integrated AI applications, port performance is maximized with ships' productive turnarounds and congestion nullifying.²⁹ Additionally, cost elimination by decreased operational expenditures and the environmental benefits classify Singapore's port as a sustainable operating hub addressing the maritime industry's decarbonization. When concluding a significant period, data assessment contributes to new decision-making procedures by analyzing the input and output of the slot coordination system.

Rotterdam's port, as showcased on the IMO Official site, operates with a robust information flow system. This system highlights the crucial role of slot coordination, a key component in the efficient management of port operations.³⁰

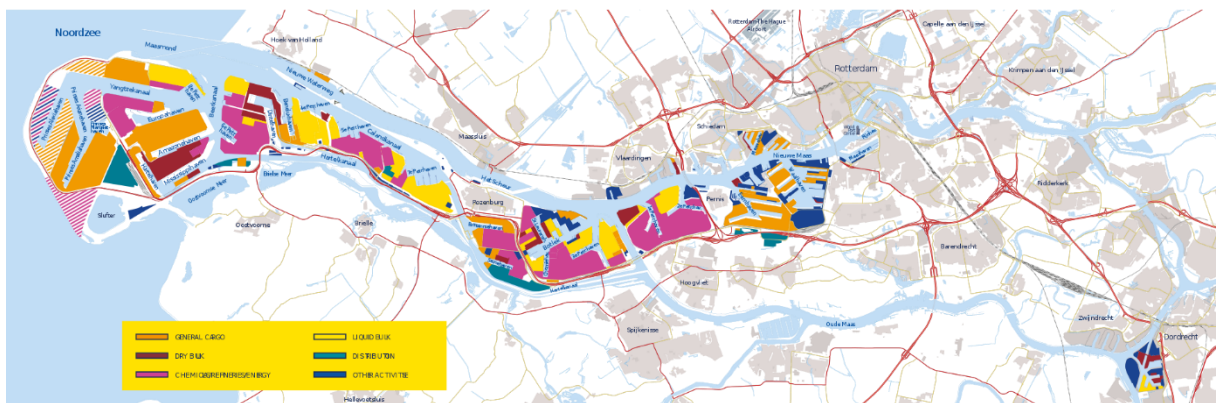


Figure 12: Port of Rotterdam Source: https://en.wikipedia.org/wiki/Port_of_Rotterdam

Rotterdam's port is the biggest port in Europe and a significant global supply chain crosspoint, recording a high freight transition volume annually. Operational efficiency is achieved by implementing high-tech systems that provide on-time information exchange.

²⁹ Competition for transshipment containers by major ports in Southeast Asia: slot capacity analysis, [Jasmine Siu Lee Lam](https://doi.org/10.1080/03088830701849043) School of Civil and Environmental Engineering, Nanyang Technological University, Singapore, <https://doi.org/10.1080/03088830701849043>

³⁰ <https://www.imo.org/en/GoogleSearch/SearchPosts/Default.aspx?q=slot%20coordination>

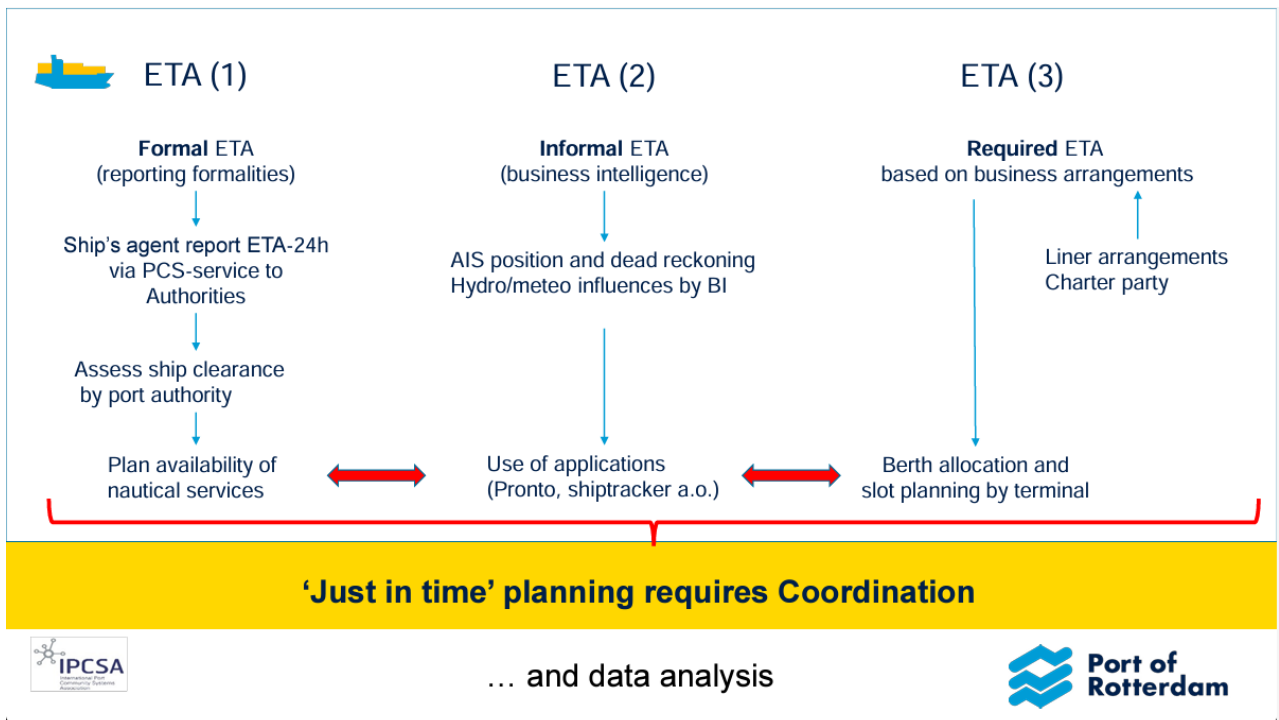


Figure 13: JIT Process Source: 3 - Raymond Seignette - IMO FAL 11 April 2019 www.imo.org

Figure 13 illustrates the collaborative procedure of updating information concerning a ship's ETA and allocating the suitable time slot under berth availability. A 24-hour notification is provided on behalf of the shipping operator to the port community system, requesting berth availability for handling operations. This collaborative effort involves national authorities being promptly informed, and customs acting as necessary to provide clearance. The ETA is updated with data received from devices on-board satellite systems, which reflect the vessel's position and combine speed and distance status to export the projected time of arrival. This comprehensive process ensures that all necessary information is promptly addressed to stakeholders involved in coordinating port functions, highlighting their crucial role. Figure 14 provides a detailed view of the data input and the information derived from the disposed communication systems, further emphasizing the importance of reliable flow exchange.



Figure 14: Vessel's position display Source: 3 - Raymond Seignette - IMO FAL 11 April 2019 www.imo.org

3.2.2 Threats and unpredicted factors downgrading slot coordination's efficiency

Slot allocation is acted upon submissions by the shipping operators, requesting specific times for ships' arrival and departure, given the on-the-dock time for port operations based on predictions and estimations. The submissions received when accepted or modified conduct to the final allocation of time slots. Slot coordination systems require observance of the allocated slots or on-time notice in case any change has to be made. Maritime transportation is significantly sensible to factors for which any adversity's impact is difficult to project. Weather conditions, social-political circumstances, systems malfunctions, and cooperation issues provoke unsteadiness in maritime movement, causing delays. Thus, slot coordination is implemented less effectively. A description of essential factors preventing maritime operations from being efficient follows.

Market Powers

Planning berths' occupation is subject to the maritime industry's powers and the determination of the terminal's service turns. For this discussion, we should distinguish the policies based on the type of vessel. Therefore, the market's powers modify bulk and tanker ships' dock permission. Specifically, the contract issued between the charterer and the terminal, known as a terminal service contract, defines the time of port operations. If encroached, the charterer has the right to place demurrage from the terminal when

demurrage is passed on to the owner in many cases. Port operator might decide to give berthing permission in priority to ships so that their service may cause lower demurrage. Furthermore, when transactions and agreements are acted upon during cargo shipment, the buyer has the right to recommend a different port, and sellers prefer plenty of options for delivering cargo to decide and respond correspondingly. It is critical that making a deal happens to a former arrival stage to maintain time slot efficiency at a high level. The domain of container shipment is less sensitive in the port of delivery alterations when the terminal cooperates with only one customer. On the other hand, a terminal that cooperates with more than one user may implement a prioritization policy depending on the ship's ownership status and obsolescence in commodities.

Environmental Factors

Weather conditions and the shift in the global climate are critical factors for the efficiency of shipping operations. Weather has a significant impact on a vessel's journey, particularly for large vessels. The wind, especially its intensity, poses a significant threat to high freeboard vessels, primarily due to their larger side surface area. Additionally, rough sea conditions can cause damage to both the ship and its cargo.³¹ Moreover, lousy visibility conditions augment the dependence on global satellite systems, which are used to represent traffic. Specific attention and handling movements, reliable technology onboard systems for weather illustration, and steering support are critical tools in confronting such circumstances.

³¹Meteorological factors that impact on shipping. (n.d.). Retrieved May 20, 2024, from <https://maritimesa.org/grade-10/meteorological-factors-that-impact-on-shipping/>



Figure 15: Sealand Express grounding close to Cape Town in 2003. Source: Maritime South Studies Africa, Meteorological factors that impact on shipping, Photograph Andrew Ingpen

Image 15 shows the containership Sealand Express went ashore near Cape Town when she dragged her anchor during heavy weather in 2003.

Climate conditions afflict the maritime circulation as well as the port performance. Winds and waves of high intensity prevent ships from berthing safely. Thus, in many circumstances, it is preferable to maintain on the anchorage rather than perform berthing movement, risking casualties on the ships, port infrastructure, and cargo. Furthermore, extreme weather phenomena cause port operations disruptions and deficiencies. Hence, port equipment should be robust for efficient handling under adverse weather conditions to minimize the negative impact. Recently, Hurricanes Harvey, Irma, and Maria occurred in 2017, causing malfunctions in logistics. Port Houston and Texas paused their operations for six days, while ports in Florida and Georgia for three, and substantial losses were noted in global trade.³²

Research findings have clearly demonstrated that the operational efficiency of vessels can be significantly hampered when weather forecasting is unreliable. This is because the forecasting of weather conditions in the maritime environment is a key factor in route-planning. The sea and air conditions directly influence the time and fuel consumption of a vessel, which in turn affects its ETA. Therefore, the climate circumstances of the route followed during a transportation trip are a critical consideration for vessel operators.

³² The Three Major Hurricanes of 2017: Harvey, Irma and Maria, First published: 15 December 2017
Last updated: 21 April 2023, access 21 April 2023

It is essential to mention that IMO has established the Polar Code, the code for vessels moving in Polar seas. Complying with the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL), the Polar Code sets the minimum standards in designing, shipbuilding, equipment, training, and operating, search and rescues procedures and protection of the environment for vessels traveling in the Antarctic and Arctic waters, issued since the 1st of January 2017.³³

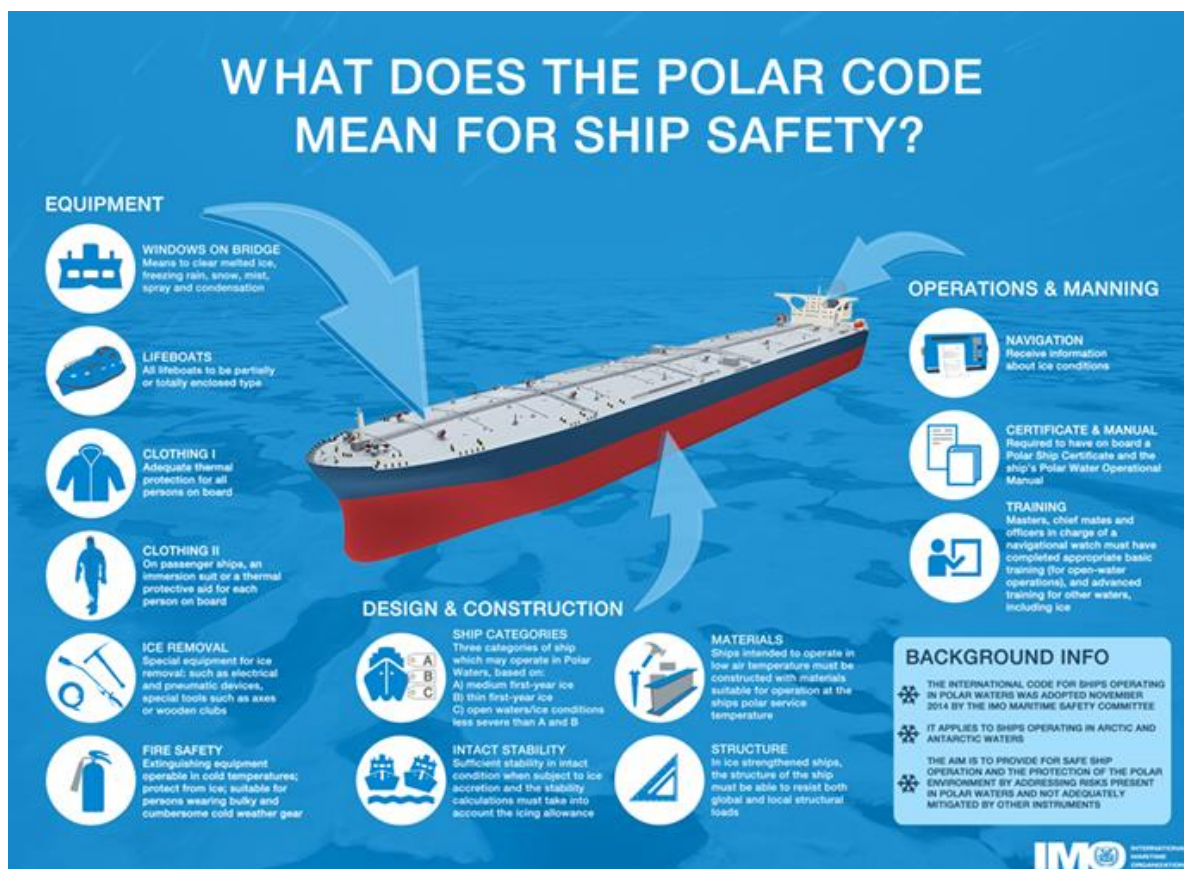


Figure 16: What does the Polar Code mean for ship safety? International Code for Ships Operating in Polar Waters (Polar Code), <https://www.imo.org/en/ourwork/safety/pages/polar-code.aspx>

Geopolitical conditions

In the last decade, the global society has observed important geopolitical and sociopolitical issues, unbalancing national economies and international trade relations. In particular, the

³³ IMO International Code for Ships Operating in Polar Waters (Polar Code)

most recent geopolitical tensions, the Houthi attacks in strategic maritime areas like the Red Sea and Bab El-Mandeb Strait, have significant implications for maritime trade. Conflicts among Houthi and allies in the Red Sea are of high navigation significance. Sailing through the Red Sea mitigates the distance and time for intercontinental transportation between Asia, Africa, and Europe. Moreover, conflicts at the Strait of Hormuz and the South China Sea obstruct transportation operations and navigating through sea areas, indicatively in Somalia territory, and the Gulf of Guinea is risking vessels' crew and cargo due to piracy and armed attacks phenomena on vessels.

First of all, the safety and security of human life are threatened by attacks on civilian ships moving in areas where geopolitical disputes are taking place. Consequently, either shipping lines prefer routing modifications to avoid routes of great danger or choose special insurance premiums that augment the operational cost. Massive routing adjustments result in delays since an alternative path is selected for many operating ships, the movement of which leads to route congestion. Considering the Red Sea's risky circumstances for navigation, an alternative shipping lane is through Cape of Good Hope, which is longer but safer.³⁴

Robust shipping networks - Strategic crossing points restrictions

Crossing points of high strategic significance ensures smooth maritime circulation and the shortest travel time. Canals and straits are indicative of such locations that enable time-saving transportation since they link areas of different regional seas when alternative paths are much longer, requiring a more extended traveling period and fuel consumption. Navigating through canals is crucial for transportation efficiency. However, restrictions imposed due to natural disasters or collapses cause sea traffic congestion, passing on ports' operations.

Panama Canal is a strategic waterway connecting the Atlantic with the Pacific Ocean. It is widely known for its function of using locks to lift and draw down the surface of the water level and transport vessels simultaneously. These locks were constructed before and after the artificial lake Gatun in order to facilitate the ships' navigation through it. Nevertheless, climate change causes severe drought, reducing the water level tremendously and forcing the Panama Canal Authorities to impose traffic restrictions, which reduced vessel

³⁴ Article Red Sea Shipping Alternatives to Avoid Trade Disruption, By [Natalie Kienzle](#) January 11, 2024

transitions by up to 40% for the last semester of 2023. Ships queued outside the canal, waiting for their turn to come, while other shipping lines were forced to reschedule routes.³⁵ Additionally, navigation would be permitted for smaller ships, as their dimensions would permit them to traverse the canal.

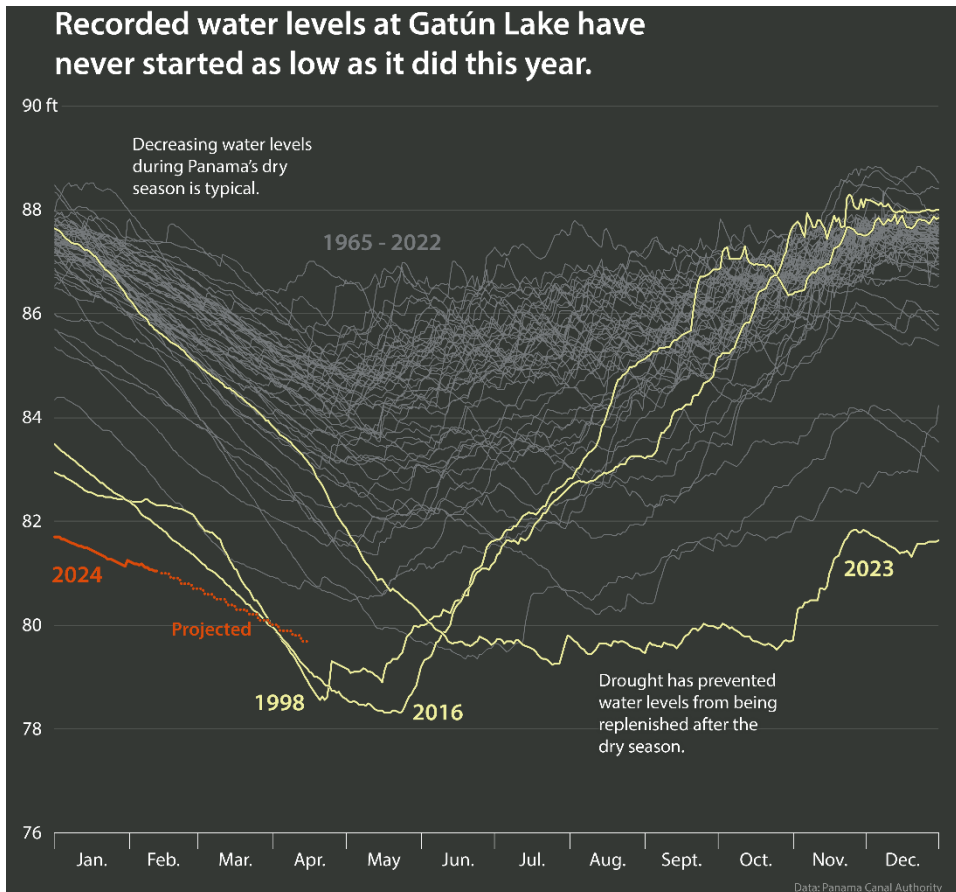


Figure 17: Recorded water levels at Gatun Lake. Source: Drought in Panama is disrupting global shipping. These 7 graphics show how, Woodwell Climate Research Center, Sarah Ruiz, Christina Shintani, Feb 20, 2024, Data: Panama Canal Authority

The Panama Canal Authority operates a slots allocation system that had to be adjusted to the new circumstances. However, the enormous decrease in freight transport, in combination with the weather conditions that improved the water level status, has led to a slight increase in the number of slots provided.

³⁵ Source: Drought in Panama is disrupting global shipping. These 7 graphics show how, Woodwell Climate Research Center, Sarah Ruiz, Christina Shintani, Feb 20, 2024, Data: Panama Canal Authority

A re-assessment of the current conditions provides a optimistic prediction that Panama Canal services will be restored and traffic limitations will be gradually lessened until 2025.³⁶

Suez Canal's blockage in 2021, caused by a containership grounded while crossing the canal, led to a six-day pause of operations, with significant implications for the global supply chain, added to the uncontrollable alterations of demand during the COVID-19 period. The Suez Canal constitutes a part of a huge number of shipping lanes connecting European, Asian, and African ports. When forced to stop its transit operations, maritime transportation dropped, and significant financial losses were noted. The impact of European ports was low due to their transportation and economic development, which was less dependent on the Suez Canal operations. However, Asian ports suffered an up to 80% decrease in cargo transport volume since they became less attractive and competitive.³⁷ Qualitative method research has proved that such a disruption's impact is intense in global trade, even when compared with a "random attack " in the maritime network (deletion of the links' number in the whole network, which is the same number as all the lanes crossing the Suez Canal). In conclusion, this disruption caused shipping companies to re-plan the routes, port calls, and timetable adjustments, while delivery delays augmented cargo obsolescence.

Cybersecurity

Cyber-attacks constitute a challenging field for maritime security, rising from the extended use of technology applications for information exchange among ships, operational centres and port management departments. Hackers, whose interest focuses on sensitive information phishing and interfering with essential navigational systems, like the Electronic Chart Display and Information System (ECDIS), the Automatic Identification Systems (AIS), the Global Navigation Satellite System (GNSS), and the Global Positioning Satellite (GPS), aiming to potential economic fraudulent benefits and misrouting. Cybersecurity is crucial for both shipping and port operations. Digital attacks

³⁶ World Cargo news, Panama Canal increases daily slots in Panamax locks, Jasmina Ovcina Mandra, 12 Mar 2024, <https://www.worldcargonews.com/news/2024/03/panama-canal-increases-daily-slots-in-panamax-locks/>

³⁷ Journal Ocean and Coastal Management, Analysis of the impact of Suez Canal blockage on the global shipping network, Zheng Wan, Yingyu Su Zimu Li, Xin Zhang, Qiang Zhang, Jihong Chen, 11 October 2023 www.elsevier.com/locate/ocecoaman

may affect terminal systems, expanding their negative implications through the logistics system in no time, causing disruptions in local, regional, national, and international trade development. Automated integrated and digital communication systems are vulnerable to cyber threats due to their dependence on the function of digital networks. TOS, responsible for operational continuity, automatically activates devices according to the data provided.³⁸ IMO has circulated guidelines on cybersecurity, which include strong suggestions for confronting cyber threats. The guidelines present the current situation and potential risks and sensitivities of the maritime industry. National authorities—members of IMO—should insert these directions within the already existing safety policy.³⁹

Cooperation Barriers

The culture of the entities acting for the maritime industry's smoothness determines the evolution of global supply chain operations. Stakeholders' mentality affects their communication levels and willingness to share important information. Efficient cooperation is strongly dependent on the transparency and reliability of the updated information flow. The maritime industry demands prompt communication among traders and consignees from different countries within different time zones. Common terminology is used worldwide to achieve adequate understanding among the corps involved. Transactions, financial agreements, and claims depend on communication efficiency, which includes the quality and quantity of information shared. The maritime market is constructed to work constantly, containing contractual procedures, INCOTERMS, and global trade's realization. Decision-makers should be able to access important information at any time and evaluate the current conditions.

National authorities constitute an influential sector that executes national legislation, implements policies, and participates in port management. However, they need to improve in adjusting to new circumstances and industry challenges. Technology systems in the public domain cannot support demanding functions, while human resources management is less often as productive as the circumstances require due to the expertise low level, adjustment resistance, and lack of flexibility. Besides, information exchange is less than in the private sector, and governmental entities cannot conform to the market's density. In

³⁸ Journal Cybersecurity in ports and maritime industry: Reasons for raising awareness on this issue, Pena Zarzuelo, 2021

³⁹ IMO, Maritime cyber risk <https://www.imo.org/en/OurWork/Security/Pages/Cyber-security.aspx>

many countries, administrative personnel act in fraudulent practices with illegal economic benefits. Digitalized strategies augment transparency and reduce fraudulent phenomena. Since national authorities participate in the supply chain's productiveness among other participants of port operations, it is crucial to acquire modernized equipment and updated skills to assist effectively in maritime activities.

Route planning is altered according to various conditions, including increased operational costs, heightened security risks, and further financial implications passed on to port performance. Marine operations are thoroughly interrelated with shipping lanes, while the ETA and ETD are calculated according to the distance, time, and general and specific conditions of regions crossing. These unstable facts necessitate enhanced security measures, strategic planning, and international collaboration to eliminate their impact and ensure the continued flow of global maritime trade. Port performance vulnerability to threats is also important, and all stakeholders involved should lean forward to a secure operational environment and take significant measures in the respective fields. Slot allocation in the maritime industry demands flexibility, which is higher than in airline slot systems. Compared to the maritime sector, air transportation is safer and more protected from the mentioned phenomena than the maritime industry, climate conditions, and geopolitical disturbances. Thus, slot allocation in maritime operations can be implemented for short- and medium-term season programming, utilizing communication systems that transfer updated information promptly to the involved stakeholders, facilitating equipment and machinery setting out. Long-term slot allocation can be executed in pilot mode in order to evaluate whether long-range scheduling is applicable for port operations and at which level.

Chapter 4: The effect of Slot port's coordination in multimodal transport operations

4.1 Multimodal transportation and the land modes' share in global trade

In the previous chapters, multimodality was introduced as a transport function that directly receives the impact of port performance. Multimodal transportation, benefiting from the volume of each mode and their operational efficiency, is a boon for logistics. However, it is important to note that any malfunction in a mode can have a severe negative impact on logistics performance, leading to a significant downgrade in service quality. Port operations, in particular, have a substantial interaction with the land modes of activities. To understand this better, we will now discuss the land modes and their share in global trade.

Railway Network

Rail transportation is used worldwide due to its commodities land conveyance efficiency in the mainland. It possesses a share that varies with regard to the region. In European countries, it reaches 50 %, while in China, it records up to 80% of the commuting volume. According to statistical analyses, it is the least affected by the weather conditions land mode, providing competitiveness compared to road transportation. It presents significant privileges at a higher level than those offered in highway, maritime, and air modes of transportation. In particular, simultaneous huge capacity is combined with high speed, sustainability, and robustness when it comes to bad weather conditions. In the last decades, railway freight networks have been developed with regard to speed, time intervals for the loading/unloading process, and capacity. Particularly, trains have evolved into high-speed means of transportation long distances, which applies to freight conveyance too, decreasing transferring time, while waiting time for loading/unloading is importantly eliminated, increasing the network's productivity and lowering operational costs.

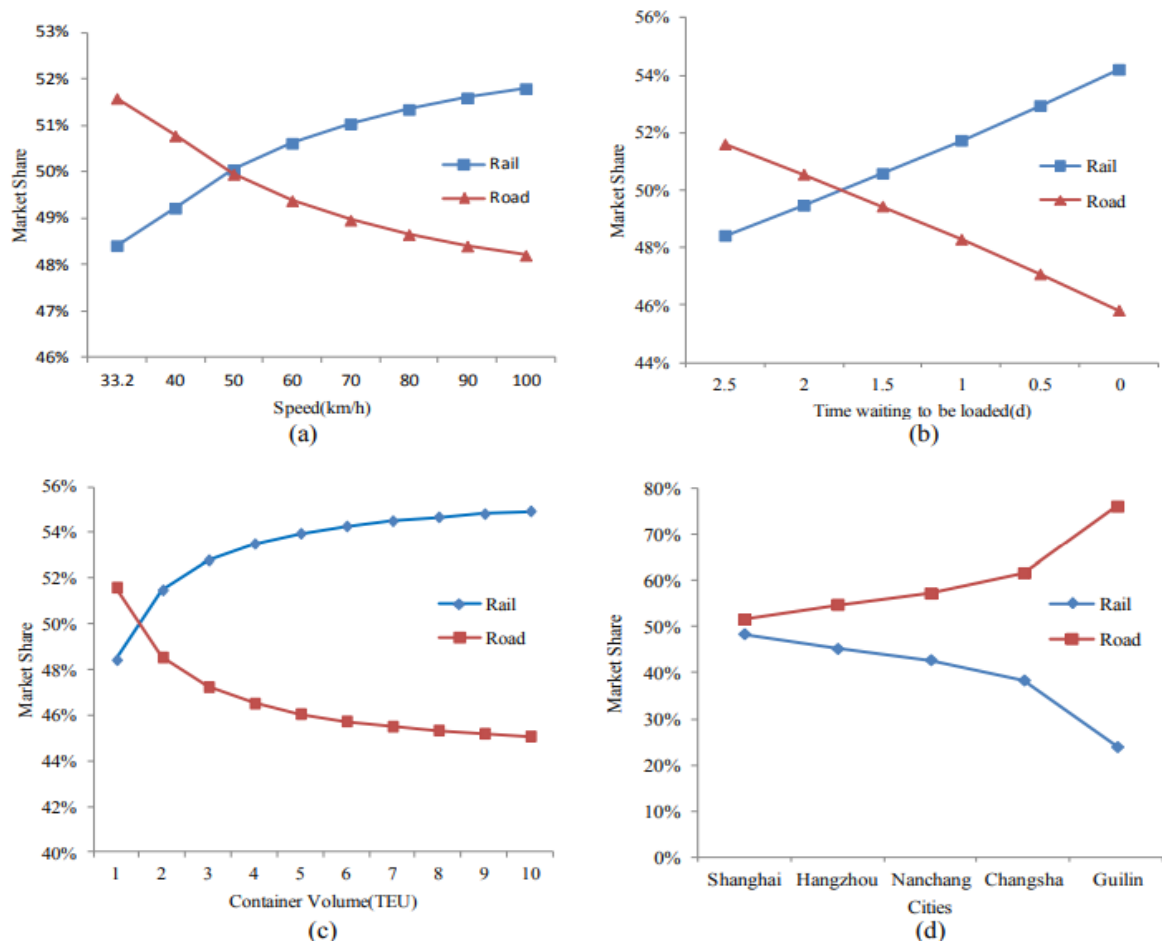


Figure 18: Impact of the four factors on the market share. Source: Research on Railway Freight Market Share Based on the Whole Process of Transport, Ruijia Shi*, Zhimin Hu, Yangfan Zhou, Penglei Liu, 2014

Although railway transportation is efficient over long distances, its speed capacity needs to improve comparably with air mode. Furthermore, for last-mile transitions the road network is preferable.

Road network

Road modality contributes to transportation efficiency in last-mile accessibility, which is conversely the case with the rest of the modes. Flexibility is the most critical advantage of cargo moving by this land mode, detecting not only the accessibility but also the adjustment of planning and routes according to the logistics demand. The mode's share in the total transportation network varies significantly. In 2022, it represented 24.9% of ton-kilometers in European territory. The development of road networks is thoroughly dependent on national economic policies. Highways and local roads facilitate cargo transportation by trucks with the corresponding capacity. Distributing commodities by

trucks occurs in distribution centers strategically established in or nearby or in a small distance from the ports. These establishments ensure storage and consolidation/deconsolidation of goods while enabling trade at local, regional, national, and international levels. Trucking and warehousing services, depending on the volume of cargo, are classified from less-than-truckload for short quantities up to full truckload for large quantities.⁴⁰ Regarding the type of cargo, the suitable type of truck is utilized: flatbeds, container chassis, and truck refrigerators. Low turnaround times are essentially small, facilitating sensitive cargo transportation and just-in-time delivery. Road transportation is efficient for small distances.

However, it's important to acknowledge the significant challenges in road operations. The limitations of the road network are a key factor in determining its share in global trade. The combination of low to medium speed, low capacity, and high GHG emissions hampers the efficiency of road commuting. Furthermore, its reliability is severely prevented by congestion, which is a major concern. These challenges underscore the need for alternative solutions like the TEN-T strategy.

It is important to mention the Trans-European Transport Network (TEN-T) strategy, a helpful tool issued by the European Union (EU) for the improvement and efficiency of multimodal services involving rail, maritime, inland waters, road, and air modes. The TEN-T is implemented to facilitate freight and passenger transportation, contributing to local, regional, national, territorial, and international economic growth and tapering member states' trading relationships. Addressing the mitigation of carbon footprint is also being revised about the minimum standards for decarbonization goals, according to [the European Green Deal](#) and [Sustainable and Smart Mobility Strategy](#).⁴¹

4.2 Dependence of multimodality on port's operations.

Rail transportation connectivity with the maritime industry, often called "rail-sea intermodal transport", is crucial for optimizing global supply chains. This connection leverages the strengths of both rail and maritime transport to enhance efficiency, reduce

⁴⁰ Less-Than-Truckload Definition and Shipping Service Basics, By TROY SEGAL, Updated December 27, 2022, Reviewed by DAVID KINDNESS

⁴¹ https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en

costs, and improve environmental sustainability. Ports where a significant amount of trade is transferred are accommodated into their infrastructure, and rail networks are established to facilitate intermodal transportation. Modern railway infrastructure connects ports with mainland and industrial areas. Specifically, in the so-called intermodal terminals, sufficient equipment functions are dedicated to conveying cargo among different networks. Containers are efficiently transferred from ships to trains and vice versa. Rail cars are designed in that way to serve container transportation, eliminating delays and casualties. Developed train services provide containers double-stacking, maximizing the transported amount of freight. Hence, operational time and costs are reduced, contributing to the performance's augmentation. The economies of scale are improved due to the mitigation of per unit operational cost. The sea-rail transportation elements are crucial for the global supply chain. The benefits of combined transportation are significant volume, cost-effectiveness, sustainability, and reliability.

Rotterdam and Antwerp are two essential ports established in Europe, conveying a significant volume of global trade. In Rotterdam, 438 million tons of cargo annually are transported by 28.000 seagoing ships and 90.000 inland annually.⁴² Antwerp port contributes to the 58.3 million metric tons of cargo moved by 3.351 seagoing vessels.⁴³ Both consist of European ports leveraging sea-train interactivity, facilitating freight transportation regionally, nationally, and across the European extension.

The road network's connectivity with maritime transportation is critical for worldwide logistics efficiency since it gains the benefits that the specific land mode offers. Flexibility and the ability to reach remote areas are crucial for facilitating effective cargo movement. Door-to-door services contribute to last-mile distribution. In particular, ports are linked with huge highways and local networks via road infrastructure designed to connect the different networks. Thus, the transition is direct, and the time for both freight and passenger conveyance is minimized.

The yard should be more than adequate in container terminals, the pivotal in-between node for containers' transshipment. It needs to be able to accommodate the physical infrastructure of road, rail, and maritime operations, including tracks, flatboats, and trains, among others. The following image provides a comprehensive view of the general concept

⁴² <https://www.portofrotterdam.com/en/experience-online/facts-and-figures>

⁴³ <https://newsroom.portofantwerpbruges.com/port-of-antwerps-quarterly-figures-confirm-importance-of-merger-and-extra-container-capacity>

of terminals' transshipment operations, highlighting the crucial role these terminals play in the smooth flow of freight movement.

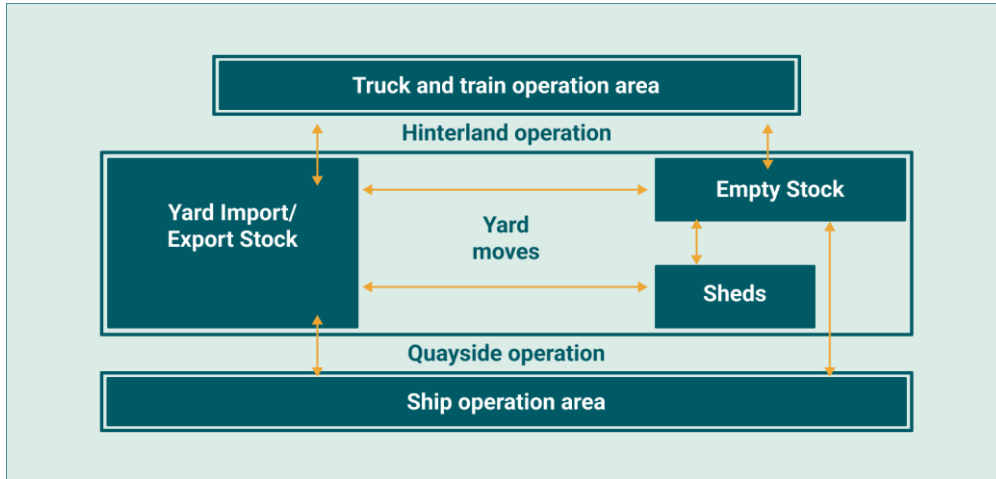


Figure 15: Container Terminal display Source: xChange, What is a container terminal? Types & top terminal operators (2024), Abigail Munroe, November 30, 2022

Container ports consist of crucial hubs where significant international trade is imported and exported. Seamless operations are ensured by adequate physical and digital equipment that provide flexibility potentials to avoid pauses. Shipping companies choose terminals regarding operational efficiency, that is, terminals that combine high-quality services and cost-effectiveness.⁴⁴ Modern facilities and capacity exploiting AI applications enhance vessel services on time, reducing periods and operational costs. Moreover, container terminals are marching towards achieving decarbonization standards set by international regulations using sustainable strategies such as alternative or hybrid energy sources, managing waste, and automated systems, eliminating carbon footprint. Thus, container ports' immediate impact on the supply chain and operational smoothness is valuable.

⁴⁴ Jeh, J., Nam, J., Sim, M., Kim, Y., & Shin, Y. (2022). A study on the efficiency analysis of global terminal operators based on the operation characteristics. *Sustainability*, 14(1), 536. <https://doi.org/10.3390/su14010536>

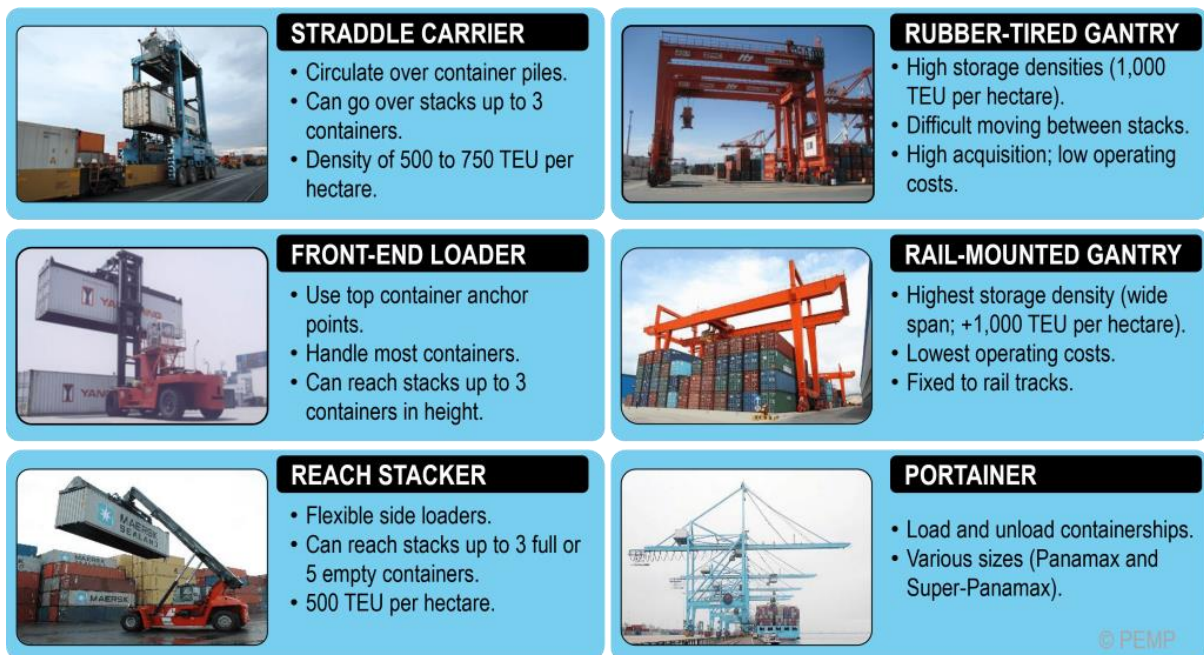
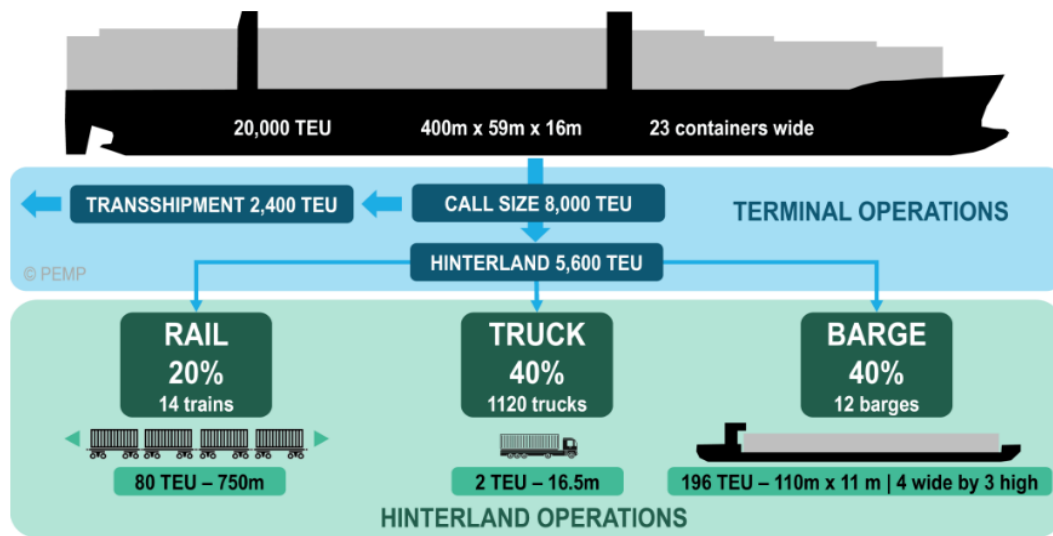


Figure 20: Cargo handling equipment. Source: Port Economics, Management and policy, A comprehensive analysis of the port industry, Impact of 20,000 TEU Vessel Call on Inland Transport, by Theo Notteboom, Athanasios Pallis and Jean-Paul Rodrigues 92022

Figure 20 shows indicative elements of the operational handling equipment machinery acting in terminals for cargo transshipment. The digitalization of the maritime industry has led to the modernization of the equipment, especially for the straddle carriers, gantries, and portainers, which are monitored remotely and function automatically.

Both Antwerp and Rotterdam ports' operations have developed multimodal functions, splitting the containerized cargo transported in 40/40/20 portions, that is, 40% loaded to trucks, 40% to barges, and 20% to trains, to service approximately 70% of 8,000 TEU call volume. The rest 30% is cargo to be transshipped. Large numbers of trucks, vehicles, and barges are required for the smooth inland distribution of commodities, which may lead to sea and land congestion. Therefore, the augmentation of land modes and barges capacity should be examined while shipbuilding provides the maritime industry with larger vessels. Vehicles and distribution networks should adequately service the hinterland and sea transshipment.



Impact of a call of a 20000 TEU vessel on inland transport

Figure 21: Impact of a call of a 20000 TEU vessel on inland transport. Source: Port Economics, Management and policy, A comprehensive analysis of the port industry, Impact of 20,000 TEU Vessel Call on Inland Transport, by Theo Notteboom, Athanasios Pallis and Jean-Paul Rodrigues 92022)

4.3 Slot port's coordination effect on multimodal transportation efficiency

Slot coordination is a crucial component of multimodal transportation, significantly influencing the supply chain's efficiency, reliability, and sustainability. Effective slot coordination requires up-to-date technology, stakeholder collaboration, and regulatory compliance. By addressing the challenges and leveraging suitable strategies, ports and logistics providers can enhance the seamless integration of different transport modes, optimize resource utilization, and improve overall supply chain performance.

Slot coordination in multimodal transportation is the dynamic scheduling and allocation of time slots for the arrival, departure, and transfer of cargo across different modes of transport, such as maritime, rail, and road. The significance of effective slot coordination cannot be overlooked, as it plays a crucial role in optimizing the use of infrastructure, reducing delays, and ensuring the uninterrupted flow of goods through the supply chain. Here's a comprehensive analysis of slot coordination and its pivotal role in multimodal transportation:

Port time slots, as described, are allocated for necessary vessel operations at the ports, particularly loading/unloading, transshipment of freight to other ships or means of transportation, etc. Port time slots can be synchronized with train and road time slots, enhancing multimodal efficiency. Road and train time slots are applied to coordinate

picking up and delivering freight functions at ports, terminals, and inventory attics. Intermodal coordination ensures that route and timetables planning for the cooperating modes conduct just-in-time cargo conveyance, preventing disruptions and minimizing time intervals. For that reason, digital applications exploiting e-platforms work on communication and timely information exchange. Stakeholders involved receive necessary information and act respectively. Equipment and infrastructure available are scheduled to function with regard to slot allocated time, ensuring that ports' capacity, road and train network establishments inside the port's yard are utilized efficiently. Slot allocation contributes to the contingency plans and strategies to be followed for cases where operations are paused or delayed due to unprojected conditions. Buffer zones assist the uninterrupted movement of cargo inside a port's yard. Specifically, the loading and unloading (for containerships) procedure is performed by AGVs, assisted by AGV mate. Buffer zone establishment is significant, especially when congestion pressure is presented, and AGVs should continue to circulate along the port's space. In cases where systems have provided data to the stakeholders concerning significant possibilities of cargo congestion, AGVs should be planned out to stay in the buffer zone as a temporary parking space. At this stage, bottlenecks are prevented, and AGVs consume low levels of energy, contributing to sustainable operational port strategies.⁴⁵ Similar functions operate to automated container terminals (ACT) globally.

Vessel loading/ unloading operations are thoroughly connected with the corresponding functions of trucks and train networks. Truck waiting times depend on slot coordination; thus, time slot management systems (TSMS) are inserted to monitor and audit trucks' movement into maritime terminals, reducing congestion issues on both maritime and land modes. Accordingly, the deficient port performance and the existence of congestion issues provoke delays and augmentation of waiting times for trucks at the terminal gates. Hence, TSMS is designed to exchange information flows among port and mainland operations participants. Tracking companies access to the systems providing essential data, in order to schedule pick-up procedure. Based on those data, trucking operating firms adjust trucking activities and warehousing. Moreover, trucks placement or temporary parking is subject to research for efficiency in transshipment.

⁴⁵ Analysis and Design of Typical Automated Container Terminals Layout Considering Carbon Emissions, Nanxi Wang, Daofang Chang, Xiaowei Shi, Jun Yuan and Yinping Gao, Published: 24 May 2019

Likewise, train network connectivity with maritime operations can be synchronized with slot coordination tools applied in common for both modes as a superior system. This specific approach facilitates all components' operations, including shippers, carriers, railway operators, etc. Slot coordination does not constitute a new time management policy for trains. Railway functions should be accomplished according to programming and adjusted when needed. Rail time slot systems allocate time regarding the time required for transportation services. They accept information and export results, respectively, indicating in a visible way the trips that ought to be carried out, when to arrive/depart, the picking-up process, and other cargo activities. Interrelating usefully with port operations is critical for the supply chain's performance optimization, given that the coordination of integrated transferring systems is highly complex. The slot allocation for trains is acted by the operator of the terminal, already implemented in many cases for dynamic planning based on the ETA and ETD. Port railway operations are programmed to eliminate dwell time for the remaining trains in the yard. Transshipment is calculated given a time range to be completed⁴⁶

A container terminal's activities are assumed; it is considered that 25 trucks are serviced simultaneously at the terminal's gate. The drivers present the necessary bill of lading (BoL) to automated systems, utilizing remote inspection functions. An inspector can remotely confirm the identification number of the container with the one indicated on the BoL without any hardcopy documentation being provided. All significant elements are recorded to digital platforms, secured, and transparent. Audits executed for the verification of chassis', driver, truck, and container evidence are accelerated, thanks to the function of modern systems, data transparency, and accessibility by the entities involved. Slot allocation enables pick up/ drop off appointments setting, and a time slot is assigned to the truck as well to remain at a designated space of the yard till the container is loaded. Straddle carriers or gantry cranes pick up the container from the yard, establish it on the chassis, if not provided by the truck, and deliver it. When exiting from the terminal, the truck is controlled so that the container loaded is the right one and proceeds to the final destination. However, delays happen during the picking-up process due to the large group of containers and the pressure put on unloading. Currently, appointments are implemented

⁴⁶ Scheduling rail freight node operations through a slot allocation approach, Dipl.-Verkehrswirtschaftler René Schönemann, 31. Mai 2016

by terminal operators and synchronized with vessel slots and port calls, assisting in minimizing picking-up and dropping-off delays.

Interrelation with rail terminals established in the expansion of port terminal or adjacent to facilitate direct intermodal transshipment. The railway network's capacity on-dock or near-dock exploits scalability through the arrangement of large rail units dedicated to container conveyance for long distances. Both options appear either individually or combined in ports where cargo is transferred to the hinterland.⁴⁷ Gate's verification procedure is not included, and therefore, sea-railway connectivity is not considered time-consuming, but more efficient than road mode, given the ability to transfer promptly higher freight volumes over longer distances.

4.4 Potential system's extension

In order to consider slot allocation further usage, it is necessary to recall the capabilities, limitations, and threats and, according to them, suggest the system's potential.

In chapter 3 of this paper, advantages and drawbacks were analyzed, emphasizing the consequences of slot distribution. Moreover, the interrelation with social, political, environmental, etc. factors were discussed as they directly affect the time of arrival and, thus, port operations and global supply chain management. Nonetheless, the maritime industry is progressing to digitalization, exploiting new technologies onboard or at port operations. Automated equipment eliminated human resources and intervention, increasing transparency and accelerating the processes. Decarbonization goals set globally for shipping trade are achieved thanks to modernized systems. JIT policy implemented for port calls reduce fuel consumption. Therefore, acknowledging arrival time leads to speed adjustment and avoidance of waiting outside the port. Finally, combined with dual or hybrid fuel shipbuilding, maritime conveyance is one of the most sustainable modalities in global trade.

Though, not everything is perfect. Slot systems require robustness of the network and credibility of the data provided. Information flows should be secured and on time. Severe cyber threats and networks crashing down may cause high financial losses. The impact of slot function is direct, especially on multimodal transportation. A SWOT analysis is

⁴⁷ Port Economics, Management and policy, A comprehensive analysis of the port industry, Impact of 20,000 TEU Vessel Call on Inland Transport, by Theo Notteboom, Athanasios Pallis and Jean-Paul Rodrigues 92022

provided below to summarize the pros and cons discussed and give the basis for the potential system's extension.

SWOT ANALYSIS	
Strengths	Weaknesses
<ul style="list-style-type: none"> • Defining the time of ships' arrival based on which port operations are planned • On-time information flow • Massive amount of data exchange, edit, saved • Adjustment to new data provided • Analytical features of vessels' position, size, and travel displayed • Necessary for port congestion confrontation • No need for new devices – utilizes data from already established systems • Facilitates scalability for the port's resource exploitation • Prediction for slot allocation in the future • Reduction of environmental pollution • Upgrading the local level of living indirectly • Elimination of operational costs for shipping companies and port authorities • Contributes to multimodal efficiency 	<ul style="list-style-type: none"> • A large number of information flows requires a robust network and machinery • Effectiveness interacting with port and other modalities operations. • Dependence on the maritime industry's powers.

Opportunities	Threats
<ul style="list-style-type: none"> • Ports where congestion is presented. • Maritime industry's digitalization • Integrated Slot allocation system for Terminal/multimodal transportation, distributing timestamps for different modalities in parallel 	<ul style="list-style-type: none"> • Cyberthreats • Weak network and equipment • Social, political, geological disruptions minimize slots allocation efficiency • Lack of willingness by stakeholders involved conducts to ineffective communication

Table 2: SWOT Analysis for Slot Allocation system

Since different time slot systems are applied more or less to most modalities, constructing an integrated slot management system is suggested for multiple modalities' operations within a common frame, assisting direct cooperation among them. Software's robustness for slot management applied to more than one mode is critical for the initial planning, monitoring procedures, evaluating historical data, and rescheduling. Platforms exploiting upgraded technology enable participating stakeholders to exchange necessary information and act correspondingly. It is a tremendous amount of data to be edited, inserted, and exported. Therefore, slot allocation systems should be resilient for the efficient cooperation of different modes.

As we move forward, it is crucial to conduct further research on the proposed integrated slot distribution system. This research should not only highlight the benefits of a system that coordinates the timestamps within multimodal operations but also address potential disadvantages. These could include the impact of data losses or digital platform malfunctions on the management of all cooperating modalities, and the quantitative calculations of such implications. It is also important to consider whether an alternative system or strategy should be activated in such cases. We must be cautious of overreliance on satellite and digital systems, as they may lead to the dissemination of false information. Therefore, alternative methods and training on these should be integrated into multimodal functions.

Bibliography

Academic Papers:

Advanced material handling: automated guided vehicles in agile ports. (2000, January). Center for Commercial Deployment of Transportation Technologies

Slot coordination in ports presenting congestion issues and its effect on multimodal transport operations: A critical analysis 60

- Ahmad, R. W., Hasan, H., Jayaraman, R., Salah, K., & Omar, M. (2021). Blockchain applications and architectures for port operations and logistics management. *Research in Transportation Business & Management*, 41, 100620. <https://doi.org/10.1016/j.rtbm.2021.100620>
- Atig, M. (2020). Supply chain risk management and the role of organisation culture : evidence from Libyan ports. Retrieved from <https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.800457>
- Bueger, C., & Liebetrau, T. (2023). Critical maritime infrastructure protection: What's the trouble? *Marine Policy*, 155, 105772. <https://doi.org/10.1016/j.marpol.2023.105772>
- Chen, P., Fu, Z., Lim, A., & Rodrigues, B. (2004). Port yard storage Optimization. *IEEE Transactions on Automation Science and Engineering*, 1(1), 26–37. <https://doi.org/10.1109/tase.2004.829412>
- De La Peña Zarzuelo, I. (2021). Cybersecurity in ports and maritime industry: Reasons for raising awareness on this issue. *Transport Policy*, 100, 1–4. <https://doi.org/10.1016/j.tranpol.2020.10.001>
- Group, T. & F., Notteboom, T., Pallis, A., & Rodrigue, J. (2022a). *Port Economics, Management and Policy*. Routledge
- Group, T. & F., Notteboom, T., Pallis, A., & Rodrigue, J. (2022b). *Port Economics, Management and Policy*. Routledge.
- Kienzle, N. (2024). Red Sea Shipping Alternatives to Avoid Trade Disruption. *Customs Clearance*. Retrieved from <https://usacustomsclearance.com/process/red-sea-shipping-alternatives/>
- Hervás-Peralta, M., Poveda-Reyes, S., Molero, G. D., Santarremigia, F. E., & Pastor-Ferrando, J. (2019). Improving the Performance of Dry and Maritime Ports by Increasing Knowledge about the Most Relevant Functionalities of the Terminal Operating System (TOS). *Sustainability*, 11(6), 1648. <https://doi.org/10.3390/su11061648>
- Jeh, J., Nam, J., Sim, M., Kim, Y., & Shin, Y. (2022). A study on the efficiency analysis of global terminal operators based on the operation characteristics. *Sustainability*, 14(1), 536. <https://doi.org/10.3390/su14010536>
- Lam, J. S. L., & Su, S. (2015). Disruption risks and mitigation strategies: an analysis of Asian ports. *Maritime Policy and Management/Maritime Policy & Management*, 42(5), 415–435. <https://doi.org/10.1080/03088839.2015.1016560>
- Lam, J. S. L., & Yap, W. Y. (2008). Competition for transshipment containers by major ports in Southeast Asia: slot capacity analysis. *Maritime Policy and Management/Maritime Policy & Management*, 35(1), 89–101. <https://doi.org/10.1080/03088830701849043>
- Liu, J., Zhang, H., & Zhen, L. (2021). Blockchain technology in maritime supply chains: applications, architecture and challenges. *International Journal of Production Research*, 61(11), 3547–3563. <https://doi.org/10.1080/00207543.2021.1930239>
- Rodrigue, J. (n.d.). *The Geography of Transport Systems*. Retrieved from <https://doi.org/10.4324/9781003343196>
- Schönemann, R. (2016). Scheduling rail freight node operations through a slot allocation approach. <https://doi.org/10.14279/depositonce-5452>
- Shi, R., Hu, Z., Zhou, Y., & Liu, P. (2014). Research on railway freight market share based on the whole process of transport. *Procedia: Social & Behavioral Sciences*, 138, 298–304. <https://doi.org/10.1016/j.sbspro.2014.07.207>

- Srour, F. J., Van Oosterhout, M., Van Baalen, P. J., & Zuidwijk, R. (2008). Port Community System Implementation: Lessons Learned from International Scan. ResearchGate. Retrieved from <https://www.researchgate.net/publication/236278299>
- Vukić, L., & Lai, K. (2022). Acute port congestion and emissions exceedances as an impact of COVID-19 outcome: the case of San Pedro Bay ports. *Journal of Shipping and Trade*, 7(1). <https://doi.org/10.1186/s41072-022-00126-5>
- Wachnicka, A., Armitage, A. R., Zink, I., Browder, J., & Fourqurean, J. W. (2020). Major 2017 Hurricanes and their Cumulative Impacts on Coastal Waters of the USA and the Caribbean. *Estuaries and Coasts*, 43(5), 941–942. <https://doi.org/10.1007/s12237-020-00702-7>
- Wang, N., Chang, D., Shi, X., Yuan, J., & Gao, Y. (2019a). Analysis and design of typical automated container terminals layout considering carbon emissions. *Sustainability*, 11(10), 2957. <https://doi.org/10.3390/su11102957>
- Wang, N., Chang, D., Shi, X., Yuan, J., & Gao, Y. (2019b). Analysis and design of typical automated container terminals layout considering carbon emissions. *Sustainability*, 11(10), 2957. <https://doi.org/10.3390/su11102957>
- Xu, B., Li, J., Liu, X., & Yang, Y. (2021). System Dynamics Analysis for the governance measures against container port congestion. *IEEE Access*, 9, 13612–13623. <https://doi.org/10.1109/access.2021.3049967>
- Mindur, M. (2020). SIGNIFICANCE OF THE PORT OF SINGAPORE AGAINST THE COUNTRY'S ECONOMIC GROWTH. *Zeszyty Naukowe - Politechnika Śląska. Transport/Scientific Journal of Silesian University of Technology. Series Transport*, 106, 107–121. <https://doi.org/10.20858/sjsutst.2020.106.9>

Books:

- Brooks, M. R., & Cullinane, K. P. B. (Eds.). (2007). *Devolution, Port Governance and Port Performance*. Research in Transportation Economics, Volume 17. Elsevier.
- Talley, W. K. (Ed.). (2009). *Port Economics*. Routledge.
- Song, D. W., & Panayides, P. M. (Eds.). (2012). *Maritime Logistics: A Guide to Contemporary Shipping and Port Management*. Kogan Page.
- Cullinane, K., & Talley, W. K. (Eds.). (2006). *Port Economics: Research in Transportation Economics*, Volume 16. Elsevier.
- Mašović, M. (2019). *Port Call Efficiency Optimization, Using Data Analysis, Process Mining and Discrete Event Simulation*. TU Delft Repositories. Retrieved from <http://resolver.tudelft.nl/uuid:235714fc-d2b1-4feb-bbf2-b00c8d01e743>
- Meteorological factors that impact on shipping. (n.d.). Retrieved May 20, 2024, from <https://maritimesa.org/grade-10/meteorological-factors-that-impact-on-shipping/>

Reports and Industry Publications:

- UNCTAD Handbook of Statistics 2023. (2023). *Manuel de statistiques de la CNUCED/UNCTAD handbook of statistics/Handbook of international trade and development statistics* - United Nations. <https://doi.org/10.18356/9789213585535>

IMO (Ed.). (n.d.). Resolution MEPC.377(80) Adopted on 7 July 2023. 2023 IMO Strategy on Reduction OF GHG Emissions from ships.

International Electrotechnical Commission [IEC]. (n.d.). Maritime navigation and radiocommunication equipment and systems Automatic identification systems (AIS). Interantional Standard

World Bank. (2016). "Port Development and Competition in East and Southern Africa: Prospects and Challenges." World Bank Group. Available at: World Bank Port Development Report

Global Environment Facility [GEF], United Nations Development Programme [UNDP], & IMO. (n.d.). Just in Time Arrival Guide – Barriers and Potential Solutions

Maritime Labour Convention, 2006. (2024, May 30). Retrieved from <https://www.ilo.org/international-labour-standards/maritime-labour-convention-2006>

Trans-European Transport Network (TEN-T). (n.d.). Retrieved from https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en

Articles and News:

Lloyd's List. (2021). "Port congestion: The chronic problem set to intensify." Available at: Lloyd's List Port Congestion Article

The Loadstar. (2021). "How port congestion is wreaking havoc on supply chains." Available at: The Loadstar Port Congestion Article

Journal of Commerce. (2021). "Port congestion worsens as supply chains brace for peak season." Available at: Journal of Commerce Port Congestion Article

Maritime Executive. (2021). "The global impact of port congestion." Available at: Maritime Executive Port Congestion Article

Airports Council International [ACI], World Wide Airport Coordiantion Group [WACG], & IATA. (2023). Worldwide Airport Slot Guidelines (WASG) (3rd ed.)

Drought in Panama is disrupting global shipping. (2024, February 20). Retrieved May 25, 2024, from <https://www.woodwellclimate.org/drought-panama-canal-7-graphics/>

Ocean & Coastal Management | Journal | ScienceDirect.com by Elsevier. (n.d.). Retrieved from <https://www.elsevier.com/locate/ocecoaman>

Port of Antwerp's quarterly figures confirm importance of merger and extra container capacity. (n.d.). Retrieved from <https://newsroom.portofantwerpbruges.com/port-of-antwerps-quarterly-figures-confirm-importance-of-merger-and-extra-container-capacity>

References

Abigail. (2024, January 10). Container terminals: All you need to know [2024 guide]. Retrieved from <https://www.container-xchange.com/blog/container-terminals/>

Airport slots. (n.d.). House of Commons Library

The digital port. (n.d.). Retrieved from <https://www.portofrotterdam.com/en/to-do-port/futureland/the-digital-port>

Facts and Figures. (n.d.). Retrieved from <https://www.portofrotterdam.com/en/experience-online/facts-and-figures>

Less-Than-Truckload Definition and Shipping Service Basics, By TROY SEGAL, Updated December 27, 2022, Reviewed by David Kindness <https://www.investopedia.com/terms/l/lessthantruckload.asp>

Author's Statement:

I hereby expressly declare that, according to the article 8 of Law 1559/1986, this dissertation is solely the product of my personal work, does not infringe any intellectual property, personality and personal data rights of third parties, does not contain works/contributions from third parties for which the permission of the authors/beneficiaries is required, is not the product of partial or total plagiarism, and that the sources used are limited to the literature references alone and meet the rules of scientific citations.