The The Role of Artificial Intelligence and Digital Applications in Enhancing the Efficiency of Logistics Services in Seaports:

An Analytical Study of the Port of Rotterdam

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Abstract

This study investigates the contribution of artificial intelligence applications and digital transformation to improving the efficiency of logistics services in seaports, with the Port of Rotterdam serving as a pioneering global case. The research employs a descriptive-analytical methodology, drawing upon secondary data, official statistics, and an extensive review of case studies and technical reports published by the Port of Rotterdam Authority. The results demonstrate that the integration of advanced digital technologies and artificial intelligence tools—such as the Internet of Things (IoT), blockchain, virtual energy systems, predictive analytics, and big data processing—has significantly reduced vessel and container handling times while simultaneously enhancing environmental sustainability within the port. The study emphasizes the importance of fostering innovation projects in sustainable energy and green logistics as a means to consolidate the global competitiveness of seaports, particularly the Port of Rotterdam, thereby safeguarding its strategic position as both a European and global logistics hub.

Keywords

Artificial Intelligence;
Digital Applications;
Logistics Services;
Seaports;
Port of Rotterdam.

دور الذكاء الاصطناعي والتطبيقات الرقمية في رفع كفاءة الخدمات اللوجستية بالموانئ البحرية: دراسة تحليلية لميناء روتردام

ملخص

هدفت هذه الدراسة إلى تحليل دور تطبيقات الذكاء الاصطناعي والتحول الرقمي على رفع كفاءة الخدمات اللوجستية في الموانئ البحرية، مع التركيز على ميناء روتردام كنموذج عالمي رائد، اعتمدت الدراسة على منهج وصفي وتحليلي مدعوم ببيانات ثانوية وإحصاءات رسمية، إضافة إلى مراجعة دراسات حالة وتقارير تقنية صادرة عن هيئة ميناء روتردام.

وقد أظهرت النتائج أن دمج التقنيات الرقمية والذكاء الاصطناعي مثل أنترنت الأشياء والبلوك تشين ونظام الطاقة الافتراضي وأنظمة التنبؤ الذكية وتحليل البيانات الضخمة أسهم في تقليص زمن معالجة السفن والحاويات وتحقيق الاستدامة البيئية بالميناء. توصي الدراسة دعم مشاريع الابتكار في مجال الطاقة المستدامة واللوجستيات الخضراء لتعزيز التنافسية العالمية للموانئ البحرية وبالخصوص ميناء روتردام للحفاظ على موقعه التنافسي كمركز لوجستي أوروبي وعالمي.

الكلمات المفتاحية

ذكاء اصطناعي؛
تطبيقات رقمية؛
خدمات لوجستية؛
موانئ بحرية؛
ميناء روتردام.

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I- Introduction:

The maritime transport sector, particularly in the field of logistics services, is currently undergoing profound transformations driven by the digital revolution. The adoption of digital technologies and artificial intelligence has become an imperative to keep pace with these rapid technological advancements, with the dual purpose of strengthening competitiveness and enhancing the efficiency of seaports. Given the growing volume of global trade and the increasing complexity of supply chains, seaports are compelled to adopt innovative solutions that enable faster responses to massive logistical operations at minimal costs while ensuring the highest levels of sustainability. Within this context, the Port of Rotterdam has emerged as a pioneering global model in embracing a wide range of digital applications and artificial intelligence systems to optimize its logistics operations. These innovations span from vessel traffic management and data exchange among stakeholders to the deployment of Internet of Things (IoT) technologies, cloud storage, and blockchain applications, all of which collectively contribute to improved service efficiency, reduced waiting times, and greater operational sustainability. Through the above, we can raise the following problem:

What is the role of artificial intelligence and digital applications in enhancing the efficiency of logistics services at the Port of Rotterdam?

Sub-Questions: 1. What contributions does blockchain technology make in strengthening transparency and expediting customs clearance processes? 2. How do digital applications improve the flow and exchange of information among various stakeholders within the port? 3. What are the key approaches adopted by the Port of Rotterdam Authority to achieve environmental sustainability? 4. What are the major contributions enabled by the application of the Internet of Things at the Port of Rotterdam?

Hypotheses: 1. The study hypothesizes that the application of blockchain technology in customs processes facilitates pre-data exchange, thereby expediting customs clearance and cargo release while reducing both time and cost. 2. The study hypothesizes that the use of digital applications in the Port of Rotterdam enhances information flow and exchange among stakeholders, improving planning, operations, transparency, and competitiveness. 3. The study hypothesizes that the Port of Rotterdam Authority's adoption of projects such as the Virtual Energy System contributes to achieving its ambition of becoming the world's most sustainable port by reducing emissions, improving quality, and increasing the efficiency of industrial and logistics services. 4. The study hypothesizes that the Port of Rotterdam's deployment of IoT technologies for data collection and cloud-based processing ensures secure and easily accessible information for all relevant stakeholders.

Significance of the Study: The significance of this research lies in its focus on one of the most dynamic domains in maritime transport and logistics: the application of artificial intelligence and digital technologies in seaports. Specifically, the study is important because it:

- Highlights the Port of Rotterdam as a global leader in adopting artificial intelligence and digital applications.
- Demonstrates the role of these technologies in reducing waiting times and costs while promoting sustainability in maritime logistics services.

Research Objective

The study aims to:

- Highlight the role of artificial intelligence applications in improving transparency and accelerating logistical operations within the port.
- Assess the economic and environmental impacts of implementing smart technologies at the port.
- Derive lessons that can inform other ports, particularly Algerian ports, in leveraging such innovations.

Methodology: This study adopts a descriptive-analytical approach. The descriptive dimension provides an overview of seaports and logistics services, while the analytical dimension is based on the examination of official scientific sources, data, and technical reports issued by the Port of Rotterdam Authority.

Literature Review

- *Anwar et al. (2019)*, in their study *"Digitalization in Container Port Logistics: A Literature Review"*, reviewed the literature on the digitalization of container port logistics. The study concluded that digital transformation enhances transparency, accelerates information exchange, and improves decision-making in supply chains, while highlighting the need for broader adoption of smart technologies and greater integration among stakeholders (Mahwish, emiliano, & Lawrence, 25-28 june 2025).

- *Dornemann et al. (2020)*, in their study *"Artificial Intelligence and Operations Research in Maritime Logistics"*, explored applications of artificial intelligence and operations research in improving maritime logistics efficiency. Their findings indicated that the focus remains on predicting vessel arrival times, optimizing routing, and scheduling equipment, though most models are still at the theoretical simulation stage and not yet widely applied (Dornemann, Rückert, Fischer, & Taraz, 2020).

- *Belmoukari et al. (2023)*, in their study *"Smart Port: A Systematic Literature Review"*, conducted a systematic review of the smart port concept, identifying 11 attributes across 7 domains, including smart infrastructure, technologies, operational efficiency, and environmental and social aspects. The study provided a comprehensive definition of the smart port as a connected, secure, and sustainable entity built on intelligent infrastructure and management practices (Belmoukari, Audy, & Forget, 2023). This study distinguishes itself from prior research by moving beyond theoretical discussions of digitalization, artificial intelligence, and smart ports.

Instead, it provides an in-depth analysis of the Port of Rotterdam's real-world experience, offering practical insights into the impact of these technologies on enhancing logistics efficiency. Furthermore, it proposes actionable recommendations that can support other ports in replicating and benefiting from this model.

I.1. Seaports:

Seaports constitute the main arteries of international trade, facilitating the movement of goods and services while significantly contributing to the national economy through efficient operations.

I.1.1. Definition of a Seaport:

A seaport is commonly defined as a location where vessels are loaded and unloaded with cargo, utilizing a range of specialized equipment and machinery that are considered integral to the port's infrastructure due to their crucial role.

Another definition describes seaport is a "logistic and industrial node in global supply chains with a strong maritime character and a functional and spatial clustering of activities directly or indirectly linked to transportation, transformation, and information" (Notteboom, Pallis, & Rodrigue,

Port Economics, Management and Policy, 2022) In contemporary contexts, ports are no longer limited to serving as interfaces between land and sea.

They have evolved into integrated industrial complexes combining cities, storage hubs, and manufacturing zones to meet rising customer demands. Over the long term, ports are envisioned as pivotal drivers of coordination among cities, logistics operations, industrial clusters, and international markets, thereby maximizing overall efficiency (Russo & Musolino, 2021)

I.1.2. Types of Seaports:

Seaports constitute one of the most critical components of the maritime transport industry, functioning as major gateways for international trade and the movement of people and goods. With rapid developments in maritime transport and rising demand for logistics services, ports have diversified based on geography, ownership, and functional specialization.

I.1.2.1. Based on Geographical Setting: Seaports may be categorized as natural ports, semi-natural ports, or artificial (man-made) ports. (Sheikholeslami & Langeroodi, 2024)

I.1.2.2. Based on Ownership: Ports may be publicly owned, typically under government authority as an expression of national sovereignty, or privately owned and managed by international corporations specializing in port operations. (Wouter, Claudio, Thierry , & Edwin , 19 july 2025)

I.1.2.3. Based on Function: This is the most widely used classification:
- **Commercial Ports:** The most common and significant type, designed for handling cargo, shipments, and services related to international trade and import-export activities. They may be general-purpose ports equipped to receive all types of merchant vessels or specialized ports dedicated to specific cargo, such as oil.

- **Shelter Ports:** Designated as safe havens for vessels during emergencies such as storms, accidents, or technical failures. (Tadini, 2024)

- **Military Ports:** Built for national security purposes, these ports include facilities beyond commercial operations, such as those required for handling weapons and ammunition, and serve as bases for warships, submarines, and aircraft carriers. (Sheikholeslami & Langeroodi, 2024)

I.1.3. Importance of Seaports:

Seaports play a central role in supporting international trade and promoting sustainable economic development by facilitating the movement of goods and services and attracting investments:
- With advanced infrastructure, ports contribute to national economic growth by generating foreign currency through international trade.

- They enhance competitiveness in global markets by facilitating the export of domestic products and attracting foreign investors who prefer countries with strong port facilities.

- Ports serve as integrated platforms for logistics services, handling imports and exports, streamlining customs and trade processes, and offering services such as cargo handling, multimodal transport, ship repair, and vessel provisioning.

- They function as hubs for information exchange between investors and maritime stakeholders, including shippers, carriers, and agents.

- Ports are central to the development of multimodal transport systems, acting as convergence points for diverse transport modes as well as centers for manufacturing, cargo consolidation, and packaging for international distribution. (Bocheński , Palmowski, & Studzieniecki, 2021)

I.2. The Contribution of Artificial Intelligence in Developing Logistics Services:

Logistics services in seaports constitute an integrated system encompassing cargo reception, storage, handling, and distribution. With the advent of modern technologies and the integration of artificial intelligence (AI), these processes have become more efficient and faster, enabling demand forecasting, optimal resource allocation, and accelerated customs clearance and handling. This integration promotes smoother trade flows, enhances port competitiveness, and advances sustainability.

I.2.1. Types of Logistics Services:

Logistics services represent a fundamental element in transforming a port from being merely a docking station for vessels into a strategic hub for international trade and a logistics center, Each type of logistics service encompasses the following (Lowe, 2002)

- **Storage Services:** Obtaining necessary licenses for warehousing and placing goods in storage facilities pending customs clearance, thereby preventing berth congestion. Specialized facilities include refrigerated warehouses for food, pharmaceuticals, and perishables, and hazardous-material warehouses for chemicals and fuels.

- **Transport Services:** Ensuring continuous and efficient cargo flow using appropriate and licensed transport modes, while reducing vessel turnaround time through expedited loading and unloading.

- **Shipping and Customs Clearance Services:** A critical link in global supply chains, connecting imports and exports while involving carriers, handling companies, and customs authorities.

- **Supply Services:** Provision of goods and materials in the right place, time, quantity, and cost, including vessel supplies (fuel, food, spare parts) and essential logistics such as containers, handling equipment, and IT systems.

- **Integrated International Logistics Services:** Expanding the logistics scope beyond national boundaries, positioning ports as regional hubs in international supply chains.

- **Cold Chain Services:** Specialized in transporting, storing, and distributing perishable goods under refrigerated conditions, ensuring compliance with global health and safety standards.

I.2.2. Applications of Artificial Intelligence in Logistics:

AI has become a cornerstone in enhancing logistics efficiency by analyzing data to design optimal supply and production plans, improving warehousing systems, and forecasting future demand. Its applications include:
- Identifying inefficiencies and reducing costs by analyzing historical and real-time data, such as fuel consumption.
- Enhancing vessel efficiency through route optimization, automation, and decision-making support.
- Promoting sustainability by minimizing waste and emissions.

- Eliminating human error by ensuring accurate and reliable data.

- Strengthening safety by predicting risks and detecting equipment failures (MITAGS, 2023)**.**

I.2.3 Contributions of Blockchain Technology in Facilitating Customs Processes:

Blockchain enhances transparency through information sharing among stakeholders while simplifying procedures and reducing both cost and time by replacing paper-based documentation with digital systems. Key applications include pre-shipment data sharing to expedite customs clearance and cargo release, as well as advanced cargo registration systems enabling risk assessment and inspection before export, thereby procedures clearance streamlining(Ok، Barnty، و Oloyede.)2025،

II– The Port of Rotterdam as a Model of Smart Technology Adoption:

II.1. Overview of the Port of Rotterdam:

II.1.1. Definition and Historical Development:

The Port of Rotterdam is one of the world's foremost seaports, extending approximately 40 kilometers in length and 10 kilometers in width, annually accommodating around 30,000 ocean-going vessels and 130,000 inland vessels. Covering about 10,500 hectares, the port includes extensive docks, warehouses, and industrial zones.
It comprises five main port areas and three distribution parks serving over 40 million consumers. From 1962 to 2002, it ranked as the busiest port in the world, before being surpassed by Singapore and later Shanghai in 2011. In 2022, the port handled approximately 467 million tons of cargo, including 14.4 million TEUs, ranking fifth globally in bulk cargo and tenth in container throughput.

II.1.2. Evolution of the Port:

Originating as a fishing port in the 15th century near the old city center, Rotterdam evolved into a major commercial port by the 19th century, serving the Dutch colonial empire and Western Europe. Its expansion was closely tied to the growth of industrial activity in Germany's Ruhr region, leading to gradual development along the Rhine toward the North Sea.

Subsequent decades witnessed the addition of bulk cargo facilities, petrochemical plants, and oil refineries, solidifying Rotterdam's role as Europe's energy and petrochemical hub. Despite wartime destruction during World War II, post-1945 reconstruction and expansion projects, including the *Europoort* and later the *Maasvlakte* reclamation projects, enabled Rotterdam to maintain global prominence. The Maasvlakte II expansion, launched in 2008 and partially operational by 2013, reflects the port's long-term growth strategy, with full completion expected by 2030 (Notteboom, Pallis , & Rod, 2022).

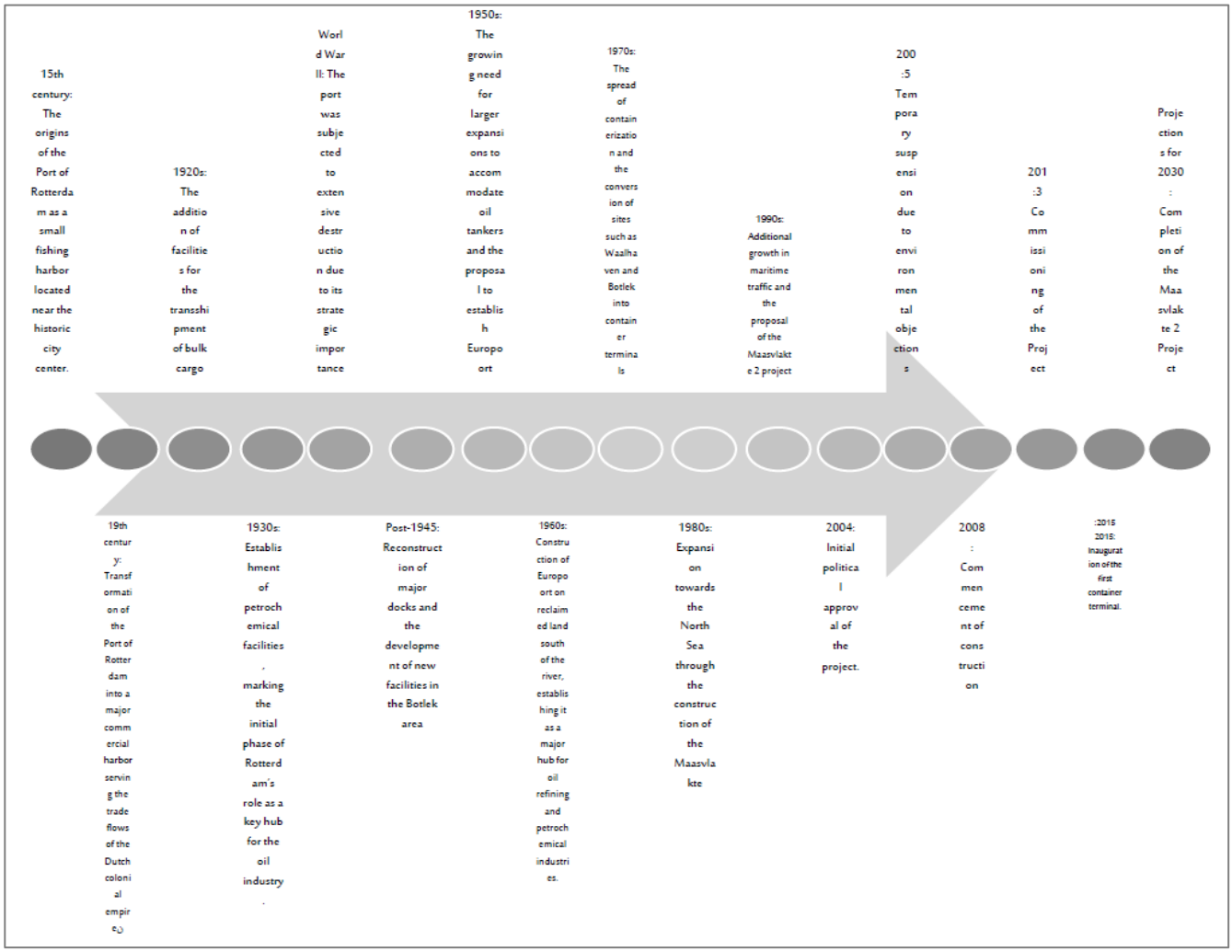
Figure (01): Evolution of the Port of Rotterdam (1400–2030).



Source: Theo Notteboom, Athanasios Pallis, and Jean-Paul Rodrigue (2022). *Port Economics, Management and Policy*. New York: Routledge, p. 690.

According to the preceding discussion, the port has been constrained between competing land uses—on the northern side largely due to urban pressures, and on the southern side due to agricultural land. The foregoing can be summarized through the following timeline illustrating the development of the Port of Rotterdam:

Figure (02): Timeline of the Port of Rotterdam's Development from the 15th Century to Projections for 2030



Source: Pepared by the researchers based on:

Theo Notteboom, Athanasios Pallis, and Jean-Paul Rodrigue (2022). *Port Economics, Management and Policy*. New York: Routledge, p. 690.

An overview of the Port of Rotterdam can be provided through the facts and figures presented in the following table:

Table (01): Facts and Figures – Port of Rotterdam Authority and the Port

Port Authority	1,150 employees; annual turnover of approximately €710 million.
Port Area	12,600 hectares (land and water), including about 6,000 hectares of industrial
Employment	sites. The port zone extends over more than 40 kilometers.
Cargo Throughput	180,000 jobs.
Shipping	Around 470 million tons of goods annually.
Value Added (Direct and Indirect)	Approximately 30,000 seagoing vessels and 105,000 inland vessels per year.
Global and European Ranking	Fourth largest port worldwide and the largest in Europe.
Total Value Added (Direct and Indirect) and Employment	± €15.5 billion and ± €6.7 billion; ± 90,000 or ± 55,000 employees, respectively.
Role of the Port Authority	Responsible for infrastructure, long-term planning and development, and safety.
Total Surface Area and Quay Length	10,570 hectares (excluding ± 1,000 hectares of Maasvlakte 2) and ± 90 km of quays.
Number of Businesses Linked to the Port	± 1,315 companies.
Tank Storage Capacity and Pipeline Length	± 30 million cubic meters and ± 1,500 km of pipelines.
Number of Terminals	50 (for containers, liquid bulk, and dry bulk).
Petroleum and Chemical Companies	± 130 (including Europe's largest refinery).
Logistics Service Providers	± 1,220 (covering transport, transshipment, warehousing, and forwarding).
Wholesale or Service Companies (Commercial and Non-Commercial)	± 650 and ± 270, respectively.

Source: Port of Rotterdam, Facts and Figures, https://www.portofrotterdam.com/en/experience-online/facts-,Consulted on May 30, 2025.

II.1.3. Strategic Location and Global Connectivity:

The geographical position of the Port of Rotterdam constitutes one of its major strengths. Situated at the Rhine–Meuse–Scheldt delta, it offers direct and unique access to the European hinterland, including Germany, Belgium, and France. This strategic location makes Rotterdam a primary gateway for goods flowing to and from the European Union. The port is connected to over 1,000 ports worldwide, forming an extensive maritime trade network that situates it at the heart of global logistics services and establishes it as a pivotal hub for transshipment and the smooth flow of goods between continents.

The port further benefits from its integration with Europe's major rivers, in addition to a comprehensive network of railways, highways, and inland waterways that facilitate rapid transportation toward industrial centers. The Betuweroute freight railway and highly efficient inland shipping serve as key components in consolidating Rotterdam's status as a central hub for importers, exporters, and logistics providers. Beyond Europe, the port plays a vital role in linking global markets—especially in Asia and North America—making it an indispensable strategic asset for e-commerce companies, manufacturers, and producers relying on cost-efficient and reliable shipping. (Port Of Rotterdam, Strategic location, s.d.).

II.1.4. Significance of the Port of Rotterdam:

The economic importance of the Port of Rotterdam is reflected in several critical indicators such as direct and indirect value added and employment levels. The port underscores its industrial nature through the diversity of sectors operating within it, including:

- Logistics services (transport, warehousing, distribution).
- Production activities (maritime equipment, transport, petroleum and chemical industries, food processing).
- Commercial services supporting these activities.

Despite its limited geographical space, the port generated a value added exceeding €45.6 billion in 2017, equivalent to 6.2% of Dutch GDP. It also offers advanced facilities for the transshipment of dry bulk goods, while its strategic location and deep waters allow easy access for the world's largest vessels. Thus, Rotterdam goes beyond serving as a mere gateway to Europe, functioning instead as a central node in the global logistics network. Handling approximately 469 million tons of cargo annually and accommodating more than 30,000 seagoing vessels, the port serves as a vital artery of international trade. From crude oil and chemicals to containerized consumer goods, its unique capabilities remain unmatched. Understanding the port's technological significance and global role is crucial for all stakeholders in the supply chain—from shipping companies and logistics service providers to customs brokers and manufacturers. Rotterdam's competitive edge stems from its advanced infrastructure, strategic location at the crossroads of global trade, increasing reliance on innovative technologies, and strong commitment to sustainability—ensuring the seamless flow of goods across continents for years to come (Port Of Rotterdam, Strategic location, s.d.).

II.2. Logistics Services at the Port of Rotterdam (Port Of Rotterdam, s.d.) :

II.2.1. Containers:

- **Container Depots:** The port has over 20 container depots spread across more than 120 hectares. These facilities go beyond storing empty containers; they also provide integrated services including sales, inspection, modification, cleaning, and repair. Some depots specialize in maintaining and cleaning tank containers.

Depots form a crucial link in the logistics chain, offering importers convenient empty-container returns and exporters ready-to-ship containers. With their diversity, service quality, and excellent transport connections, Rotterdam has become Europe's most important hub for empty containers.

- **Sustainability through Inland Shipping:** More than 75% of depots have their own quays, enhancing efficiency and sustainability. Since 2009, inland shipping volumes to and from depots have nearly doubled, growing by over one million TEU annually.

- **Tank Containers:** Specialized depots handle tank containers, providing cleaning, inspection, and maintenance. These depots are also equipped to manage hazardous cargo and connect to inland transport. Over the past five years, traffic in liquids, powders, and gases in tank containers has grown by more than 10%, and the volume is expected to double in the next decade.

- **Container Flows:** Rotterdam's extensive container traffic secures strategic advantages. It maintains direct shipping lines with over 1,000 global ports and offers multimodal transport networks to ensure efficient inland distribution.

Key stakeholders in container shipping networks include five groups (Kersbergen, 2023):

- **The Client Group:** This category includes the shippers and the final recipients of containers.

- **The Organizational Group:** This group encompasses companies responsible for organizing container transportation. These companies often rely on external service providers specialized in transport, such as shipping lines and logistics service providers.

- **The Physical Group:** These are the entities that physically handle the containers and oversee their transportation operations, including terminal operators and transport companies.

- **The Authorization Group:** Represented by governmental bodies that establish and enforce regulations within the port, such as port authorities and customs.

- **The Financial Group:** This group consists of banks and insurance companies, responsible for managing the financial aspects and transactions among the various stakeholders (Kersbergen, 2023).

II.2.2. Value-Added Services:

Beyond transshipment, Rotterdam is a fully integrated logistics hub. Hundreds of service providers engage in distribution, adding value to goods and simplifying supply chain management.

II.2.3. Chemical Cargo Shipping:

Rotterdam is Europe's largest hub for containers and petrochemicals, serving as a critical link in the supply chain for containerized chemical products.

II.2.4. Transport (Port Of Rotterdam, Intermodal transport, s.d.) :

- **Multimodal Transport:** A comprehensive system combining rail, inland shipping, road, and pipelines.

- **Rail:** Over 400 international rail services weekly, including container, liquid, and bulk cargo trains.

Germany can be reached within 3 hours, and many European destinations in less than 24 hours.

- **Road:** Trucks cover short-distance routes efficiently, with 40% of trips remaining within Rotterdam, 50% within the Netherlands, and just 10% cross-border.

II.2.5. Inland Shipping:

Logistics providers can handle the entire logistics process—including inventory management, labeling, consolidation, and even veterinary inspections—ensuring full-service supply chain solutions (Port Of Rotterdam, Storage and Transhipment, s.d.).

II.3. Technologies Used in the Port of Rotterdam:

II.3.1. Artificial Intelligence (Port Of Rotterdam, Artificial Intelligence in the port)
The Port of Rotterdam in the Netherlands is one of the world's leading ports in terms of employing artificial intelligence (AI) and advanced technologies to enhance its development and improve the efficiency of its services. The port offers an intelligent infrastructure capable of fully leveraging the progress achieved in AI.
- **Future Vessel Traffic System (VTS):** The Future Vessel Traffic System (VTS) is one of the most advanced systems worldwide. It relies on cutting-edge technologies that enable the Port of Rotterdam to strengthen safety, sustainability, and efficiency in managing the movement of thousands of vessels each year. According to the International Maritime Organization, the main objectives of this system are to monitor and guide vessel traffic within ports to ensure maritime safety, reduce collision risks in congested harbors and waterways, protect the marine environment, allow for advance planning of vessel movements, and provide navigational information and support to improve the effectiveness and efficiency of maritime transport services.

- **Virtual Energy System:** The "Virtual Energy System" project is one of the most innovative initiatives in sustainable energy management. It aims to build a more efficient, reliable, and competitive energy framework. The project is based on a simulation model powered by AI and high-quality data, enabling stakeholders to visualize and measure the impact of sustainable energy solutions within energy clusters, thereby supporting more accurate and effective decision-making.
The prototype developed provides real-time insights into energy flows, sustainability indicators, reliability, and competitiveness. It also manages these flows through integrated digital platforms that incorporate renewable energy sources and offer high flexibility in distributing energy across the port's components. By simulating multiple scenarios, the system helps determine optimal measures to achieve Rotterdam's ambition of becoming the world's most sustainable port, thereby driving the transition of industry and logistics toward greener pathways through reduced emissions, improved quality, and enhanced efficiency.
- **Drones:** The Port of Rotterdam employs drones extensively to inspect systems and areas that are difficult to access through conventional means. Their applications also extend to other fields, such as transporting people or goods. In collaboration with several partners, the Port Authority is exploring various possibilities for applying this technology within and around the port area.
Global transport companies such as Amazon, UPS, and DHL have already initiated drone delivery trials. Within the port, this technology can be used to deliver essential supplies to ships, including spare parts, navigation equipment, blood, or medicines. In May 2020, the Port of Rotterdam witnessed the delivery of its first package by drone, followed by a series of pilot projects.
- **Dynamic Data:** In the Port of Rotterdam, infrastructure dimensions such as quay walls and cranes are recorded in a Geographic Information System (GIS). However, the main challenge lies in integrating this information with various types of dynamic data, such as weather conditions, currents, visibility, and wind speed, into a unified platform.

Through the adoption of Internet of Things (IoT) technologies, the Port Authority can collect such data in the cloud, process it, and make it securely and easily accessible to all relevant stakeholders. The IoT team at the port collaborates with companies like IBM Watson, Cisco, Tele2, and Axians to develop this platform effectively. Storing dynamic data in a cloud environment poses a critical challenge, as it must be 100% reliable, secure, and available in real time to allow stakeholders to make informed decisions.

This data is essential for determining the feasibility of vessel entry—from the registration stage, through integrating information about channel depth, vessel size, and weather conditions, to berth characteristics and availability. IoT data can also be leveraged for predictive maintenance, further enhancing the efficiency and reliability of port operations.

II.3.2. Digital Applications as Tools for Competitive Advantage:

Digital transformation projects that primarily focus on improving port logistics can be regarded as a direct investment in Rotterdam's competitive positioning and the added value it offers to its users. The Port Authority has adopted a number of initiatives in this field, including (Port Of Rotterdam, All tools and services, s.d.) :
- **Routescanner:** The Routescanner.com platform is a digital tool that enables cargo owners to explore door-to-door container transport routes across ports, rail, and road networks, thereby enhancing supply chain transparency. Since its launch in 2022, it has attracted thousands of monthly users and over 150 operators have joined the platform. Its ambition is to become the global neutral reference point for container route visibility.

- **PortXchange:** A digital data-exchange application designed to coordinate port call activities more effectively. It reduces vessel turnaround times, optimizes terminal utilization, and enhances service quality through improved forecasting accuracy.

- **Nextlogic:** A digital platform for inland container shipping coordination at the Port of Rotterdam. It minimizes waiting times and congestion, while increasing the reliability and competitiveness of inland shipping operations.

- **Ontrack:** This application provides real-time data on rail freight movements within the port and their processing at terminals. It equips terminals and transport companies with accurate information to support more efficient planning and predict potential deviations.

- **Riverguide:** An application serving both inland shipping and recreational boating in the Netherlands. It consolidates port and waterway data to provide up-to-date navigational information on routes, berths, and water resources for users of inland waterways.

III- Impacts of Digital Transformation and AI on Logistics at the Port of Rotterdam:

- **Accurate prediction of vessel berthing times:** It has now become possible to accurately predict the expected berthing time more than 20 minutes in advance, even when the vessel is still several days away from the port (Staff , 2019).

- **Reducing in-port time for inland vessels and berths:** Through the *Nextlogic* project, inland vessel time spent in port has been reduced by more than 20%, thereby accelerating vessel handling operations. This improvement was achieved by facilitating coordination among port stakeholders, and in 2023 alone, the system processed one million container movements at one of its implementation stages. The application also contributes to reducing operating costs, as shorter port stays translate into lower port fees, labor costs, and fuel consumption (Port Of Rotterdam, 2024) .

- **Cost savings through shorter berthing times:** The application of Internet of Things (IoT) technologies has shortened berthing time by approximately one hour, which translates into savings of up to USD 80,000 per call for certain vessels (Leong, 2020).

- **Reducing carbon emissions:** Within the framework of the *Just-in-Time Sailing* initiative, studies conducted by the TNO Research Institute and the Port of Rotterdam Authority indicate that improving the digital flow of information between ports and seagoing vessels is an effective strategy for achieving environmental sustainability. An analysis of container vessel movements bound for the Port of Rotterdam in 2017 showed that providing vessels with accurate information on berth availability and berthing schedules could reduce CO_2 emissions by approximately 4%, equivalent to 134,000 tons annually. Greater reductions can be achieved if vessels are provided with this information more than 12 hours prior to arrival (Port Of Rotterdam, 2018).

IV- Conclusion: This study has demonstrated that the integration of artificial intelligence and digital applications into the logistics services of the Port of Rotterdam has driven a profound transformation in port 12 operations management. These technologies have accelerated information exchange, reduced waiting times, and enhanced coordination among stakeholders. Moreover, they have improved service quality, lowered operational costs, and reduced carbon emissions, positioning the port as a global benchmark in innovation and sustainability.

IV.1. Results:

- Artificial intelligence and digital applications have enhanced both the speed and transparency of information exchange among all actors in the Port of Rotterdam.

- Smart technologies, such as the Internet of Things (IoT), have improved service quality by enabling predictive maintenance, thereby increasing the efficiency and reliability of port operations.

- Blockchain technology has strengthened transparency and efficiency in customs management, leading to reduced costs and processing times while enhancing the overall performance of logistics services.
- Digital transformation has contributed to reducing the environmental footprint and consolidating the port's position as a sustainable logistics hub.

IV.2. Suggestions :

- Strengthen digital infrastructure and further develop shared platforms to facilitate real-time data exchange among all stakeholders.
- Support innovation projects in sustainable energy and green logistics to enhance the global competitiveness of seaports, particularly the Port of Rotterdam, in maintaining its leading position as both a European and global logistics hub.

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