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Sustainability of Maritime and Inland Ports

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Abstract

Maritime and inland ports are a cornerstone in the transport system of each state, providing different types of logistics services. In the last 80 years, they have undergone significant changes because of increased cargo volume transported by maritime and inland water transport, the transport capacity of different types of vessels, and their transport speed, and the introduction of push technology in inland navigation. Nowadays, they play a role as logistics hubs, and their activities can significantly impact the environment and local communities living close to these ports. The sustainability of ports is determined by some aspects like environmental, economic, social, and energy efficiency. This paper aims to investigate the sustainable port development. Nowadays port automatization is very important cognitive decision is needed to find the most suitable development strategies.

Keywords
sustainability, maritime and inland ports, emergency efficiency, automatization, emissions,

1. Introduction

Transport is the most crucial element in a logistics system. It connects different parts of the logistics chain. The transport of raw materials, semi-finished or finished products is carried out by moving various means of transport on the transport route from the production site to the point of composition. The downtimes that arise while transporting goods in the system door to door can be eliminated by incorporating multimodal logistics hubs in the logistics chain, providing storage, distribution of goods, and other logistics services. Each maritime and inland port can be considered as such a hub because it performs loading, unloading, transporting goods, and other functions associated with the complex services of vessels, crew, or goods.

Sustainability has become a fundamental element in the operation of modern maritime and inland ports (Maternová, Materna, Dávid, 2022). Revealing causal factors influencing sustainable and safe navigation in central Europe.

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Sustainability, 14(4), 2231.). These ports are part of the global logistics chain, playing the role of gateways for international trade and billions of goods transported by seagoing vessels on oceans or seas between the continents or inland vessels on waterways. Their activities can significantly impact the environment and local communities, which creates an imperative need for some changes in ports based on environmental, economic, and social aspects and energy efficiency. In this paper the automatization and sustainability is investigated. Our hypothesis is that there is a financial, social and environmental balance in sustainable automatization of ports.

2. Maritime and inland ports as logistics hubs

The primary role of logistics hubs is to increase the quality and efficiency of transport and manage transport flows. These hubs are typically established in places where transport flows are concentrated, essential transport routes intersect each other, and the directions of transport flows alter. Natural places for their location are economic and industrial agglomerations, transport junctions, container terminals, state borders, maritime or inland ports.

According to the establishment, multimodal logistics hubs can be divided into two groups. The first group consists of hubs that arise randomly according to the actual requirements and development of the market (most hubs are established this way). The second group consists of centers that are constructed according to a set model.

The main determinants for the location of these hubs are:

- transport routes and their capacity,
- transport infrastructure (a direct connection of the logistics hub with other modes of transport),
- the distance between the city core and the logistics hub,
- the distance between customers and the logistics hub,
- the distance between an airport/maritime or inland port and the logistics hub,
- the total area of the logistics hub and its possibilities for future development.

The disposition of the logistics hub depends on the volume of transport flows, the structure of handling products, and its infrastructure. The most important parts of logistics centers are transshipment areas and their infrastructure (handling facilities and devices, road and railway infrastructure) and storage facilities (warehouses and open storage areas).

In multimodal logistics hubs, there are concentrated:

- container terminals,
- entities that carry out transport operations (forwarders, carriers, navigation companies),
- entities that offer various services associated with cargo (custom or quality inspection, tallyman or stevedore services, special treatment of cargo)
- technical, operational, and administrative facilities associated with transport (warehouses, facilities which offer various services, for instance, supplying, repair, guard, rescue, and emergency services) (Dávid A., Sosedová, J. 2005).

2.1 History and functions

At the beginning of the 20th century, ports used to be places located on the coast of the seas, oceans (maritime ports), or waterways (inland ports) where maritime or inland water transport used to meet with other modes of transport (rail, road). Transport of cargo used to take about two-thirds of operating time and its transshipment in maritime or inland ports used to take only one-third of this time.

The situation changed after the Second World War due to the increase in cargo volume, which was transported by maritime and inland water transport, the introduction of push technology in inland navigation, and the increase of the transport capacity of different types of vessels and their speed. These factors caused the disproportion between the performance and efficiency of maritime and inland water transport and the handling facilities and devices of maritime and inland ports. Therefore, it was necessary to increase their efficiency, to enlarge port areas, and to build a new generation of maritime and inland vessels.

Maritime ports are generally located on the coasts of oceans or seas. In comparison with inland ports, they provide a larger scale of logistics services (see Figure 1), have more sophisticated handling facilities and devices used for

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transshipment cargo operations than inland ports, and are designed for different types of large seagoing vessels carrying cargo.

Nowadays, inland ports are transport hubs situated on waterways such as navigable rivers, lakes, or canals. They consist of berths, where cargo is handled by different types of cranes, stored in warehouses or open storage areas, or transported to the customers by other modes of transport. In comparison with maritime ports, they provide a smaller scale of logistics services.

An important part of each maritime and inland port is its connection with other modes of transport (road and railway transport). Railway transport carries mainly bulk cargo for longer distances between the port and the hinterland. Road transport carries mainly general cargo, including containers, and is used by companies in the vicinity of the port.

Maritime and inland ports should be designed and constructed to provide (Maternová et al., 2023:

- a fast and safe sailing of vessels from the waterway to port,
- smooth and safe maneuvering of vessels into water area, their anchoring, formation of convoys,
- a fast loading/unloading of cargo between vessels and the land of the port,
- a direct connection with other modes of transport.

A lot of factors influence the location of maritime and inland ports. Due to economic reasons, ports are generally situated near industrial and commercial centers. The topography of the site and its geological structure are very important factors for the construction of a new port. Additionally, the total area of the port and its surroundings are important for the location of basins, berths, handling and storage facilities (cranes, warehouse), infrastructure (roads and railways), and other buildings that are required for the operation of maritime or inland port (Dávid, 2023).

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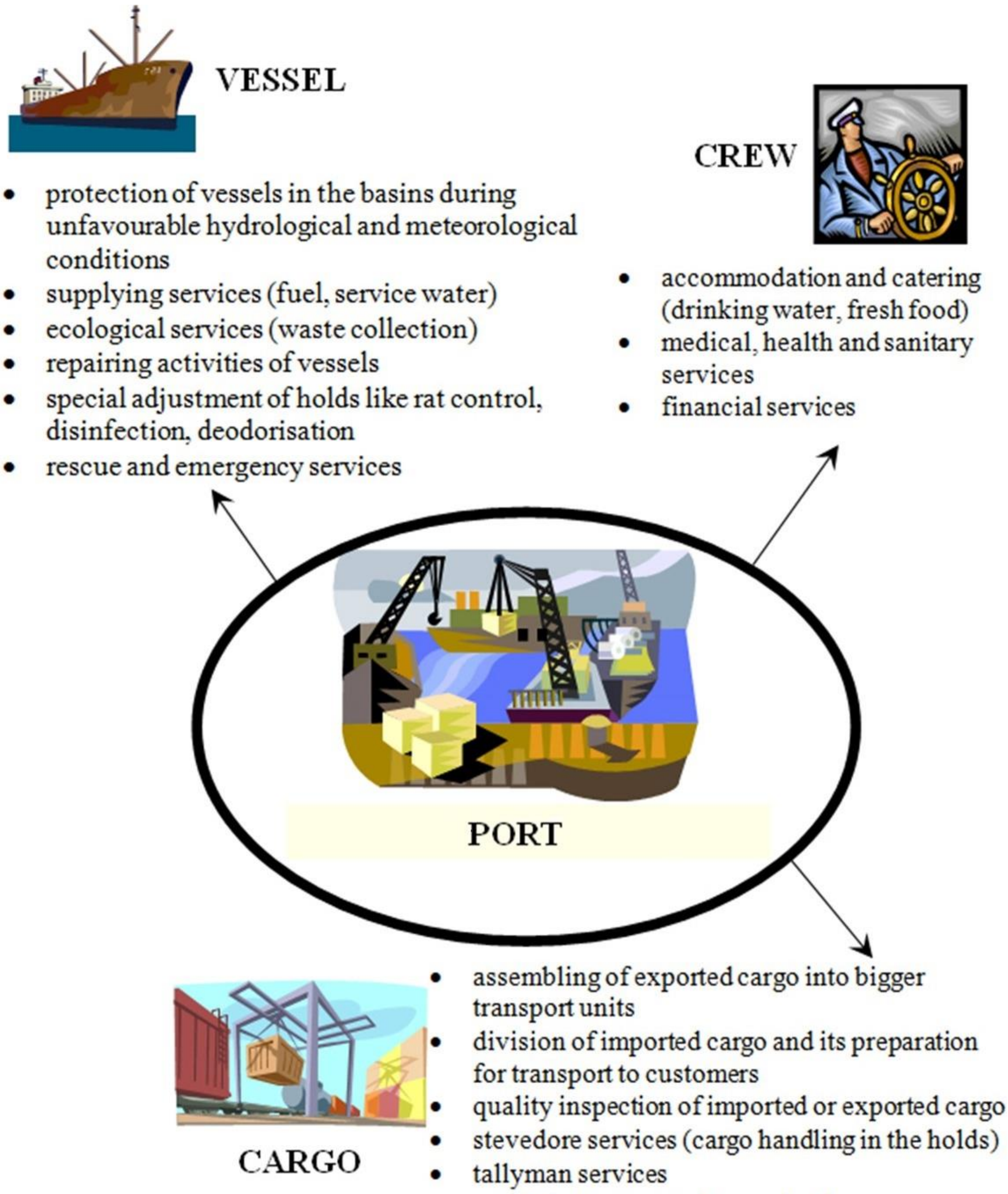

Figure 1. Services provided by a port (Dávid A. 2023)

2.2 Division of maritime and inland ports

Ports can be classified according to the purpose into the following categories.

1. **Business (public) ports** that transfer bulk, general, and liquid cargo, including containers between vessels and other modes of transport by port cranes. They also store cargo in the warehouses or on the open storage areas, transport it, and pack it for the customers. They usually have a water area and a land area. The port's land is equipped with handling facilities (gantry or container cranes) and infrastructure (roads and railway), enabling cargo transport between the port and its customers. Business ports are situated near big commercial and industrial areas. They are usually divided into various berths according to the type of cargo which is transferred there, for instance, transshipment areas for bulk, general, and liquid cargo, container terminals, Ro-Ro Ramp for cars, and areas for transshipment of oversized or overload cargo.

2. Private companies use **industrial ports** to tranship raw materials and semi-finished or finished products between vessels and the port's land. They are usually equipped with specialized handling facilities.

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3. **Passenger ports** are used for embarking or disembarking passengers between vessels and land. They are usually in the city centers because their area does not occupy too much space.

4. **Shipyard ports** are used for repairing or reconstructing vessels. They are equipped with gantry cranes, ship lifts, dry or floating docks, warehouses, and workshops.

5. **Specialized ports** are designed for particular purposes and unique vessels such as military, army, sport, fishing, or recreation ports.

Business (public) or industrial ports are the most import ports from the point of view of transport (Kubec J. 2003).

3. Energy efficiency and automatization of ports

Energy efficiency is a key aspect of sustainable ports (Savu et al., 2022). It involves optimizing energy use, such as improving the operational efficiency of handling facilities and devicesduring cargo transshipment or implementing alternative fuels like liquefied natural gas (LNG) or renewable sources (Andrejszki et al., 2014).

The optimization of energy use is often achieved by the automatization of handling operations, especially in the container terminals of maritime ports. Automated container terminals have container-handling equipment that works without direct human interaction. Crane drivers have been physically removed or have remained in their cabins. Still, they are not needed for the entire duty cycle – various automated handling equipment handle and transport containers between different container locations.

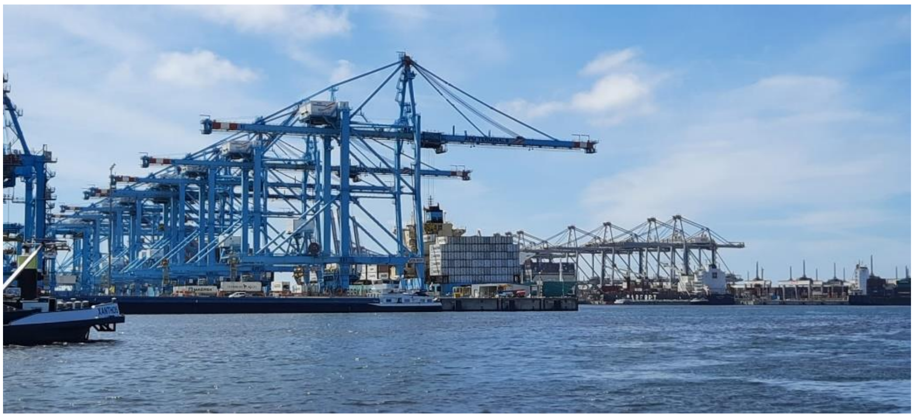

Figure 2. Automated container terminals in the port of Rotterdam (Dávid A.)

Automated guided vehicles (AGVs) have been transporting containers in container terminals since the beginning of the 1990s. They often carry containers at the water-side transfer area, and occasionally at the land-side transfer area. At the water-side transfer area, they move containers between container gantry cranes, and the container yard is divided into blocks. Automated guided vehicles decrease the downtimes in container terminals and minimize accident rates, the number of port workers, and staff costs. The first AGVs used to have diesel engines. In the last few years, they have been replaced by electric models (e.g., the APM 2 or RWG Terminal located in the port of Rotterdam). The batteries are charged twice a day, and electricity is obtained from renewable sources (wind power plants or solar panels in the port area).

Two types of rail-mounted gantry cranes are used in automated container terminals. The first type, which replaced diesel rubber-tired gantry cranes, transports containers between the water-side transfer area and the container yard, or between the container yard and the land-side transfer area, or places containers into the blocks of the container yard. These blocks are perpendicular to the wharf.

The second type of crane operates at the railway station at the land-side transfer area. It moves containers between wagons and semi-trailer trucks (railway and road transport). These cranes typically have large spans and can stack the containers up to 6 tiers high.

Some automated container terminals worldwide, such as Terminal Patrick in the port of Brisbane, or Terminal TraPac in the port of Los Angeles use automated straddle carriers to handle containers across the entire terminal. These automated straddle carriers replaced diesel straddle carriers operated by port drivers (Agershou, 2004; Tsinker, 2004)

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4. Sustainability of ports from an environmental point of view

Warning messages about climate change are becoming increasingly serious, and all possible measures are needed to jointly mitigate these threats. The maritime sector encompasses all industrial sectors and represents 3% of total global greenhouse gas (GHG) emissions, 13% of nitrogen oxide (NO_x) emissions and 12% of sulphur oxide emissions (SO_x) (Gray et al., 2021). In 2018, the global carbon dioxide (CO_2) emissions of shipping amounted to 1.06 gigatons (Gt) representing a share of 2,89% of global anthropogenic CO_2 emissions. Since 2008, the volume and CO_2 emissions from shipping have decoupled along with improved carbon intensity (mainly in attempts to save on fuel costs). However, in the worst case scenario, CO_2 emissions from merchant vessels could increase in the absence of preventive actions (Friedlingstein et al., 2019). An ambitious greenhouse gas (GHG) strategy by the International Maritime Organization (IMO, 2023) aims to cut the shipping sector`s carbon intensity by up to 40% by 2030 and 70% by 2050 compared to 2008. An even more challenging goal is to achieve 100% carbon emission reduction by 2050 across maritime sector globally. The IMO aims to help increase the energy efficiency of ships by measures such as an Energy Efficiency Design Index (EEDI), Energy Efficiency Existing Ship Index (EEXI) and carbon intensity indicator (CII). Regional targets and regulations have also been set, for example, the FuelEU Maritime Initiative in the EU Green Deal Fit for 55 package (14 July 2021) proposing a maximum limit on the GHG intensity of energy used on-board by ships. The Fit for 55 package also suggests shipping to be included in the EU 's Emission Trading System (ETS) (Aakko-Saksa et al., 2023).

Air pollution in ports from berthed vessels has a negative impact on people and nature near the port. Air pollution alone is estimated to cause approximately 6,5 million death a year. Despite the 2020 marine fuel sulphur limit of 0,5%, shipping is estimated to cause 250 000 premature deaths and 3 million cases of childhood asthma a year. Emissions such as particulate matter emission (PM), particle number emission (PN) and black carbon (BC) are particularly harmful. Particle emissions are linked to heart and pulmonary diseases and recently Alzheimer`s disease. Particles may carry species, such as PAHs related to carcinogenic and mutagenic activity (Schünemann et al., 2019). Reactive compounds and metal potentially cause inflammation and tissue damage. The residual fuel use in diesel engines emits exhaust particles with marked oxidative activity on the epithelial lining fluid in the lungs. Ship $PM_{2.5}$ emissions near port communities contribute to a health risk disparity based on ethnicity and income since low-income households are overrepresented in the affected populations near harbors. By further considering that the 40% of global population is settled within 100 km from the coastline and that half of the global tourism develops in coastal areas, it is clear as the impact of ports and shipping pollution represents an important health and social issue (Pivetta et al., 2024).

The European Union (EU) considers green hydrogen as one of the main pillars to be integrated in the future energy systems and it is often proposed as a promising option for decarbonizing industrial port areas (IPA). The role of green hydrogen in decarbonising ports was assessed as irreplaceable in the future. In the future, hydrogen and electricity will be needed in 2050 to ensure the transport of both freight and passengers on Europe 's Atlantic coast with only renewable energy. Green hydrogen will be essential to guarantee more sustainable maritime transport along Europe 's Atlantic coast. The challenge to achieve this now is the high cost of creating a green hydrogen plant capable of meeting market demand (Pivetta et al., 2024).

But as for now, the equipment for cargo handling and inter-port vehicles (except for railways) is almost entirely powered by oil-fueled internal combustion engines (ICE). It was estimated that port equipment involved in cargo handling activities is responsible for up to 15% of air emissions in port areas. The replacement of ICEs by using the best available technology can pass through three different paths: the adoption of alternative fuels, hybrid systems, and fully electrified ones. The ports of Hamburg and Bremerhaven tested a fuel-cell-powered forklift and hydrogen-fueled ICE straddle carriers. A more flexible solution is proposed in the Port of Antwerp, where a tugboat powered by dual fuel engine (diesel and hydrogen) is under construction (Colarossi et al., 2022).

Alongside hydrogen-fueled fuel cells, equipment electrification can also achieve local zero emissions, coupled with a reduction of global emissions. For instance, by means of life cycle assessment comparison between an ICE-powered yard tractors and their electrified counterparts, it was shown that the electrification of the 50% of the yard tractor fleet operating within the Port of Los Angeles could reduce the pollutant emissions up to 60%. Moreover, the connection of rubber-tired gantry cranes to the grid was found to reduce CO_2 emissions up to 80%. Also, onshore power supply (OPS) could effectively contribute to the reduction of GHG emissions in ports, as 70–100% of emissions in IPA are due to ship traffic. However, the installation of new infrastructures is challenged by port grid capacity, high capital investments, operating expenses, and by the different power supply specifications between port grids and vessels (Vichos et al., 2022).

Regarding inter-port transportations, railways are the most electrified mean of transport, but in several circumstances, convoys need to operate disconnected from the grid. Some examples include border crossing, service towards low populated areas, cargo handling on port branch lines or industrial spurs, or for maintenance purposes. In such situations, despite traction can be still supported by adopting battery-based storage systems, batteries cannot cope with the daily energy demand. This is especially true when long working shifts are required or duty cycles peak in power consumption as it happens with cranes and reach stackers. Swappable batteries seem a viable strategy to cover daily usage without recurring to oversize capacity installed on vehicle. Off-grid electrification using battery-based storage systems is currently the primary development path for light good vehicles. Similarly, the overall road transportation sector (light-duty vehicles and passenger cars included) is driven towards electrification by a supportive policy framework (Vichos et al., 2022).

5. Conclusion

Since the second half of the 20th century, maritime and inland ports have undergone considerable transformations due to various global changes. Nowadays, ports are logistics hubs that provide different types of logistics services. Environmental, economic, and social aspects and energy efficiency determine their sustainability. Automatization is considered as a part of energy efficiency. On the one hand, it is necessary to optimize all handling operations through various handling devices in the ports. On the other hand, it is essential to focus on protecting the environment. Maritime transport is one of the biggest polluters of the environment. Polluting gases are produced not only during cargo transporting but also during the anchoring of vessels in the ports waiting for all handling operations or embarking or disembarking of passengers. One way to reduce the volume of these harmful gases is to optimize all logistics operations in the ports.

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