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PhD THESIS SUMMARY

LOGISTIC CHAINS IN LINER MARITIME TRANSPORT

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Chapter 1. INTRODUCTION

1.1. Necessity of research topic

1.1.1. Introductory Elements

The liner shipping for goods is an integral part of international trade, facilitating the transfer of goods (typically in containers) through regularly scheduled services along specified routes.

Liner shipping involves the determination/design of at least the following elements:

- Selecting the ports of call, choosing the vessels, and determining the frequency of transport to configure the maritime transport line.
- Designing port operating technologies, including logistics processes, to ensure uninterrupted operation and efficient handling, maximizing the use of resources (quay cranes, port cranes, storage areas and warehouses, internal transport equipment and vehicles), including the allocation of handling and transfer machinery/equipment.
- Planning the stacking/storage of containers for minimal handling during ship unloading and loading, under complete security conditions, and therefore minimizing the ship's dwell time in the port.

Optimizing the technological processes in liner shipping leads to reduced operating times in ports and compliance with the total dwell times in ports, increased vessel operating efficiency, cost savings, and increased customer satisfaction. These can be realized through effective coordination of economic agents and port authorities, integrating advanced methods and technologies while adhering to standards and regulations. In this way, the maritime transport line can align with European policy objectives of shifting goods from road transport to other modes that have fewer negative environmental impacts, such as maritime, river, or rail transport.

1.1.2. European View on Maritime transport

Maritime transport, along with river and rail transport, represents one of the tools used in the global competition and the economic development of the European Union, as well as in achieving sustainable development goals.

a. EU Program "European Maritime Highways"

The "Maritime Highways" represent a course of action, part of the development program for the core network and priority corridors, aiming for a structural transformation of European transport by enhancing and promoting maritime transport in various regions and decongesting land transport networks (EC, 2008). Among these are the most important maritime transport routes called, for the resonance of the concept, "highways", such as the Baltic Sea Highway, the West European Sea Highway, the Southwest European Sea Highway (Western Mediterranean), and extensions to the Black Sea and onwards to the Danube. The fundamental concept of the "maritime highway" is liner shipping over short distances.

b. Short Sea Shipping (SSS)

Despite efforts made in most EU countries to promote the modal shift of goods from road to maritime mode over short distances, the results remain limited (Vanroye, van Bree & de Bruin, 2015). Even in the academic realm, research proves to be limited. Addressing these shortcomings can strengthen the European maritime transport industry (Baindur & Viegas, 2015). Given the expectation that intra-European maritime transport will increase, new infrastructure must be developed, and existing ones modernized to make short sea shipping more competitive. More importantly, this type of transport should be included in door-to-door logistics chains, by integrating it on one side with land transport and, on the other, with large transoceanic liner transport (Deep Sea Shipping), contributing to restoring the balance between different modes of transport (EC, 2013). Thus, the concept of inter-modal integration becomes applicable through the operation of liner ships, according to rigorous planning in maritime line terminals. This thesis, through its theoretical and practical research, can lead to the consolidation of knowledge, models/methods, and solutions for the development of short-distance maritime transport lines integrated into land logistics chains, which can alleviate congestion on Europe's major road transport routes.

1.1.3. Service Network Structure in Maritime Transport

1.1.3.1. "Hub-and-Spoke" Networks in Maritime Transport

The "hub-and-spoke" network structure is found in all transportation service networks and is defined through economies of scale effects (Popa, 2009). It is composed of ports of different categories and their corresponding maritime lines as follows:

- **"Hub" Ports** are situated on major international trade routes, functioning as large continental access terminals. They perform consolidation/deconsolidation functions for major primary flows of containerized goods, ensuring transfers between high-capacity mainline ships and vessels on the secondary ("feeder") lines (Fig. 1.1).
- **"Feeder" Ports** are regional access "gates" that are connected to other maritime ports through "feeder" type container ships of small and medium capacity.
- **"Trunk" Ports** are deep-water ports with large operational capacity where high-capacity mainline ships connect.

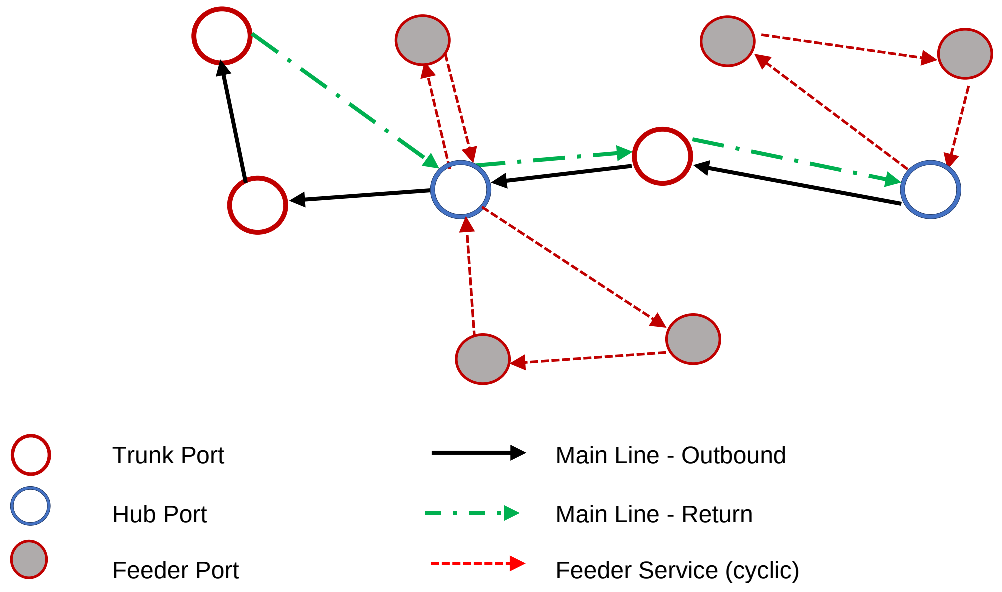

Figura 1.1. Maritime Network with "hub-and-spoke" Structure

Source: (Adapted from Styhre, 2010)

1.1.3.2. Short Sea Shipping vs. Deep Sea Shipping

Short Sea Shipping (SSS) and Deep Sea Shipping (DSS) are two essential components of the global maritime transport network, each having its own characteristics and operational requirements that distinguish them. Both facilitate international trade, but on different geographical scales, both having environmental impacts.

Although SSS and DSS have distinct operational characteristics and fulfill different roles in the global maritime transport system, both are vital for the functioning of national, regional, and global economies.

1.2. Literature Review in the Field of the Thesis

The synthesis of the literature in the field of the thesis (120 references) is structured along several study directions, as follows: (i) - Liner maritime transport and its characteristics; (ii) - existing models for optimizing container handling operations in the port terminal; (iii) – operations aboard the ship and models/methods for ensuring the ship's stability during loading/unloading operations and during navigation; (iv) - integration of information technologies in port handling and transfer processes.

1.3. Objectives of the Thesis

The general objective of the thesis is to design, analyse, and evaluate solutions to reduce the operating durations of container ships in Short Sea Shipping (SSS), mainly the technological processes in ports and aboard ships.

To achieve the general objective, the following specific objectives are pursued:

O1- Identifying the specificities of a generic maritime transport line by synthesizing the domain literature,

O2- Study of technological processes in port terminals, with special interest for container terminals and proposals for practical solutions to optimize handling and transfer times,

O3- Examination of the interdependencies between the processes in the port and those on board the ships and the design of solutions for unloading/loading containers from/on board the ship respecting the stability conditions,

O4- Validation of the proposed solutions through a test case study.

The research methods used belong to the field of operational research. Analytical models of queuing theory are used in the thesis. For the calculation of the performance indicators of the analysed port systems, calculation algorithms are developed using the C++.

The structure of the thesis is consistent with the established objectives.

Chapter 2. LINER MARITIME TRANSPORT

2.1. Liner Shipping - Concepts and Definitions

2.1.1. Basic terms on in liner maritime transport

Similar to other modes, in maritime transport, there are several types of operations that serve distinct market purposes and needs. Among these, one can distinguish "tramp" (on-demand) shipping, industrial shipping, and liner shipping.

While "tramp" (on-demand/charter) ships operate without a fixed schedule, catering to immediate delivery needs and having costs based on the prevailing rates at the given time (often higher), industrial transport is mainly characterized by the control exerted by goods owners over the ship, with the primary objective being to minimize transport costs.

Liner shipping corresponds to a periodic demand, as defined, and modelled in literature (Raicu, 2009). Ships follow a predefined route that is established over time, and the frequency is almost constant. Containers are the most encountered cargo unit in liner shipping (Mulder et al., 2014).

In the field of liner shipping, decision-making covers a wide spectrum, ranging from strategic considerations to day-to-day operations. These decision-making processes can largely be separated into three distinct levels: strategic, tactical, and operational (Agarwal & Ergun, 2008).

2.1.2. Fleet Design in Liner Shipping

The fleet's structure and its efficient utilization is a strategic issue known as the "fleet design problem," where not only the number of ships needs to be determined, but also their sizes across different categories of vessels (Mulder et al., 2014).

The most important factors influencing fleet design are costs: investment, operational, navigation, etc.; the size of the demand; the existing route network; and the balance between economies of scale versus the size and evolution of costs.

2.1.3. Ship-Scheduling in Liner Shipping

The navigation schedule of ships represents a tactical decision and encompasses several stages: (i) designing the service network, determining the ports visited during a voyage (which might be called twice, once outbound and once on the return, unless the route is circular, in which case a port might be visited only once); (ii) allocating ships of various capacities to the different routes of the network; (iii) determining the most suitable speed for each route. The parameters of this task are established by several interconnected factors.

2.1.4. Allocating Goods/Containers to Routes

For decisions related to container routing/allocation on routes, the following are considered: types of goods and their transport conditions (for perishable goods, specific types of containers are required); intermediate transfer ports; operational capacities for each intermediate port on the considered navigation line.

Challenges in maintaining a consistent circulation schedule arise from: (i) unforeseen events, for which solutions for adjustments/re-establishment of the program are sought; (ii) the need to choose between a faster direct route with higher costs versus using a slower route that implies lower costs; (iii) integrating handling and transfer operations in ports with the logistical operations that containers undergo (e.g., goods inventory management, customs services, cargo security checks, etc.), which can't always adhere to a fixed schedule.

2.2. Efficiency and Sustainability in Liner Shipping

2.2.1. Revenue Management in Liner Shipping

Focuses on strategies and tactics to maximize the financial profitability of the transport capacities allocated to a route, taking into account both demand fluctuations and operational constraints.

The main components of revenue management include pricing strategies that can be adopted, capacities allocated for different routes, goods transported, etc., as well as the forecast of goods transport demand generated in the regions connected to the line services.

Revenue management in liner shipping aims at making strategic decisions to maximize returns by finding a balance between demand, supply, and operational constraints.

2.2.2. Digital Transformation in Maritime Shipping

Liner maritime transport can integrate digital technologies into many of its components. The most important digital innovations already implemented include digital platforms; automation and robotics in port operation and navigation; data analysis; cybersecurity, and the use of Blockchain technology in various segments of liner maritime transport.

2.2.3. Environmental Concerns in Maritime Transport

The most important environmental issues generated by maritime transport include carbon emissions; atmospheric pollutants; ballast water; waste management in transit and in ports. Research in associated fields has identified solutions whose effectiveness is already demonstrated.

Chapter 3. OPTIMIZATION OF PORT PROCESSES

3.1. General Concepts

Technological processes (including logistical ones) are numerous, and their study and analysis can start from the functions fulfilled by a port in the context of a maritime line. The most important processes, in terms of the time required for their realization, are as follows:

- planning and scheduling ships for docking operations (Delgado et al., 2012).

- allocating transfer and handling equipment (cranes and means of internal transport or for exit from the port to the terrestrial network).
- handling goods and/or cargo units.
- storage and warehousing.
- maintenance of infrastructure and port equipment is essential for the uninterrupted conduct of activities.

Figure 3.1 illustrates the main operations and the associated durations in maritime logistics.

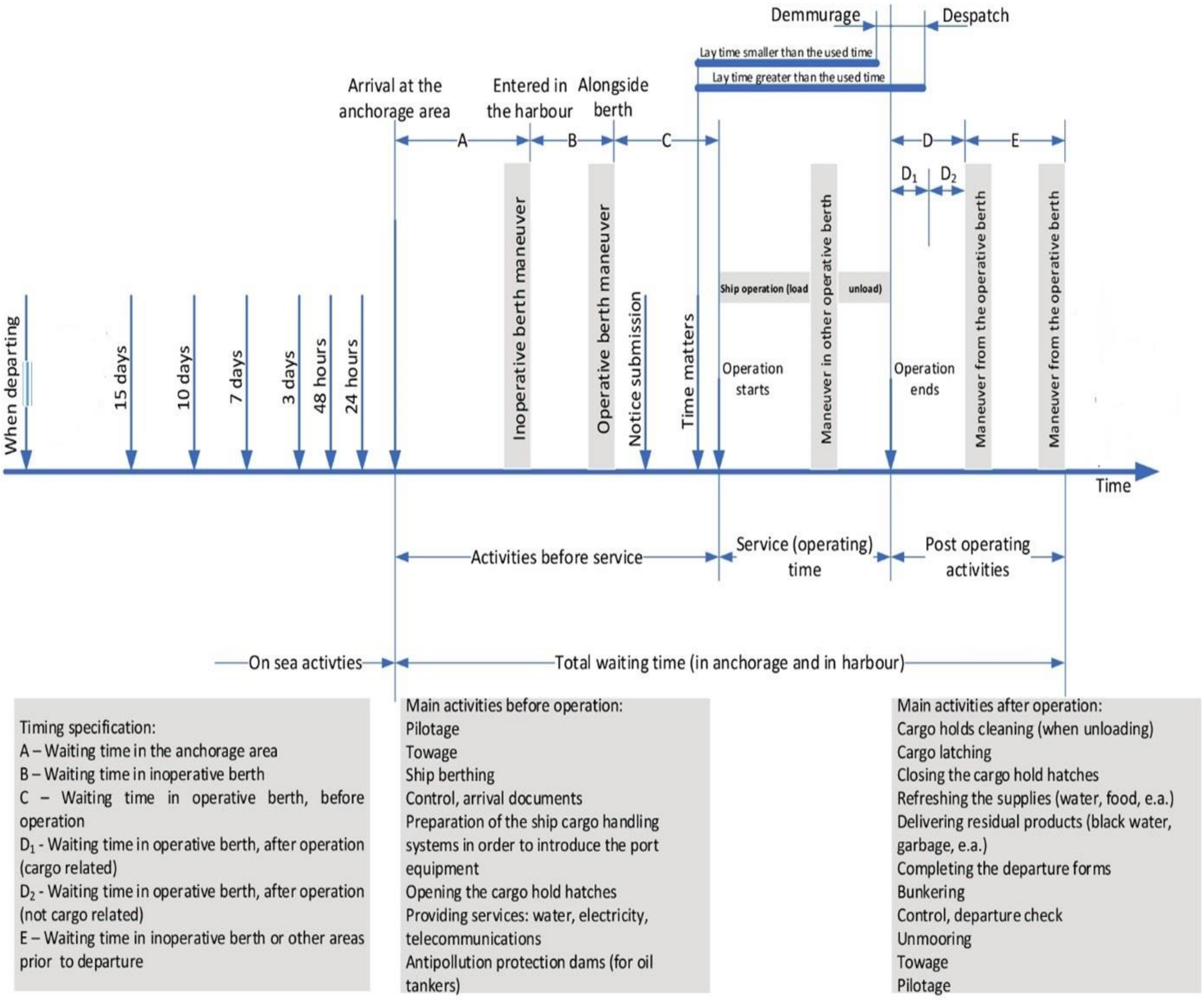

Figure 3.1 – Processes and associated times in maritime logistics

Source: (Adapted from Nicolae et al., 2012)

In maritime transport, the particularities of logistic processes are defined and analysed in relation to the goods, the ship, and the visited ports. The connection and interdependence between these three elements lead to the need to correlate technological processes, including logistical ones.

If one considers, for instance, the ship element, the main technological processes for port operations are docking; checks and preparation of documentation upon arrival; unloading of goods/cargo units; preparation activities for the ship; customs inspections, checks on the integrity of the goods, security checks; loading the ship with goods/cargo units for shipment; preparation of departure documentation; departure and unmooring from the quay.

3.2. Container Terminal

3.2.1. Operations in the container terminal

In the container terminal of the port, a variety of operations are carried out, but the predominant ones are handling (unloading/loading) and transfer (Fig.3.2). These operations involve the use of several types of equipment, grouped according to the nature of specific tasks. Depending on the size of the terminal, the transfer of containers can be:

1. Direct Transfer – where crane operations in the storage area are not required. The equipment used to lift or lower containers from their storage area is also used to transport them to or from the dockside crane. This system minimizes the need for additional equipment and simplifies the transfer process in a small-sized terminal.

2. Indirect Transfer - which involves using cranes to lift containers from their storage area and load them onto trucks or other internal transport equipment in the terminal, up to the dockside crane. Indirect transfer provides flexibility in handling containers and allows the operation of a larger number of containers, that is, it ensures high productivity.

In the case study, in the thesis, ports that provide indirect transfer of containers are considered.

3.2.2. Structure of a container terminal and type of storage

Within a container terminal, different sectors are determined for shorter-term storage, longer-term storage, waiting areas, or specific operations. Such storage sectors in the terminal can be: the export/outgoing container sector by ship or via the land network; the import/incoming container sector, by the same means; the empty container sector; specific transfer areas to the rail and road land networks; the roll-on/roll-off sector (if present) for combined transports, areas reserved for various other purposes (e.g., processing goods from containers) etc.

3.2.3. Container flow in the terminal and handling and transfer equipment

From the entrance to the terminal, through the land networks, by train or truck, and by water, by container ship, until exiting the terminal space (using the same three modes), containers can have an operational route that occupies different sectors in the terminal (Figure 3.2).

The allocation of space in the terminal can begin before the arrival of a ship when the sizes and locations of storage areas for containers to be loaded on the ship are determined, or conversely, allocation is made upon the ship's arrival.

In all cases, before the arrival of a ship, the unloading and loading sequence of containers for the ship and the dockside cranes that will be allocated to the ship are determined.

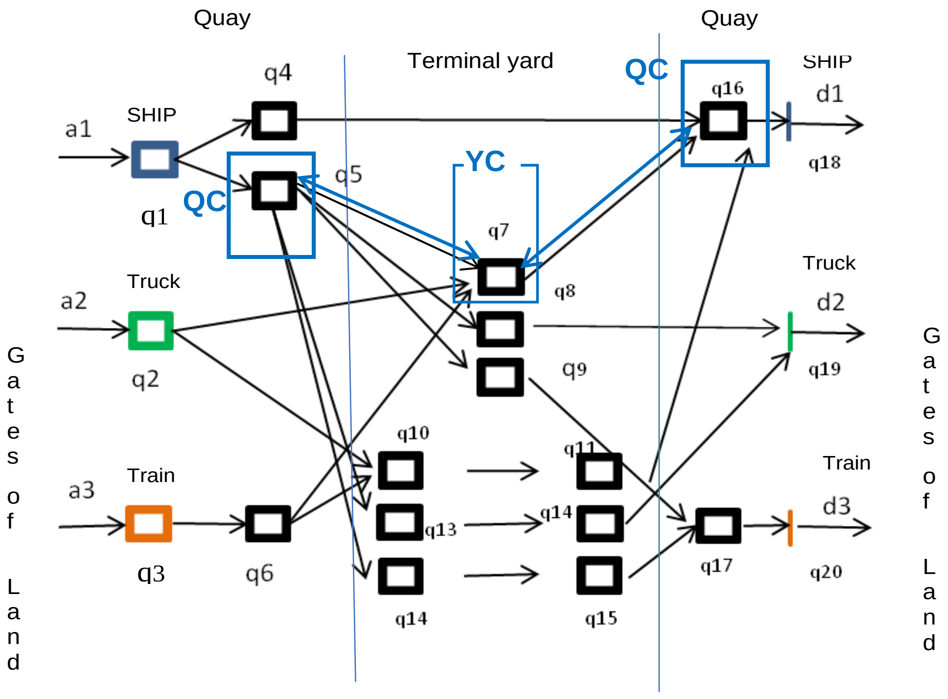

Figure 3.2 Container flow in the port terminal and operating sectors

Source: Adapted from (Mărăcineanu, 2012)

From the multitude of operations to which containers are subjected in the terminal, this thesis addresses the flow of containers related to the maritime route served by the ship. This container flow requires elements of the terminal infrastructure as follows:

- The "yard" of the terminal and YC - the yard crane for handling,

- The dock/wharf and the quay crane for handling - QC,

- The road infrastructure within the terminal for transfer equipment (double arrow lines in Figure 3.2).

3.2.4. Handling Equipment in Container Terminals

Handling equipment facilitates the efficient movement of containerized goods between container ships, warehouses, and other modes of transport. This section synthesizes the various types of goods handling equipment frequently used in container terminals. The analysis is structured around: quay cranes; rubber-tired gantry cranes (RTGs); straddle carriers; high-stack forklifts; terminal tractors and trailers; and Automated Guided Vehicles (AGVs) when operations are automated.

3.2.5. Interdependence between Port Processes and Onboard Ship Operations

There are multiple logistical operations that connect the ship to the terminal. However, among the most important, we can identify the following: the transfer of containers from consignors to the terminal; their verification and acceptance for transport; the preparation of containers in the terminal; the transfer of containers to the ship; the loading of containers onto the ships; the transfer of containers within the ship with or without additional arrangements/handlings; and the stowage of containers in the ship's hold and on its deck.

3.3. Mathematical Models for Optimizing Container Operations in Terminals

3.3.1. Mathematical Models of Mass Service Systems

It is well-known that the functioning of complex components in transportation (such as a maritime port) can be formally represented and analytically modelled through mass service models (or queueing systems).

Service stations are considered handling equipment, park and quay cranes, YC and QC respectively. An elementary mass serving type system is used for modelling M/ M/ c: (∞/FIFO) according to Kendall-Lee classification, that means that that is, the hypothesis is accepted that the arrivals of trucks for loading/unloading follow a Poisson process, and the intervals between servings (handling) have an exponential distribution. Another simplifying hypothesis is that the number of waiting places in the system is very large for each type of crane and can be considered infinite. Serving discipline is FIFO (first-in-first-out). The following variables and performance parameters are used in the considered generic terminal:

λ- truck arrival rate at the handling operation (trucks arrived per minute),

μ- service rate at one of the YC or QC cranes (trucks served per minute),

ρ- the load coefficient of the system equal to $\frac{\lambda}{c \cdot \mu}$

c- number of crane

For model M /M / c, the number of trucks which are waiting in system (L), is:

$$L = \frac{\rho^c \cdot c \cdot \rho}{c! \cdot (1-\rho)^2} \cdot P_0 + \frac{\rho}{(1-\rho)} \tag{3.1}$$

where:

P_0 – the probability that the crane has no trucks in the row and no load, given by:

$$P_0 = \left(\sum_{n=0}^{c-1} \frac{(c \cdot \rho)^n}{n!} + \frac{(c \cdot \rho)^c}{(c-1)! \cdot c \cdot (1-\rho)}\right)^{-1} \tag{3.2}$$

The average waiting time (W) can be obtained using the relation:

$$W = \frac{\mathrm{L}}{\lambda} \text{ (minute)} \tag{3.3}$$

The rate of truck arrivals at YC is directly related to QC productivity. Similarly, the arrival rate of trucks at QC dependent on YC productivity.

The total time of a service cycle of a truck transferring a container to the crane is T and includes:

- Travel time from the quay crane to the park (Td) (minutes)
- Waiting to serve at YC (W) (minutes)
- handling YC (TY) (minutes)/ container loading.
- Return journey time to the quay area, Tr (minutes).

Thus, the total cycle time (T) (minutes) is the sum of these individual times:

$$T = T_d + W + T_Y + T_r \tag{3.4}$$

The model has a similar formalization for waiting trucks for operation (unloading/loading) in the terminal park at QC.

Applying these models to empirical port operation data allows the calculation of the number of trucks in the system, the total times in a service cycle as well as the average waiting time of a truck.

3.3.2. Harmonizing Handling Capacities with Transfer Capacities

Quay cranes (QC) and those in the container yard (YC) can perform both loading and unloading operations. It's clear that the ship first needs to be unloaded and then loaded, leading to several storage strategies for containers in the yard.

The simplest analysis is where containers are first unloaded and then loaded (Fig. 3.4). The transfer equipment, for instance, the truck, makes circular routes between the quay crane and the yard crane, initially for unloading and then for loading (the point A).

Container positions in the storage park can be segregated, i.e. those that arrive are located in a different area from the container shipping area (this is known as a traditional storage structure). If both categories of containers, those for shipping and those originating from ship discharges, are located in the same area, the location structure is called mixed.

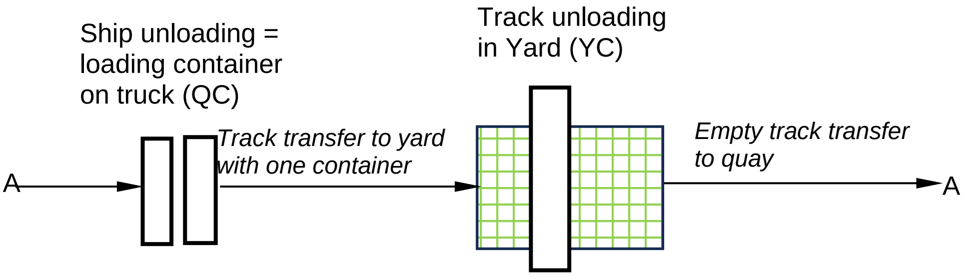

Figure 3.4. Diagram of handling and transfers between the quay and the container yard.

Each of the two cranes, at the quay and the yard respectively, can be formalized as two mass service stations where service requests are represented by trucks arriving for handling operations, and the services themselves are represented by the actual handling.

Under these conditions, the duration of a work cycle for a truck, T_t, whether it's performing unloading transfers from the ship or loading transfers onto it, is

$$T_t = t_Q + t_Y + \frac{d}{s_l} + \frac{d}{s_e} \tag{3.5}$$

where t_Q is the duration of handling operations (unloading/loading) at the quay, using QC,

t_Y – the duration of the handling operation in the storage yard, using YC,

d – the average driving distance of the truck (loaded or empty) between the quay and the yard,

s_l, s_e – the average speeds of the truck when loaded and empty, respectively (without any container).

If trucks are always available, theoretically, between successive arrivals at a quay or yard crane, equal intervals can be achieved, with a value of:

$$\Delta t_1 = \frac{T_t}{n_1} \tag{3.6}$$

Where n_1 is the number of trucks operating between QC and YC for a given shipping line.

To avoid discontinuities, the handling productivity of the cranes should be closely matched. The following cases can be analysed:

d Unloading the truck in the yard takes longer than at the quay, i.e., 0, $t_Y > t_Q$, In this scenario, if the number of trucks is reduced such that the duration between successive arrivals is greater or equal to the longer unloading time in the yard, trucks will not queue for unloading (and then loading) with YC.

This means $\Delta t_1 \geq t_Y$, meaning no truck reaches YC before the preceding one has completed its operation. As a result, the transfer capacity between the two representative locations for the QC and YC models, separated by an average distance *should increase proportionally with the number* n_t of trucks used.

1. In the situation where the number of trucks increases so much that the theoretical time interval between their successive arrivals reduces to a value where $\Delta t_1 < t_Y$, the scenario described in point 1 becomes invalid.

If a truck arrives before the previous truck's operation has finished, it will need to wait. This results in the container handling time in the yard being longer, not only for the second truck but also for the subsequent trucks that will arrive in the yard. Consequently, the cycle T_t for a truck will also increase.

In conclusion, regardless of the time of arrival, delays will inevitably occur.

Trucks departing from the yard after being handled by the YC crane might be out of sync with the new time interval t_1' which also includes the wait time for starting operations at YC).

Assuming that the handling in the yard is slower, i.e., $t_Y > t_Q$, it results in no interruption at the quay due to transshipment time. All the trucks are consistently operated within the time frame t_Q.

It results that any increase in the number of trucks beyond a certain value

$$\bar{n}_t = \frac{T_t}{max.(t_Q, t_Y)}, \qquad (3.7)$$

will not lead to an improvement in transfer capacity (figure 3.4), but on the contrary, it will create a number of non-operational transportation means.

$$\Delta n_t = n_t - \bar{n}_t. \qquad (3.8)$$

The actual transfer capacity with the truck C_t, between the two handling systems, QC and YC for all the trucks loaded and unloaded in the port, $N_C = N_{IN} + N_{OUT}$ is:

$$C_t = \frac{N_C}{T_t} n_t, \text{ for } n_t \leq \bar{n}_t \qquad (3.9)$$

$$C_t = \frac{N_C}{T_t} \bar{n}_{t1}, \text{ for } n_t > \bar{n}_t \qquad (3.10)$$

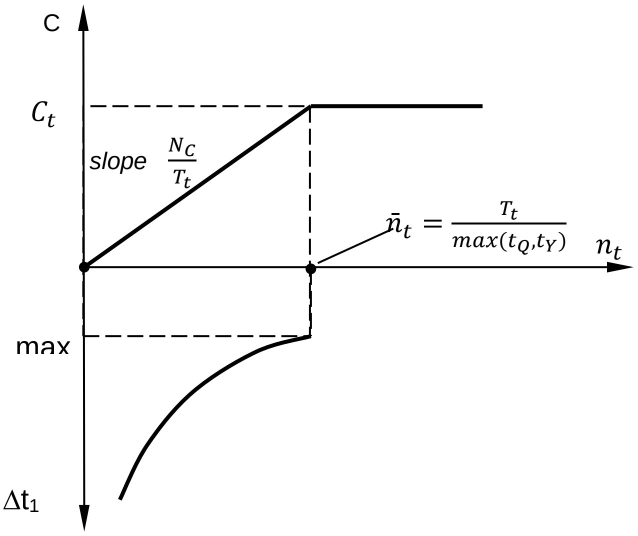

Figure 3.4. Transport capacity of the system depending on the number of sets used

Source: (adapted from Raicu et al., 2022)

From Figure 3.4, it is evident that there is a point beyond which increasing the number of trucks inevitably leads to the rise of a non-operative capacity and not to the truck's transfer capacity between the locations of the two cranes. If one aims to effectively correlate the port's handling capacity (for the containers loaded and unloaded on the liner ship) and the transfer system's capacity, it's clear that the handling operations (loading/unloading) determine the resulting capacity of the internal transfer systems.

3.4. Assessing performance of operations in the port terminal

Each of the operational strategies in the port is evaluated using various indicators, such as:

- the total duration of a complete cycle of using a piece of equipment from the park designated for loading/unloading a liner ship in a given port,
- the total number of necessary container transfer equipment from/to the wharf to/from the container storage/warehouse area,
- the total waiting times of the cranes (either at the wharf or in the container warehouse) that service the liner ship in a port.

Performance indicator evaluations can be the basis for decisions to choose solutions to improve port operations with investments or through management measures without investments.

Chapter 4. OPTIMIZATION OF PROCESSES ON BOARD THE SHIP

4.1. Logistic and Technologic Processes on Board Ships

Logistic processes involve the planning, coordination, and execution of activities related to the movement and provisioning of resources, equipment, and personnel on board a ship. This includes tasks such as ”bunkering”, which involves supplying the ship with fuel, as well as providing food, water, and other consumable materials.

Technological processes on board ships today involve the use and management of advanced technologies and systems that contribute to the efficient operation and maintenance of the vessel. These processes encompass various aspects such as navigation, communication, machinery control, cargo handling, and safety systems. Technological innovations, such as automated systems and digital solutions, have significantly improved ship productivity and performance, expanded their capabilities, and reduced human errors.

4.1.1. Simultaneous Technological Processes

Simultaneous technological processes on board ships encompass a wide range of activities that can be carried out concurrently by different teams or departments. These processes are essential for the continuous operation of a ship. The most important ones include navigation-related processes, onboard and external communications, power generation/utilization, environmental control systems, onboard safety systems, and cargo handling**.**

4.1.2. Consecutive Technological Processes

Sequential technological processes on board ships are activities that are performed in a specific order or sequence, depending on the completion of previous tasks, the interdependencies between activities, and the personnel teams performing them. These processes include fueling, provisioning, dry docking, retrofitting, modernization, and routine maintenance.

Most technological processes on board the ship can be designed and sized using project planning and coordination methods such as the Perth or Critical Path Method.

4.2. Ship Stability Analysis

4.2.1. Introductory Concepts

The verification of a ship's stability in port involves a set of operations to ensure the ship's buoyancy during each loading/unloading operation of a cargo unit, as well as during navigation between ports under various ship conditions and weather conditions.

The analysis of ship stability is carried out in various stages, starting from the ship's design, through shape and design optimization, to compliance checks with standards and regulations. But most importantly, stability analyses are conducted operationally for cargo management, navigation safety, emergency planning, as well as vessel maintenance and refurbishment operations.

4.2.2. Basic Conditions for Ship Stability

In the analysis of ship stability, **the ship's displacement** is considered, which represents the weight of the water displaced by the submerged volume of the hull (below the waterline W_0L_0 in the transverse representation, Fig. 4.1) when the ship is afloat.

Under the action of an external force, the ship can experience translations along the three coordinate axes as well as rotations around the same coordinate axes.

The ship is in a stable equilibrium if, when it is moved out of the equilibrium position by an external cause, it returns to the initial position as soon as the cause is removed. Otherwise, when it is no longer possible to return to the initial stability after the cause is removed, but the conditions of equilibrium are still met, the ship is said to reach an unstable equilibrium.

It is demonstrated that at the same angle of inclination, the longitudinal stability moment is much greater than the transverse stability moment. This is why transverse stability is studied, especially in two cases: for small angles of inclination - between 7o and 10o, and then for larger angles of transverse inclination.

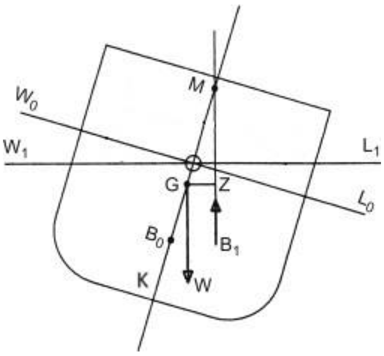

Figure 4.1. Basic Conditions for Transverse Ship Stability

Source: (Adapted from Tupper, 2013)

In Figure 4.1, the most important basic elements of transverse stability are distinguished as follows:

W_0L_0- The initial "waterline" before the ship is inclined.

W_1L_1- The "waterline" after the ship has been inclined at a small angle (max 7^o - 10^o).

G- The centre of gravity of the ship.

B0- The centre of buoyancy in the initial vertical position.

B1- The centre of buoyancy after the ship has been inclined.

M- The transverse metacentre (or simply, the ship's metacentre), defined as the point where the upward buoyancy force (through B1) intersects the original vertical line.

GZ- The righting arm, defined as the perpendicular line drawn from the centre of gravity of the ship, G, to the direction of B1M, the vertical line through the metacentre.

The ship exhibits stability when the transverse metacentre is positioned above the centre of gravity of the ship (Tupper, 2013)

4.3. Mathematical Models for Determining Ship Stability

4.3.1. Models for Static Stability

These are used to assess a ship's stability under static or stable conditions. This means they evaluate how the ship will behave when not subjected to additional external forces or movements, taking into account factors such as hull design, weight distribution, and the centre of gravity.

4.3.2. Models for Dynamic Stability

These models are used for real-time stability assessment, for analysing behaviour during sea navigation, for stability analysis in case of damage occurrence, or for analysing and simulating vessel manoeuvres or loading/unloading operations.

4.3.3. Models for Intact Stability

These models are used to assess a ship's stability in an intact condition, without any damage to the hull or superstructure. They are necessary during the ship's design phase as well as during routine operations without incidents, to verify loading conditions, compliance checks, and for simulations.

4.3.4. Models for Damage Stability

These models are used to assess stability in the event of damage (e.g., hull rupture due to collision or grounding). The evaluation is necessary to ensure the safety of the ship, crew, and cargo, and to comply with regulatory requirements. It is also used to simulate other incidents that can affect the ship's integrity.

4.3.5. Probabilistic Stability Models and Software

These are stability analysis models that apply probabilistic methods to assess a ship's stability in a variety of scenarios. Instead of considering a single worst-case scenario, as in deterministic models, probabilistic stability considers a wide range of potential situations based on their probability of occurrence. This analysis can be particularly valuable in situations with high uncertainty.

4.3. Loading Plan Development

The development of the loading plan on board the ship (also known as a cargo-plan) is a two-step process.

The first step in developing the cargo plan is carried out by the coordinators of the shipping line. The shipping line's loading plan is designed for all the ports on the ship's route starting from the first port of departure.

At the shipping line level, the loading plan usually does not specify individual containers but rather categories of containers grouped according to different attributes. These attributes may include container types (e.g., 20ft or 40ft), refrigerated or non-refrigerated, loading levels (fully loaded or empty), and destination ports, among others. Groups of containers with specific characteristics are assigned to positions within the ship.

Groups of containers with specific characteristics are assigned to positions within the ship.

The optimization objective from the shipping line's perspective is to minimize the turnaround times in ports and maximize the utilization of loading capacity allowed by regulations while ensuring the ship's stability.

In the second step of developing the cargo plan, specific adjustments are made at each port based on the actual situation encountered. This includes variations in the number of containers, their weight, or their destination (reorientation to other ports). The second step involves additional handling compared to the initial cargo plan.

These additional handling operations can be performed on board or, in the case of a large number of container movements, by using the shore for temporary storage. Creating precise cargo plans has an impact not only on the degree of loading capacity utilization but also on the port's performance (utilization of dock space, productivity of cranes at the dock, and transfer equipment between the container storage area and the dock).

In Chapter 5, an example of a cargo plan is provided for each of the ports for the selected ship in the case study, using a practical and effective method, especially suitable for short sea shipping (SSS) and small to medium-sized vessels.

Chapter 5.

OPTIMIZATION SOLUTIONS FOR VESSEL OPERATIONS IN LINE SHIPPING: A CASE STUDY

5.1. Operational Context and Study Assumptions

5.1.1. Shipping Line

The shipping line is considered a known entity, identified in a previous stage of strategic planning, which is beyond the scope of this thesis.

We assume a generic shipping line where the ports have known handling and transfer equipment, storage spaces, and the liner vessel has a transport capacity of 2000 containers. The navigation frequency is already established.

The objective of the case study is to design and evaluate solutions for optimizing the handling and transfer processes at the terminal and on board the vessel to reduce the total vessel turnaround times at the line's ports while ensuring vessel stability.

Other study assumptions include:

H1-The shipping line comprises five ports: the port of origin (P0) and four subsequent ports (P1, P2, P3, and P4).

H2 -The containership is loading containers onboard at the port of origin (P0) for the next four intermediary ports (P1, P2, P3, P4). Containers loaded at intermediary ports P1, P2, and P3 have as destination all the subsequent ports.

In Table 5.1 and Table 5.2 the total number of containers (full and empty) loaded and unloaded, according to H2 hypothesis.

Table 5.1 Shipping line voyage orders for loading/unloading full(F)/empty(E) containers

	Unloaded in P1	**Unloaded in P2**	**Unloaded in P3**	**Unloaded in P4**
Loaded from P0	380F/70E	360F/90E	340F/50E	380F/30E
Loaded from P1	-	150F/40E	130F/30E	140F/20E
Loaded from P2	-	-	260F/70E	150F/50E
Loaded from P3	-	-	-	750F/190E
Loaded from P4	-	-	-	-

Table 5.2 Containers loaded/unloaded in the ports P_0 to P_4

Port	Full Containers to be unloaded	Empty Containers to be unloaded	Full Containers to be loaded	Empty Containers to be loaded	Total onboard after operations	Percentage of Ship Utilisation
P0	-	-	1460	240	1700	85%
P1	380	70	420	90	1760	88%
P2	510	130	410	120	1650	83%
P3	730	150	750	190	1710	86%

P4	1420	290	-	-	-	-

5.1.2. Route and container characteristics

The container flow from P0 to P4 is depicted in Fig.5.1, where the filled arrows suggest the full containers, and otherwise, the arrows represent empty containers. At the same time, the arrow pointing up means the loading container on ship, and the arrow pointing down means the unloading containers from ship.

In figure 5.1, the largest number of containers is carried between ports P1 and P2 (1760 F+E), that means a rate of ship capacity utilisation around of 90%.

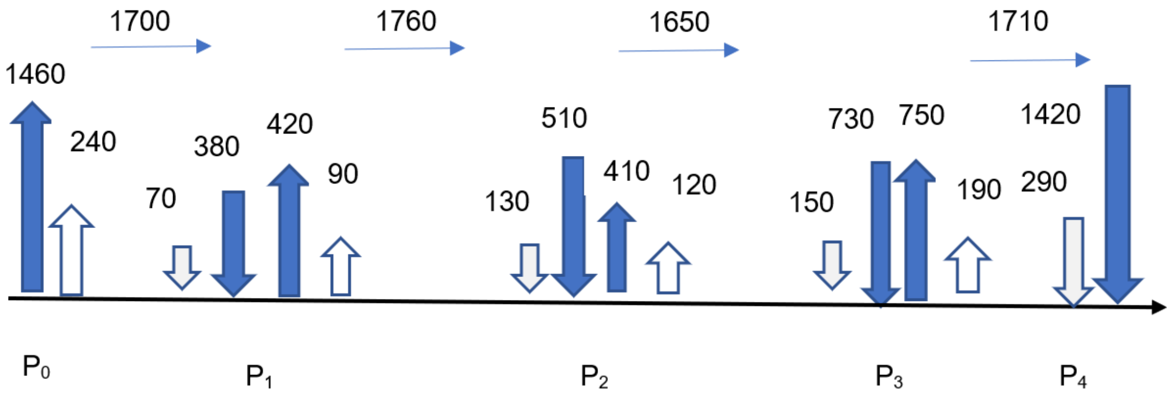

Figure 5.1 Flow diagram of containers transported between P_0 and P_4

H3 - All containers considered in this research are 20ft containers with a tare weight of 2.3 tons, payload capacity of 25 tons, and cubic capacity of 33 m^3.

H4.1 - Each container is assumed to be either fully loaded or entirely empty, with no intermediate load states. This assumption is not intended to limit the model's generality but to simplify the problem context.

H4.2 – The full containers weight differently as follows: 40% of full containers weight 25 tons, 30% of full containers weight 20 tons, 20% of full containers weight 15 tons, 10% of full containers weight 10 tons.

5.1.3. Containership characteristics

The chosen container ship is associated with an SSS shipping line and has a capacity of 2000 20ft containers (TEUs) (see Figure 5.15 below). The structure of the container storage areas on board the considered ship is: Bay 1C (Central Bay) - 200 TEU capacity: Bay 1C: 4 bays (on the Ox-longitudinal axis), 5 rows (on the Oy-transverse axis), 10 layers (on the Oz-vertical axis). In each of the port and starboard side bays (2P, 2S, 3P, 3S, 4P, 4S) - storage capacity is 300 TEU each, with the structure: 4 bays, 5 rows, 15 layers. The difference between the central bay and all the others is the number of layers.

5.2. Improvements for terminal operation without investments

5.2.1 Operating Model for Containers with a Traditional Structure

The designed algorithm (in C++ language) calculates performance indicators for operations: the average number of trucks in the system, the queue length, their average waiting time in the system, and the total time of a service cycle.

Input data considers the arrival rate of transfer equipment (for example, trucks) at the quay crane (QC) and at the yard crane (YC), the service rate of the quay cranes and those in the storage yard, and the number of YCs and QCs (**Appendix A**1).

Table 5.8 Performance Indicators of Traditional Berth Across Ports of the Line

Performance Indicators	P0
Arrival Rate of Trucks (λ) (trucks/min)	0.25
Service Rate of a Single YC (μ) (trucks/min)	0.33
Number of YCs (c)	4
Travel Time from Parking Area (Td) (min)	5
YC Operation Time (Ty) (min)	3
Return Travel Time (min)	5
Average Number of Trucks in the System (L)	0.23
Average Waiting Time (W) (min)	0.9
Total Cycle Time (T) (min)	13.9

5.2.2. The operating model of containers with a mixed storage structure

The calculation algorithm (in C++ language) uses the same input data. Using similar indicators, it allows a comparative analysis of the operational performance of the three organizational structures of the storage space. Table 5.9 presents an example of calculation.

Table 5.9 Performance indicators of mixed storage berth across ports of the line

Indicators	P0
Arrival rate of trucks (λ) (trucks/min)	0.25
Service rate of a single YC (μ) trucks/min)	0.5
Number of servers (YCs) (c)	4
Travel time from the parking area (Td) (min)	4
YC operation time (Ty) (min)	2
Return travel time to the parking area (min)	4
Average Number of Trucks in the System (L)	0.52
Average Waiting Time (W) (min)	2.08
Total cycle time (T) for Mixed Storage Strategy (min)	10.6

Table 5.11 Performance Indicators in the case of a dedicated "reserved zone" separation across ports of the line

Performance Indicators	P0
Arrival Rate of Trucks (λ) (trucks/min)	0.25
Service Rate of a Single YC (μ) (trucks/min)	0.33
Number of YCs (c)	4
Travel Time from Parking Area (Td) (min)	5
YC Operation Time (Ty) (min)	3
Average Number of Trucks in the System (L)	0.23
Average Waiting Time (W) (min)	0.9
Total Cycle Time (T) (min)	8.9

Table 5.12 Comparative Analysis of Total Cycle Time Across Storage Methods

	P0
Total cycle time (T) for traditional storage	13.9
Total cycle time (T) for mixed storage	10.6
Total Cycle Time (T) (min) for the case of a dedicated "reserved zone" separation	8.9
Reduction in time from traditional storage to mixed storage	23.7%
Reduction in time from traditional storage to the case of a dedicated "reserved zone" separation	36%

5.3. Terminal operation enhancement through equipment renewal

Replacing the crane in the container park is achieved through investments. The proposed solution to replace the initial park crane for each port is presented in Table 5.15. The recommendations aim to introduce more automated, efficient, and higher-capacity equipment. This approach suggests a direction towards increased throughput, reduced operational delays, and improved port performance.

The results of the calculations are summarized in the following table, where the performance indicators of each port are compared for each improvement scenario analyzed. In relation to the storage structure in the park and the type of handling equipment in the park (YC), one analysis scenario is distinguished, six in total (S0-S6), S1 - traditional storage; S2 - mixed storage; S3 - storage with reserved space; S4 - traditional storage after equipment renewal; S5 - mixed storage after equipment renewal; S6 - storage with reserved space after equipment renewal. As expected, combining fleet storage structures with equipment upgrades (S4-S6) yields the best results in terms of average waiting time and total cycle time.

In addition, traditional storage (S1 and S4) in all ports has higher total cycle times compared to mixed storage (S2 and S5) but also to storage of shipping containers with a reserved area for the ship (S3 and S6). Mixed storage after equipment renewal (S5) consistently provides the best performance in the analyzed ports..

Table 5.15 Comparison of performance indicators for the considered strategies

Port	Strategy	Arrival Rate of Trucks (λ) (trucks /min)	Service Rate of a Single YC (μ) (trucks/ min)	Number of YCs (c)	Travel Time (Td) (min)	YC Operation Time (Ty) (min)	Return Travel Time (min)	Average Number of Trucks waiting in the System (L)	Average Waiting Time (W) (min)	Total Cycle Time (T) (min)
P0	S1	0.25	0.33	4	5	3	5	0.23	0.9	13.9
	S2	0.25	0.5	4	4	2	4	0.52	2.08	10.6
	S3	0.25	0.33	4	5	4	5	0.23	0.9	8.9
	S4	0.25	0.41	4	4.3	2.4	4.2	0.21	0.8	12.7
	S5	0.25	0.55	4	3.6	1.8	3.6	0.12	0.48	9.0
	S6	0.25	0.38	4	5	2.8	5	0.2	0.8	8.6
P1	S1	0.17	0.25	3	6	4	6	0.29	1.7	17.7
	S2	0.25	0.4	3	4	2.5	4	0.37	1.5	11.6
	S3	0.17	0.25	3	6	4	6	0.29	1.7	12.7
	S4	0.17	0.31	3	5.1	3.2	5.1	0.26	1.5	16.4
	S5	0.25	0.44	3	3.6	2.25	3.6	0.21	0.85	9.45
	S6	0.17	0.28	3	6	3.7	6	0.25	1.5	12.2
P2	S1	0.17	0.20	3	6	4	7	0.39	2.3	19.3
	S2	0.24	0.52	3	4	2	4	0.24	0.98	10.5
	S3	0.17	0.20	3	6	4	6	0.39	2.3	12.3
	S4	0.17	0.25	3	5.1	3.2	5.95	0.36	2.1	18.3
	S5	0.24	0.57	3	3.6	1.8	3.6	0.14	0.61	9.0
	S6	0.17	0.23	3	6	3.7	6	0.35	2.1	12.0
P3	S1	0.14	0.25	3	6	5	6	0.24	1.7	18.7
	S2	0.24	0.51	3	4	2	4	0.25	1.0	10.8
	S3	0.14	0.25	3	6	5	6	0.24	1.7	12.7
	S4	0.14	0.31	3	5.1	4	5.1	0.22	1.5	17.7
	S5	0.24	0.56	3	3.6	1.8	3.6	0.15	0.62	9.0
	S6	0.14	0.28	3	6	4.6	6	0.22	1.6	12.2
P4	S1	0.14	0.25	4	6	4	6	0.17	1.2	17.2
	S2	0.14	0.4	4	5	3	5	0.15	1.1	13.7

Port	Strategy	Arrival Rate of Trucks (λ) (trucks/min)	Service Rate of a Single YC (μ) (trucks/min)	Number of YCs (c)	Travel Time (Td) (min)	YC Operation Time (Ty) (min)	Return Travel Time (min)	Average Number of Trucks waiting in the System (L)	Average Waiting Time (W) (min)	Total Cycle Time (T) (min)
	S3	0.14	0.25	4	6	4	6	0.17	1.2	11.2
	S4	0.14	0.31	4	5.1	3.2	5.1	0.15	1.0	16.4
	S5	0.14	0.44	4	4.5	2.7	4.5	0.08	0.57	11.7
	S6	0.14	0.28	4	6	3.7	6	0.16	1.1	10.8

5.4. Stowage optimisation

The designed algorithm (A3 in Annex C) leads to a container handling solution on the ship, respecting the stability conditions.

In a synthetic description, the algorithm chooses the port of departure the compartment on the ship for the vertical placement of a stack of selected containers (depending on the destination port and the loading level of the containers). The vertical container stacks dedicated to a port are divided equally (from the point of view of mass) between the port and starboard bays (mirrored), symmetrical to the vertical plane through the longitudinal axis of the ship.

The compartment load level is iteratively checked and updated in each port of the line. The following table summarizes the result obtained, the stacking plan, after the operations in ports P0, P1, P2 and P3. The algorithm leads to the on-board container handling solution in each port by identifying the available compartments and the existing load level in each. After the allocation of containers (unloading/loading) in the compartment associated with a port of destination, it is checked that the capacities of the compartments are not exceeded and that the stability conditions are met.

By implementing the calculation algorithm on the travel orders presented in Section 5.1, a stacking plan is generated for each of the five ports.

The table below shows the ship's loading plan in the port of origin where, for each port of destination, stacks of containers are allocated distributed in the seven compartments of the ship, after the unloading related to the port.

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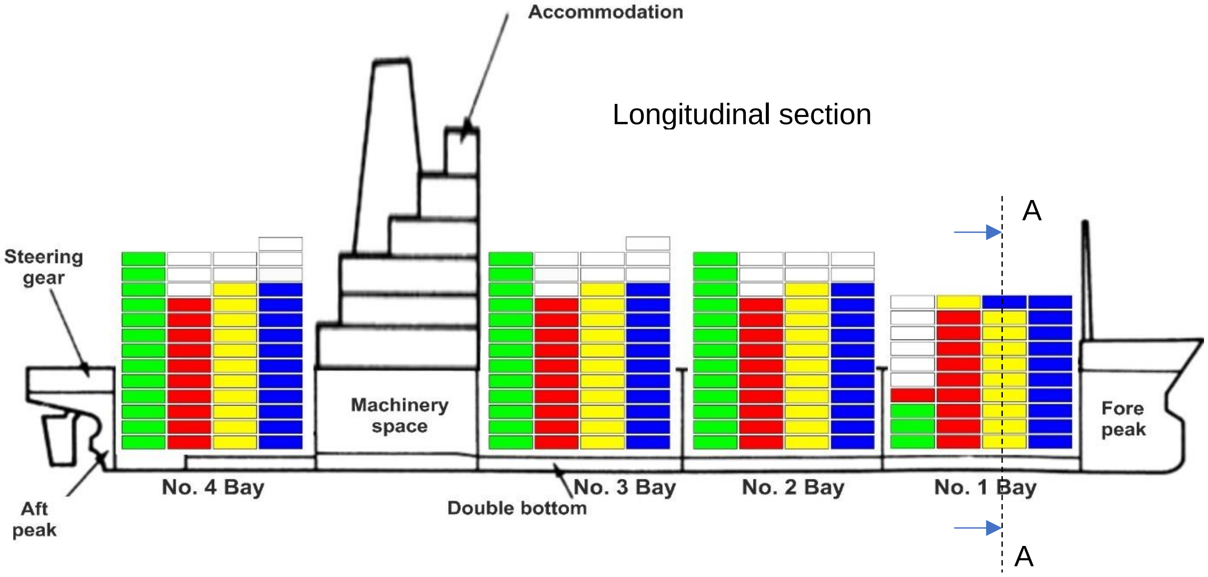
Table 5.20 Stowage plan in P0

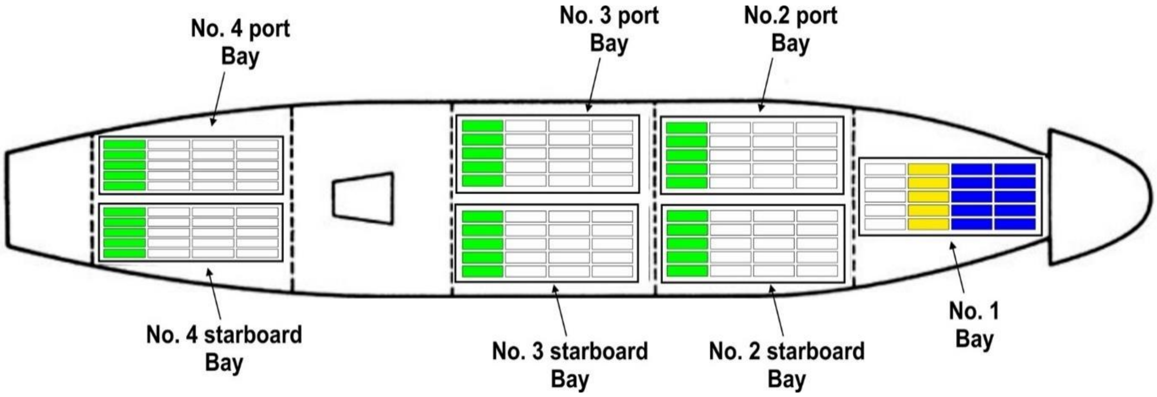
Bay Location	Port of Origin	Port of Destination	Container Count	Percentage of Bay Utilised
1 Central	P0(169F,31E)	P1(55F,10E); P2(52F,13E); P3(49F,8E); P4(13F)	200	100%
2 Port	P0(218F,32E)	P1(55F,10E); P2(52F,13E); P3(49F,7E); P4(62F,2E)	250	83%
2 Starboard	P0(217F,33E)	P1(54F,10E); P2(52F,13E); P3(49F,7E); P4(62F,3E)	250	83%
3 Port	P0(215F+35E)	(P1-54F,10E; P2-51F,13E; P3-49F,7E; P4-61F,5E)	250	83%
3 Starboard	P0(214F+36E)	(P1-54F,10E; P2-51F,13E; P3-48F,7E; P4-61F,6E)	250	83%
4 Port	P0(214F+36E)	(P1-54F,10E; P2-51F,13E; P3-48F,7E; P4-61F,6E)	250	83%
4 Starboard	P0(214F+36E)	(P1-54F,10E; P2-51F,12E; P3-48F,7E; P4-61F,7E)	250	83%

In the figure below, the structure of the loading plan in port P0 is graphically represented, where you can identify the empty containers, placed above the loaded ones, the vertical columns with loaded containers for each port (which has an associated color), distributed in each of the seven compartments to meet the stability conditions.

The practical model for allocating containers on board the ship is suitable for small-medium capacity ships for medium volumes of containers for short "feeder" navigation lines, serving ports of the European "belt" navigation.



Top view



Cross section A-A

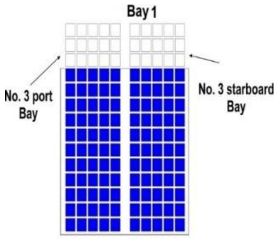


Figure 5.15 Stowage plan representation after operations in port P0

Chapter 6. CONCLUSIONS, CONTRIBUTIONS, AND FUTURE RESEARCH

6.1. Conclusions

The synthesis of the literature in the field of the thesis and the studies and analyses of the strategic and political documents regarding the European maritime transport led to the need to substantiate some solutions to improve the performance in short-distance liner maritime transport, and at the same time, to establish the research objectives.

The main conclusions of the research undertaken are:

1. Short-line shipping and the associated logistics elements, especially for containerized shipping, present both different characteristics from transoceanic liner shipping (Deep Sea Liner Shipping) but also similarities (regarding, above all, the choice of vessels, scheduling and routing vessels, setting the traffic frequency),

2. Liner shipping has negative effects on the environment, but the synthesized literature highlights important research related to the identification of alternative solutions for propulsion, friendly to the environment,

3. At the same time, digital progress in navigation but also in logistic and technological operations in terminals is accelerated, producing positive effects especially on the safety and security of transport,

4. For the effective operation of containers in the port, it is necessary to harmonize the performance levels of the handling and transfer equipment, ensuring that neither the port nor the ship becomes an obstacle in the logistics chain.

5. The arrangement structure of the stored containers together with the performance of the handling and transfer equipment influences the productivity of the overall ship operation process in the port and thereby influences the port dwell time and compliance with the schedule and frequency of the shipping line.

6. Logistics processes on board the ship, including the loading plan and the stability conditions of the ship, also influence the port dwell times.

7. In the short-haul liner transport of containers with small and medium-sized container ships, practical on-board loading solutions can be identified that do not involve additional handling for rearrangement (to meet stability criteria).

6.2. Contributions

The following contributions can be highlighted:

- Synthesis of liner shipping literature, with the selection of particular elements of short-distance containerized liner shipping with small and medium-sized ships by comparison with long-distance containerized liner shipping,

- Analysis and structuring of the most important innovations in the field of information technology with applications in maritime transport,

- Examining the interdependencies between the processes in the port and those on board the ships and the theoretical and practical justification (through the case study) of the need to harmonize the productivity of the handling and transfer equipment in the container park and on board the ships,

- Proposing solutions to increase the performance of container operations in the terminal regarding the container storage structure in the park and the development of calculation algorithms (in C++ language) of performance indicators,

- The foundation of a practical solution for loading containers on board the ship which, on the one hand, minimizes the number of additional re-arrangement operations (for access to containers destined for a certain port) and, on the other hand, guarantees the stability of the ship,

- Validation of the practical solution for loading containers on board through calculations to verify compliance with the ship's stability, in the developed case study.

6.3. Opening future research

- Analysis of the simultaneous handling of several ships at the quay.
- Solutions for a direct ship-to-ship transfer involving terminal-ship operation.
- Study on the use of the proposed on-board loading method for large ships.

APPENDIX

Appendix A – A1.Algorithm for calculating performance indicators for traditional storage

Appendix B – A2.Algorithm for calculating performance indicators for mixed storage and reserved area

Appendix C – A3.Algorithm for loading and unloading containers onboard

Appendix D – A4.Algorithm for Container Weight Discrepancy

REFERENCES (SELECTION)

1. *Agarwal, R., and Ergun, Ö. (2008) Ship Scheduling and Network Design for Cargo Routing in Liner Shipping. Transportation Science, 42, 175-196. http://dx.doi.org/10.1287/trsc.1070.0205*
2. *Ambrosino, D., Sciomachen, A., & Tanfani, E. (2004), Stowing a Containership: The Master Bay Plan Problem, Transportation Research Part A: Policy and Practice 38 (2), 81–99.*
3. *Ambrosino, D., Paolucci, M., & Sciomachen, A. (2013), Experimental Evaluation of Mixed Integer Programming Models for the Multi-Port Master Bay Plan Problem, Flexible Services and Manufacturing Journal 27 (2–3): 263–284.*
4. *Ambrosino, D., Paolucci, M., & Sciomachen, A. (2015). A MIP Heuristic for Multi-Port Stowage Planning. Transportation Research Procedia, 10, 725-734. ISSN 2352-1465. https://doi.org/10.1016/j.trpro.2015.09.026.*
5. *Ambrosino, D., Paolucci, M., and Sciomachen, A.. (2017), Computational Evaluation of a MIP Model for Multi-port Stowage Planning Problems, Soft Computing 21 (7): 1753–1763*
6. *Aldona Jarasuniene (2016), Optimisation of technological processes in terminals, Transport, 19:5, 207-213*
7. *Andersson Karin, Brynolf, Shipping and the Environment, Springer, 2016, ISBN:9783662490433.*
8. *Avriel, M., Michal, P., Naomi, S., & Smadar, W., Stowage Planning for Container Ships to Reduce the Number of Shifts. Annals of Operations Research - Annals OR. 76. 55-71, 1998, 10.1023/A:1018956823693*
9. *Bacioiu Alexandru Stefan, Goia Ionela, On adjustment of stowage plan with minimum resources, 20th International Conference on Transport Science ICTS 2022 23rd and 24th May 2022, Conference Proceedings, Portoroz, Slovenia*

10. *Bacioiu Alexandru Stefan, Goia Ionela, Stability of the Ship Using Intact Stability Criteria and Empirical Formulas, WSEAS Transactions on Engineering World, vol. 4, pp. 1-4, 2022*
11. *Balaban I. Gh., Tratat de navigaţie maritimă, Editura Leda, Bucureşti, 1996.*
12. *Bichou, Khalid (2009), Port Operations, Planning And Logistics, Informa Law from Routledge, ISBN 13: 978-1-843-11805-3*
13. *Brooks, M. R., Blunden R. G, Bidgood C. I. (1993), Strategic Alliances in the Global Container Transport Industry, R. Culpan, Multinational Strategic Alliances, Binghamton, NY: Haworth Press, 221-48.*
14. *Brouer, B.D., Desaulniers, G., & Pisinger, D. (2014). A matheuristic for the liner shipping network design problem. Transportation Research Part E, 72, 42–59*
15. *Caimao T., Junliang H., Hang Y. (2019), Mathematical modeling of yard template regeneration for multiple container terminals, Advanced Engineering Informatics 40 (2019) 58–68*
16. *Carlo, H., Vis, I., & Roodbergen, K. J. (2014). Transport operations in container terminals: Literature overview, trends, research directions and classification scheme. European Journal of Operational Research, 236, 1–13. https://doi.org/10.1016/j.ejor.2013.11.023.*
17. *Cascetta E. (2001), Transportation Systems Engineering: Theory and Methods, Kluwer Academic Publishers, ISBN: 978-0792367925, 722pg.*
18. *Chen, L., & Langevin, A. (2011). Multiple yard cranes scheduling for loading operations in a container terminal. Engineering Optimization, 43, 1205-1221. https://doi.org/10.1080/0305215X.2010.548865.*
19. *Chen, X., He, S., Zhang, Y., Tong L., Shang, P., Zhou, X., Yard crane and AGV scheduling in automated container terminal: A multi-robot task allocation framework, Transportation Research Part C: Emerging Technologies, Volume 114, 2020, Pages 241-271, ISSN 0968-090X, https://doi.org/10.1016/j.trc.2020.02.012*
20. *Chung, S.-H. (2021). Applications of smart technologies in logistics and transport: A review. Transportation Research Part E: Logistics and Transportation Review, 153, 102455. https://doi.org/10.1016/j.tre.2021.102455.*
21. *Commission of the European Communities, Towards a future Maritime Policy of the Union: A European vision for the oceans and seas, 2006.*
22. *Committee on the Motorways of the Sea in the Logistics Chain, 2008.*
23. *Delgado, A., Jensen, R. M., Janstrup, K., Rose, T. H., & Andersen, K. H. (2012), A Constraint Programming Model for Fast Optimal Stowage of Container Vessel Bays, European Journal of Operational Research 220 (1), 251–261.*
24. *De Juan, M., Benitez, I., Marcos, J. MOSES Project: Enhancing Short Sea Shipping with Automated Technologies. WIT Transactions on The Built Environment, Vol. 212, Urban and Maritime Transport XXVIII, 2022, 173. doi:10.2495/UMT220151.*
25. *Di Francesco, Massimo. (2023). New optimization models for empty container management.*
26. *Ding, D., & Chou, M. C., Stowage Planning for Container Ships: A Heuristic Algorithm to Reduce the Number of Shifts. European Journal of Operational Research 246 (1), 242–249, 2015, DOI: 10.1016/j.ejor.2015.03.044*
27. *Dokkum Klaas (2003), A modern Encyclopedia, Dokmar, Enkhuizen, ISBN 90-806330-2-X, 341 pg*
28. *European Commission, Corridor Descriptions, 2013.*
29. *European Commission DG Mobility and Transport (2015), Analysis of Recent Trends in EU Shipping and Analysis and Policy Support to Improve the Competitiveness of Short Sea Shipping in the EU.*
30. *Fazi, S. (2019). A decision-support framework for the stowage of maritime containers in inland shipping. Transportation Research Part E: Logistics and Transportation Review, 131, 1-23. https://doi.org/10.1016/j.tre.2019.09.008.*
31. *Goia Ionela, Bacioiu Alexandru-Stefan, The Analysis of Freight Forwarding Services Using the*

Business Process Modelling Tools. Study Case in Constanta Port, WSEAS Transactions on Design, Construction, Maintenance, vol. 2, pp. 217-220, 2022

32. *Hong, C., Guo, Y., Wang, Y., Li, T. The Integrated Scheduling Optimization for Container Handling by Using Driverless Electric Truck in Automated Container Terminal. Sustainability, 2023, 15, 5536. https://doi.org/10.3390/su15065536.*
33. *IMO. International Convention for the Safety of Life at Sea (SOLAS) 1974.*
34. *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). 1978.*
35. *Jansson, J. O. & Shneerson, D. (1987) Liner Shipping Economics, Chapman and Hall, New York, ISBN 978-94-010-7914-3, 299 pg.*
36. *Jansson, J. O. & Shneerson, D. (1982) The Optimal Ship Size. Journal of Transport Economics and Policy, 16(3): 217-238.*
37. *Kai Yu, Jingcheng Yang (2019), MILP Model and a Rolling Horizon Algorithm for Crane, Mathematical Problems in Engineering, Volume 2019, Article ID 4739376, 16 pg.*
38. *Lambert, D.M., Cooper, M.C. and Pagh, J.D. (1998) Supply Chain Management: implementation Issues and Research Opportunities, International Journal of Logistics Management*
39. *Lee, D.-H., & Jin, J. G. (2013). Feeder vessel management at container transshipment terminals. Transportation Research Part E: Logistics and Transportation Review, 49(1), 201-216. https://doi.org/10.1016/j.tre.2012.08.006.*
40. *Lee, P. T.-W., Oh, K. K., & Ruan, X. (2019). Sustainability Challenges in Maritime Transport and Logistics Industry and Its Way Ahead. Sustainability, 11(5), 1331. https://doi.org/10.3390/su11051331.*
41. *Lee Tae-Woo, Cullinane Kevin (2016), Dynamic Shipping and Port Development in the Globalized Economy. Volume 1. Applying Theory to Practice in Maritime Logistics. London: Palgrave Macmillan, ISBN: 978-1-137-51421-9.*
42. *Lee Tae-Woo, Cullinane Kevin (2016), Dynamic Shipping and Port Development in the Globalized Economy Volume 2 Emerging Trends in Ports. London: Palgrave Macmillan, ISBN 978-1-137-51427-1.*
43. *Legato P., Canonaco P., and Mazza R. M. (2009), Yard crane management by simulation and optimisation, Maritime Economics & Logistics, vol. 11, no. 1, pp. 36–57.*
44. *Lehnfeld, J., & Knust, S. (2014), Loading, Unloading and Premarshalling of Stacks in Storage Areas: Survey and Classification, European Journal of Operational Research 239 (2), 297–312.*
45. *Li, H. A heuristic algorithm for equipment scheduling at an automated container terminal with multi-size containers. Archives of Transport, Volume 65, Issue 1, 2023, e-ISSN: 2300-8830, DOI: 10.5604/01.3001.0016.2478.*
46. *Liu, C. (2020). Iterative heuristic for simultaneous allocations of berths, quay cranes, and yards under practical situations. Transportation Research Part E: Logistics and Transportation Review, 133, 101814. https://doi.org/10.1016/j.tre.2019.11.008.*
47. *Liu, C.-I., Jula, H., & Ioannou, P. (2002). Design, Simulation, and Evaluation of Automated Container Terminals. IEEE Transactions on Intelligent Transportation Systems, 3, 12-26. https://doi.org/10.1109/6979.994792.*
48. *Luna, J. H., Mar-Ortiz, J., Gracia, M., & Moralez-Ramirez, D. (2017), An efficiency analysis of cargo-handling operations at container terminals, Macmillan.*
49. *Maracineanu, M., Cercetari pentru cresterea eficientei si eficacitatii transportului cu nave portcontainer, 2012.*
50. *McGeorge H.D.,. Marine Auxilliary Machinery, Elsevier, 2013.*
51. *Meiswinkel, S. (2018), On Combinatorial Optimization and Mechanism Design Problems Arising at Container Ports, Wiesbaden: Springer Gabler.*
52. *Merk Olaf (2019), Container Shipping in Europe, International Transport Forum*
53. *Meyer, N.K. (2018), A Practical Guide To The Designation Of Ship Corridors In Maritime Spatial*

Planning

54. *Mohseni, S., Developing a Tool for Designing a Container Terminal Yard, 2011*
55. *Mulder, J., & Dekker, R. (2014). Methods for strategic liner shipping network design. European Journal of Operational Research, 235(2), 367-377. https://doi.org/10.1016/j.ejor.2013.09.041*
56. *Naeem, D., Gheith, M., Eltawil, A,. A comprehensive review and directions for future research on the integrated scheduling of quay cranes and automated guided vehicles and yard cranes in automated container terminals, Computers & Industrial Engineering, Volume 179, 2023, https://doi.org/10.1016/j.cie.2023.109149*
57. *Ng W.C., Mak K.L. (2005), Yard crane scheduling in port container terminals, Applied Mathematical Modelling 29 (2005) 263–276*
58. *Nicolae, F.(2012), Instalaţii navale şi portuare, vol. I şi II, Editura Academiei Navale „Mircea cel Bătrân", Constanţa.*
59. *Nicolae, F.(2012), Sisteme navale si portuare de operare Vol. I și II, Editura Academiei Navale „Mircea cel Bătrân", Constanţa.*
60. *Nishimura, E., Imai, A., Janssens, G. K., & Papadimitriou, S. (2009). Container storage and transshipment marine terminals. Transportation Research Part E: Logistics and Transportation Review, 45(5), 771-786. https://doi.org/10.1016/j.tre.2009.03.003.*
61. *Notteboom, T., Pallis, A., & Rodrigue, J.-P. (2022). Port Economics, Management and Policy (1st ed.). Routledge. https://doi.org/10.4324/9780429318184*
62. *Notteboom, T., & Rodrigue, J.-P. (2009). The Future of Containerization: Perspectives from Maritime and Inland Freight Distribution. GeoJournal, 74(1), 7-22.*
63. *Olaf Merk (2019), Container Shipping in Europe, International Transport Forum*
64. *Parreño-Torres, C., Çalık, H., Alvarez-Valdes, R., & Ruiz, R. (2021). Solving the generalized multi-port container stowage planning problem by a matheuristic algorithm. Computers & Operations Research, 133, 105383. ISSN 0305-0548. https://doi.org/10.1016/j.cor.2021.105383.*
65. *Popa M. (2009) Economia transporturilor, Ed. POLITEHNICA PRESS, Bucuresti, ISBN 978- 606-515-036-2, 325 pg*
66. *Psaraftis, H. N., & Kontovas, C. A. (2010). Balancing the economic and environmental performance of maritime transportation. Transportation Research Part D: Transport and Environment, 15(8), 458-462.*
67. *Regulation (EU) No 1315/2013 Of The European Parliament And Of The Council.*
68. *Sacone S., Siri S., Mathematical and Computer Modelling of Dynamical Systems: Methods, Tools and Applications in Engineering and Related Sciences, 15:3, 275-293*
69. *Saghir, M., (2002) Packaging Logistics Evaluation in the Swedish Retail Supply Chain, Lund University, Lund.*
70. *San Cristobal Mateo Jose Ramon (2015), Management Science, Operations Research and Project Management, Gower Publishing, Surrey, ISBN 9781472426437, 221 pg.*
71. *Sciomachen, A., & Tanfani, E. (2007). A 3D-BPP approach for optimizing stowage plans and terminal productivity. European Journal of Operational Research, 183, 1433-1446. https://doi.org/10.1016/j.ejor.2005.11.067.*
72. *Serban P. S., Nedelcu A. T., Pocora A. and Băcioiu Alexandru Stefan, Comparison of CFD determined squat on sailing ship MIRCEA with empirical methods, Scientific Bulletin of Naval Academy, Vol. XXII 2019, pg. 247-255.*
73. *Sha M., Zhang T., Lan Y. et al. (2017), Scheduling optimization of yard cranes with minimal energy consumption at container terminals, Computers & Industrial Engineering, vol. 113, pp. 704–713*
74. *Stahlbock R., Voß S., Operations research at container terminals: a literature update, OR Spect. 30 (1) (2008) 1–52*
75. *Stavrou, D., Timotheou, S., Panayiotou, C.G., Polycarpou, M.M.. Assignment and Coordination of Autonomous Robots in Container Loading Terminals, IFAC-PapersOnLine, Volume 50, Issue 1,*

2017, Pages 9712-9717, ISSN 2405-8963, https://doi.org/10.1016/j.ifacol.2017.08.2054

76. *Steenken D., Voβ S., Stahlbock R., Container terminal operation and operations research-a classification and literature review, OR Spect. 26 (1) (2004) 3–49*
77. *Styhre, Linda. (2010). Capacity utilisation in short sea shipping*
78. *Sun, P. Z. H., You, J., Qiu, S., Wu, E. Q., Xiong, P., Song, A., Zhang, H., Lu, T. AGV-Based Vehicle Transportation in Automated Container Terminals: A Survey. IEEE Transactions on Intelligent Transportation Systems, vol. 24, no. 1, pp. 341, January 2023.*
79. *Tan C.M., He J.L., Wang Y., Storage yard management based on flexible yard template in container terminal, Adv. Eng. Inform. 34 (2017) 101–113*
80. *Toma Alecu, Bacioiu Alexandru Stefan, Chirita Iulian Adrian, Influence of trim and rudder angle on ship handling, Scientific Bulletin of Naval Academy, Vol. XXII 2019, pg.228-233.*
81. *Tupper, E. C. (2013), Introduction to Naval Architecture (5th ed.), Butterworth-Heinemann. ISBN-13: 9780080982373*
82. *Vis I.F.A., De Koster R., Transshipment of containers at a container terminal: an overview, Euro. J. Oper. Res. 147 (1) (2003) 1–16*
83. *Wang, Z., Zeng, Q., A branch-and-bound approach for AGV dispatching and routing problems in automated container terminals, Computers & Industrial Engineering, Volume 166, 2022, Pages 107-968, ISSN 0360-8352, https://doi.org/10.1016/j.cie.2022.107968*
84. *Wei, M., He, J., Tan, C., Yue, J., & Yu, H. Quay crane scheduling with time windows constraints for automated container port. Ocean & Coastal Management, Volume 231, 2023, 106401, ISSN 0964-5691, https://doi.org/10.1016/j.ocecoaman.2022.106401.*
85. *Wei-Ying, Z., Yan, L., & Zhuo-Shang, J., Model and Algorithm for Container Ship Stowage Planning Based on Bin-Packing Problem. Journal of Marine Science and Application 4 (3): 30–36, 2005, https://doi.org/10.1007/s11804-005-0018-z*