

The Importance of Developing the Maritime Transport Sector through Smart Ports in Enhancing the Blue Economy: A Case Study of Singapore

أهمية تطوير قطاع النقل البحري عبر الموانئ الذكية في تعزيز الاقتصاد الأزرق: دراسة حالة سنغافورة

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Abstract:

This research aims to study the importance of developing the maritime transport sector through smart ports in supporting and strengthening the blue economy, given that the maritime transport is one of its most important sectors, through a case study of Singapore.

The descriptive and analytical methodologies were adopted, as they are suitable for building the theoretical framework of the research variables and for presenting and analyzing the Singaporean experience.

The research concluded with several important results, most notably that smart ports have come to represent a strategic development for the maritime transport sector, as this development contributes to enhancing efficiency, reducing emissions, and supporting sustainability. The Singaporean experience represented the best model to be emulated in port management using smart technologies, demonstrating how the integration of innovation and digital infrastructure can transform ports into global competitive hubs, exemplified by the Port of Tuas project. Singapore has succeeded in becoming a leading model in port development in line with the goals of the blue economy.

Keywords: Maritime Transport, Ports, Smart technologies, Blue Economy, Singapore.

JEL Classification Codes: R41, L92, Q57, O53.

ملخص:

يسعى هذا البحث إلى دراسة أهمية تطوير قطاع النقل البحري عبر الموانئ الذكية في دعم وتعزيز مسار الاقتصاد الأزرق كون أن النقل البحري أحد أهم قطاعاته من خلال دراسة حالة سنغافورة .

تم الاعتماد على المنهجين الوصفي والتحليلي كونهما مناسبين في بناء الإطار النظري لمتغيرات البحث وعرض وتحليل التجربة السنغافورية. وخلص البحث إلى مجموعة من النتائج المهمة، أبرزها أن الموانئ الذكية أصبحت تمثل تطورا استراتيجيا لقطاع النقل البحري، حيث أن هذا التطور يساهم في تعزيز الكفاءة، وخفض الانبعاثات، ودعم الاستدامة. وإن التجربة السنغافورية مثلت أحسن نموذج يستدل به في إدارة الموانئ باستخدام التقنيات الذكية حيث أظهرت كيف يمكن لتكامل الابتكار والبنية التحتية الرقمية أن يحوّل الموانئ إلى مراكز تنافسية عالمية، وقد جسد مشروع ميناء تواس هذا التحول. فسنغافورة نجحت في أن تكون نموذجا رائدا في تطوير الموانئ بما يتماشى مع أهداف الاقتصاد الأزرق.

كلمات مفتاحية: نقل بحري، موانئ، تقنيات ذكية، اقتصاد أزرق، سنغافورة.

تصنيفات JEL : R41, L92, Q57, O53.

Introduction:

In light of global economic and environmental challenges, the concept of the Blue Economy has emerged as a strategic path to achieving sustainable development. It aims to utilize marine and water resources in a balanced manner that promotes economic growth while preserving biodiversity and the marine environment. The Blue Economy is not limited to traditional economic activities such as fishing or maritime transport; rather, it encompasses technological innovation, marine renewable energy, marine tourism, and marine scientific research, forming an integrated model that combines economic performance with environmental efficiency.

The maritime transport sector is considered one of the most important pillars of the Blue Economy, given its vital role in facilitating international trade and transporting raw materials, food commodities, and energy sources between countries. Improving this sector and developing its infrastructure is a priority for coastal nations, as it directly impacts economic growth, job creation, and global competitiveness.

In this context, smart ports have played a pivotal role in restructuring the maritime transport sector by integrating digital technologies, big data, artificial intelligence, and the Internet of Things to facilitate the management of ship and cargo traffic, improve operational efficiency, and reduce environmental emissions.

Singapore has emerged as a leading global model in this field, combining strategic planning, technological innovation, and the practical application of Blue Economy principles. It has established an integrated network of smart ports that rely on 5G technologies, smart logistics systems, and big data management, making it a global hub for maritime trade and smart port management .

Study problem:

The research problem is represented by the following main question: How do smart ports contribute to achieving the goals of the blue economy, based on Singapore's experience?

Study hypotheses:

Based on the research problem, the following hypotheses were proposed:

- Smart ports are a fundamental pillar in achieving the goals of the Blue Economy by enhancing operational efficiency and environmental sustainability;
- Singapore's experience represents a successful model for leveraging smart ports to achieve the goals of the Blue Economy.

Study objectives:

This research aims to:

- Define the conceptual framework for both the Blue Economy and smart ports;
- Clarify the relationship between the Blue Economy and the maritime transport sector;
- Highlight the role of smart ports in supporting the goals of the Blue Economy;
- Examine Singapore's experience in developing smart ports within the framework of the Blue Economy.

Study methodology:

The descriptive analytical approach was adopted, as it is the most appropriate for building the theoretical framework of the research variables and for presenting and analyzing the Singaporean experience.

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Previous studies :

Several previous studies have addressed the research variables. (Youssef, 2023), in his study "Blue Economy Literature Review," presented a comprehensive overview of the blue economy concept, highlighting its economic, environmental, and social dimensions, and its role in achieving sustainable growth through the rational use of marine resources in sectors such as transport, energy, tourism, fishing, and biotechnology. He also pointed out key challenges including pollution, overfishing, and climate change that threaten marine ecosystem balance. Similarly, (Bentayeb & Nouar, 2024), in their study "Challenges of Maritime Transport for the Blue Economy in the Mediterranean Basin," examined maritime transport in the Mediterranean region and found that efforts toward sustainable transport have not yet yielded tangible results, particularly in reducing carbon emissions, underscoring the need for greater environmental coordination and technological innovation.

Regarding smart ports, (Lin & al, 2022), in "Exploring the Impact of Different Port Governances on Smart Port Development Strategy in Taiwan and Spain," analyzed how governance styles influence smart port development. The study showed that Taiwan focused on maritime safety, while Spain prioritized economic efficiency, reflecting different strategic orientations. Similarly (Chowdhury & al, 2023), in "Smart Port Management Practices and Implementation: An Interpretive Structural Modelling Approach," examined Chattogram Port in Bangladesh and highlighted that limited technical knowledge and resistance to change are major obstacles to digital transformation in developing ports. Finally, (Theppitak & Noijsaroen, 2024), in "Sustainable Smart Port Development: How to Create a Competitive Advantage for Thai Ports and Developing to be Green and Smart Ports," explored the link between green and smart strategies and port efficiency, emphasizing that smart practices enhance operational efficiency, sustainability, and competitiveness, while calling for alignment with global technological trends.

Although some previous studies have focused on the theoretical framework of the blue economy, while others have addressed smart ports, their development strategies, and management mechanisms, there is a clear lack of literature that practically examines the link between smart ports and the objectives of the blue economy. Most studies have been limited to theoretical analysis or to examining general trends in smart port development, without providing a clear assessment of how these ports contribute to enhancing maritime sustainability and economic efficiency within the blue economy framework. Accordingly, there is a need for an applied study that focuses on successful practical experiences, such as the Singapore experience, to understand the mechanisms and strategies that can enhance the integration between smart ports and blue economy goals, and to provide a model that can be used in other international contexts.

1. Blue economy : definition, goals, and sectors

1.1.Blue economy definition :

During the Rio+20 Summit in 2012, the Blue Economy was defined as an economic model that aims to achieve sustainable economic and social growth through the rational use of marine resources, both saline and freshwater, through a range of activities including marine fishing, aquaculture, marine mining, marine renewable energy, transportation and navigation,

and coastal tourism. The Blue Economy is based on the principle of sustainable exploitation of marine resources, ensuring the preservation of the ecological balance of seas and oceans and preventing the depletion of natural resources or harm to marine biodiversity. (Elbahri, 2025, p. 469)

The United Nations Environment Programme (UNEP) defines the Blue Economy as one that enhances human well-being and promotes social equity, while significantly reducing environmental risks and resource scarcity.

The World Bank defines the Blue Economy as the aggregate of economic sectors and related policies that collectively determine whether the use of ocean resources is sustainable.

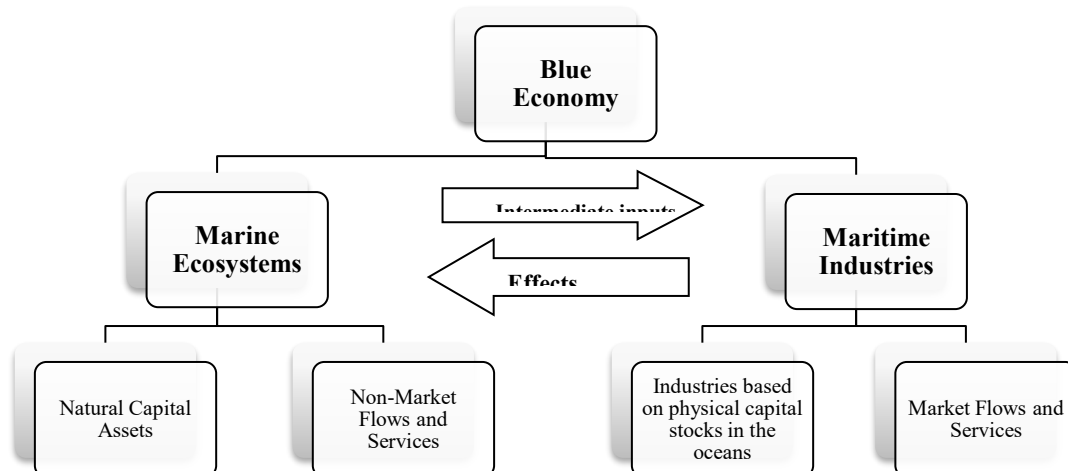
The European Commission defines it as encompassing all economic activities related to oceans, seas, and coasts. (Boumarafi & Boubou, 2023, p. 21)

According to the **Organisation for Economic Co-operation and Development (OECD)**, the ocean economy comprises the economic activities related to ocean-based industries and the assets, goods, and services generated by marine ecosystems. It focuses on ensuring the sustainable use and preservation of oceans, seas, and marine resources to achieve sustainable development. As outlined in the Sustainable Ocean for All initiative, the sustainable ocean economy underlines the responsible utilization and conservation of natural resources in marine and coastal areas, in alignment with the 2030 Agenda for Sustainable Development and the ocean-related SDGs. (OECD, 2024, p. 15)

Based on the above definitions, it can be concluded that the blue economy is an economy that focuses on the importance of water resources and their wise management in a way that supports both the local and global economy while preserving these resources for current and future generations.

Ecosystems represent natural capital assets that provide a range of intermediate inputs and resources upon which various maritime industries rely, whether they are industries based on physical capital or services. In addition, they provide non-market services such as coastal protection, climate regulation, biodiversity support, and others. Conversely, maritime industries impact these systems to varying degrees. This requires the optimal utilization of blue economy resources in a way that meets the needs of current and future generations.

Figure (1) : Blue economy concept



Source : (OECD, 2016, p. 23)

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1.2. Blue economy goals :

The blue economy aims to: (al-Mayali, 2024, pp. 29-31)

- **Protecting the marine environment and ensuring its sustainability:** The marine environment faces significant degradation and damage as a result of economic activities, leading to a decline in marine biodiversity.
- **Achieving food security and livelihoods:** The blue economy seeks to combat hunger and poverty and achieve food security through the sustainable exploitation of resources. It aims to promote investment, innovation, and supportive policies for food security, such as aquaculture and fisheries, particularly in small island states and coastal countries.
- **Achieving sustainable economic growth:** This is accomplished by utilizing ocean resources to create new economic activities such as mining, aquaculture, and marine biotechnology, while also developing traditional sectors like tourism and fisheries through research, development, and innovation.
- **Capacity building and innovation:** Through developing human resource capabilities, enhancing local knowledge, fostering innovative solutions, and improving operational strategies and educational tools.
- **Rational and prudent management of marine resources:** By providing incentives to both the public and private sectors to support efforts that preserve the well-being of local communities and the health of the oceans, ensuring continued ecosystem productivity for future generations.
- **Eliminating the concept of waste:** By improving the entire life cycle of products and promoting circular economic practices.
- **Relying on renewable energy sources:** Such as solar and natural energy flows to support sustainable development.
- **Harnessing the potential of the marine environment:** Through strong institutional frameworks for projects and programs that promote economic diversification, job creation, food security, poverty reduction, and other social and economic benefits.
- **Viewing marine and ocean resources as development assets:** That can be used sustainably to drive economic growth and ensure long-term prosperity.

1.3. Blue economy sectors:

Blue Economy encompasses a wide range of activities, including marine tourism, fisheries, maritime transport, and mining operations involving the extraction of mineral resources, petroleum, and natural gas from seas and oceans, in addition to other water-related activities. (Suleiman, 2023, p. 75). These activities are divided into two main sectors : (Kheloufi & Cherayett, 2021, pp. 124-125)

- **Traditional blue economy sector** , which include:
 - Transportation, shipping, and logistics.
 - Offshore oil and gas exploration, desalination, and processing.
 - Fishing, aquaculture, and fisheries.
 - Communications, ecotourism, culture, and lifestyle.
 - Marine protection services and ocean management.

- **Modern blue economy sector** , which include:
 - Renewable energy and seabed mining.
 - Remediation and restoration.
 - Blue biotechnology, blue carbon, and blue technology.
 - Nutrients, cosmetics, fisheries by-product conversion, and the innovative marine molecules sector.

Moreover, the Blue Economy encompasses activities driven by innovation, such as the development and application of new information technologies, the digitization of logistics chains, the adoption of alternative energy sources, the advancement of port infrastructure, and the transition toward intermodal transport, among others. (Bentayeb & Nouar, 2024, p. 80)

International organizations, such as the European Commission, the OECD and the United Nations , have divided the blue economy sectors into two sectors: Established sector and Emerging sector ,as shown in Table (1).

Table (1) : Sectors of the blue economy according to international organizations

Organisation	Established sector(s)	Emerging sector(s)
European Commission	– Living marine resources; – Non-living marine resources; – Renewable ocean energy; – Port and harbor operations; – Ship construction and maintenance; – Maritime and sea transport; – Coastal and seaside tourism.	– Ocean-based energy; – Marine bioeconomy and biotech; – Seawater desalination; – Marine mineral resources; – Maritime defence and security; – Research and education; – Marine infrastructure.
OECD	– Wild marine fisheries; – Processing of seafood products; – Ocean freight and transport; – Port operations; – Vessel construction and maintenance; – Offshore petroleum and gas (shallow zones); – Marine industrial production and construction; – Coastal and maritime tourism; – Ocean-related business services; – Marine R&D and educational activities; – Seabed dredging.	– Large-scale marine aquaculture; – Deep and ultra-deep offshore oil & gas extraction; – Offshore wind power generation; – Renewable energy from oceans; – Seabed and marine mineral mining; – Maritime security and monitoring; – Ocean biotechnology; – Advanced marine technologies and services.
United Nations	– Marine fisheries; – Fisheries-related industries and services; – Trade in seafood products; – Marine tourism and leisure; – Coastal area development; – Shipbuilding and maritime operations; – Offshore oil and gas sector; – Ocean transport services; – Port management and associated activities.	– Ocean renewables (e.g., offshore energy) – Marine aquaculture – Seabed resource extraction – Blue biotechnology and bioprospecting – Seawater desalination * Indirect supporting activities: – Blue carbon and carbon capture – Coastal and shoreline protection – Marine waste management – Conservation of biodiversity and habitats

Source : (OECD, 2024, pp. 15-16)

2.Maritime transport as a sector of the blue economy :

Maritime transport is a key sector of the Blue Economy, representing the primary means of international trade and the movement of goods, raw materials, and energy, contributing to

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supporting economic growth and enhancing job opportunities both on land and at sea. It is estimated that more than 80% of global trade volume is transported by sea, with maritime trade expected to double by 2030 and port activity to increase significantly by 2050. This makes investment in infrastructure and logistics services a strategic necessity for achieving sustainable development. (United Nations & World Bank Group, 2017, pp. 21-22)

The maritime transport sector includes coastal and inland freight and passenger transport, making it a key component of the Blue Economy due to its reliance on waterways, lakes, and rivers. It also depends on the physical characteristics of the marine environment and the ecosystem services that support ports. (al-Mayali, 2024, p. 33). This vital sector also faces increasing environmental and climate challenges that require a shift towards sustainable transport patterns based on “greening maritime transport” by reducing emissions, adopting clean technologies, and promoting digitalization in transport chains, thereby ensuring greater efficiency and environmental sustainability. (Union for the Mediterranean, 2021, p. 16)

Ports have evolved through four main generations, each reflecting the technological and economic transformations of its era : (Park, 2022, p. 3)

- **First-generation ports** were primarily used for loading and unloading goods, focusing mainly on maritime transport without strong connections to inland logistics or industry.
- **Second-generation ports** emerged as industrial ports, integrating manufacturing and processing activities alongside traditional port operations.
- **Third-generation ports** evolved into logistics and supply chain centers, enhancing connectivity and cooperation between maritime and inland transport systems.
- **Fourth-generation ports**, known as smart ports, appeared after 2010. They rely on digital technologies, automation, and data analytics to improve operational efficiency, sustainability, and integration within the global supply chain.

Table (2) : Port development phase.

	Port 1.0	Port 2.0	Port 3.0	Port 4.0
Operation	Manned Operation	Semi-auto Operation	Fully Automated Operation	Smart Operation
Equipment control	Manned ASC	Auto ASC	Auto ASC	Remote control QC
	Manned QC	Manned QC	Manned QC	Auto RMGC
	Manned yard tractor	Manned yard tractor	AGV	AGV
	Manned shuttle carrier	Manned shuttle carrier	Auto shuttle carrier	Auto shuttle carrier

Source : (Park, 2022, p. 3)

3.The global trend towards smart ports :

3.1.Smart ports definition :

A smart port can be described as one that strives for automation and autonomy in its facilities by adopting Fourth Industrial Revolution technologies to enable integrated information systems, data-based decision-making, and optimal resource utilization. (Chowdhury & all, 2023, pp. 250-251)

According to the ESCAP (2021) Report titled “Smart Port Development Policy in the Asia-Pacific Region”, a smart port is characterized by its automation of facilities and integration of digital information systems, enabling autonomous decision-making and

efficient resource management. (ESCAP, 2024, p. 32). Becoming a smart port requires continuous advancement and maturity in the following areas: (Betz & Reincke, 2022, p. 2)

- Integrated and efficient port operations ;
- Flexible, balanced, and well-coordinated transport modes ;
- Comprehensive and robust cybersecurity measures ;
- High standards of energy efficiency and environmental performance ;
- Strong digital capabilities supported by skilled human capital and enabling market conditions.

3.2. Smart port components :

The creation of a smart port depends on five interlinked components that must work together effectively : (Saudi Telecom Company, 2022, p. 7)

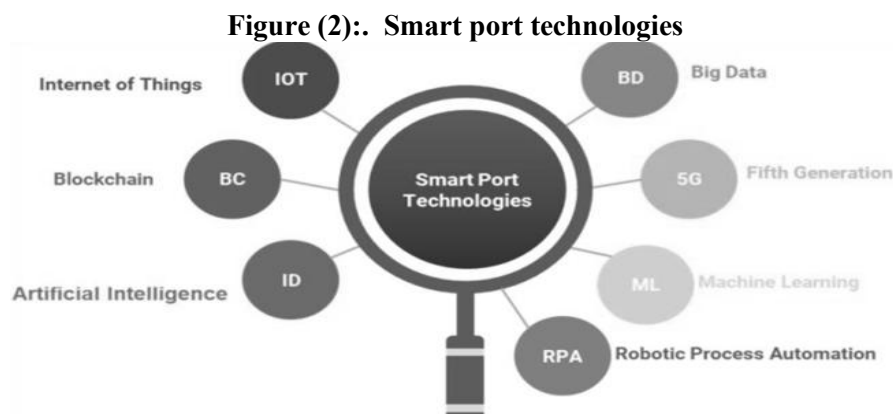
- **Automated Machinery:** Automation covers cranes, yard operations, internal transport, and gates, ensuring smooth and continuous port activities.
- **Equipment Control Systems:** These systems manage machines and provide real-time data for decision-making. Integrated gate software with cameras and OCR technology automates container and truck identification and routing.
- **Control Tower:** Acting as the central hub, it oversees forecasting, workflow, scheduling, monitoring, and optimization. Analytics and machine learning improve demand predictions and operational efficiency across the port.
- **Human-Machine Interaction:** Effective interaction between staff and automated systems is essential. Technologies like augmented and virtual reality assist in controlling robots, guided vehicles, and performing complex tasks such as maintenance.
- **Communication Systems:** Seamless data exchange among all stakeholders, on land and at sea, enhances coordination. Real-time digital connectivity supports collaboration between shipping lines, logistics providers, consignees, and customs, ensuring an integrated and responsive port ecosystem.

3.3. Technological techniques used in smart ports :

The technological techniques used in smart ports are as follows: (Saudi Telecom Company, 2022, p. 9)

- **5G Networks:** 5G provides fast, reliable, and low-latency connectivity, enabling seamless communication between intelligent port systems. It supports automated operations such as cranes, guided vehicles, video monitoring, and AI recognition, forming the backbone of digital port transformation.
- **Big data:** Ports generate massive amounts of real-time data from ships and cargo. Big data systems analyze this information to optimize operations, prevent congestion, and enhance overall efficiency.
- **Artificial Intelligence (AI):** AI and machine learning support decision-making, predict operational demands, reduce human errors, and improve safety and performance.
- **Internet of things (IoT):** Connected sensors and devices allow ports to track cargo and ships in detail, providing data for informed, real-time decisions.
- **Blockchain technology:** Blockchain ensures secure, immutable storage of operational data, improving visibility, demand management, and supply chain tracking. It enables paperless, platform-independent systems with permanent access to critical information.

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Source : (Chowdhury & all, 2023, p. 250)

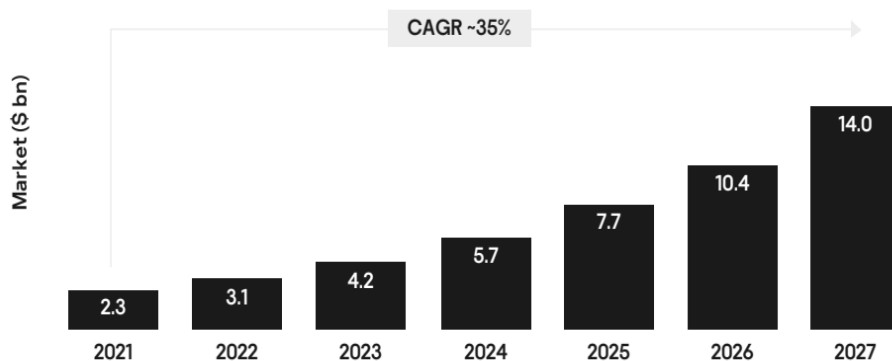
3.4.Expected effects of smart ports :

- **Economic impact:** Smart port technologies enhance the utilization of port resources, which in turn reduces ship operating costs and improves overall logistics productivity.
- **Safety enhancement:** By monitoring the activities of port workers and using intelligent systems to detect irregularities or risks, especially in handling hazardous cargo , smart ports can significantly reduce the likelihood of major accidents.
- **Operational efficiency:** Through advanced automation and remote-control systems, cargo handling and movements are managed in a coordinated and cost-effective manner, allowing for stable and high-performance port operations.
- **Environmental sustainability:** The electrification of port equipment and the optimization of transport routes within the port area contribute to lower emissions and promote the development of eco-friendly, low-pollution port environments. (ESCAP, 2024, p. 32)

3.5.Global smart ports market :

The figure.2 illustrates the projected growth of the global smart port market from \$2.3 billion in 2021 to \$14 billion by 2027, at a CAGR of over 35%. This surge is driven by the adoption of AI, Blockchain, IoT, and Automation in port operations. Around 35% of maritime trade volume and over 60% of its commercial value are shipped in containers. The top 10 container ports handled 250 million TEUs in 2020, representing 21% of global container trade, with major hubs in China, Singapore, and South Korea leading in digitalization and automation. The Asia-Pacific region dominates the smart port market with a 30–35% share due to large, technologically advanced ports. (Saudi Telecom Company, 2022, p. 10)

Figure (3): Global Smart Port Market Trends



Source: (Saudi Telecom Company, 2022, p. 10)

4.Singapore's maritime transport sector :

4.1. The reality of the blue economy in Singapore :

Given its limited maritime space, Singapore emphasizes the efficient management of its marine areas. The Singapore Food Agency (SFA) has set a goal to meet 30% of the nation's nutritional needs by 2030 through expanding aquaculture production. Currently, about 10% of fish consumed locally is produced by 122 domestic fish farms (most of which are located in southern coastal waters) yielding roughly 4,700 tons of fish each year. Facing constraints in freshwater availability, Singapore has developed an integrated water management system, combining desalination, water reuse, and wastewater treatment to guarantee a reliable and affordable supply of high-quality drinking water.

coastal and marine areas, Singapore has introduced numerous initiatives, policies, and regulatory frameworks to ensure sustainable ocean governance. Regionally, the country participates in the Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) and actively supports the Blue Economy Model Program under the Asia-Pacific Economic Cooperation (APEC). At the national level, Singapore implements an Integrated Urban Coastal Management (IUCM) framework that coordinates sea space use while minimizing energy consumption, waste generation, and carbon emissions. This integrated approach strengthens inter-agency collaboration to protect and manage coastal and marine environments.

One key policy, the Maritime Singapore Green Initiative (MSGI), focuses on reducing the ecological footprint of shipping operations to create sustainable ports. In parallel, the Liquefied Natural Gas (LNG) Bunker-Ready Port Pilot Programme encourages the adoption of cleaner fuels in maritime transport. Further advancing its green agenda, the Singapore Green Plan (SGP) 2030, announced in March 2021, emphasizes international collaboration on sustainable fuels through the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) to reduce global greenhouse gas emissions. In April 2021, the Maritime and Port Authority of Singapore (MPA) also launched a SGD 120 million fund to establish a maritime decarbonisation centre, with strong support from industry partners.

Aligned with its vision of becoming a "City in Nature," Singapore promotes biodiversity conservation and the protection of urban greenery. Initiatives such as the Reef Rejuvenation Project led by the Tropical Marine Science Institute (TMSI) aim to restore local coral ecosystems, while the Singapore Blue Plan 2018, proposed by the Singapore Institute of Biology, provides a roadmap for marine ecosystem preservation. The SGP 2030 also reinforces Singapore's position as a sustainable tourism destination, seeking to attract environmentally conscious visitors who value natural and cultural heritage.

To strengthen local aquaculture, the Marine Aquaculture Centre (MAC), established in 2003 and now managed by the Singapore Food Agency (SFA), conducts advanced research on hatchery and production processes. Moreover, the government actively supports Research, Development, and Demonstration (RD&D) programs focused on Ocean Renewable Energy (ORE). A notable example is the MAKO Tidal Energy Site at Sentosa Boardwalk, launched in 2019, which converts water flow into electricity for local use. (Quirapas-Franco, Low, & Ng, 2021, pp. 2-3)

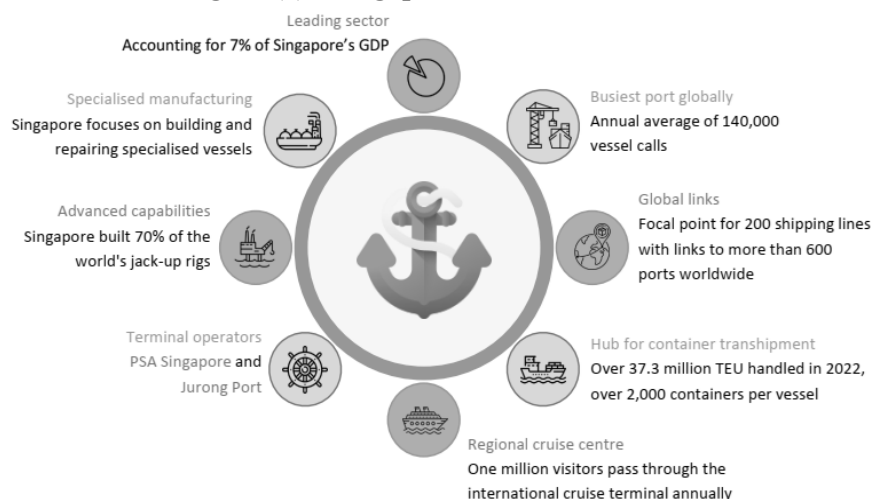
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4.2. Overview of the port of Singapore :

The maritime and port industries are vital pillars of Singapore's economy, contributing about 7% of GDP and employing over 170,000 individuals. The country possesses the world's fourth-largest fleet, with a total of around 88 million gross tonnes. (Innovation Norway, 2017, p. 14).

Singapore possesses advanced industrial and technological capabilities, having built around 70% of the world's jack-up rigs, in addition to its excellence in the manufacturing and maintenance of specialized vessels. The country also hosts one of the busiest ports globally, recording over 140,000 vessel calls annually, and is connected to more than 600 ports worldwide through over 200 shipping lines. Major operators such as PSA Singapore and Jurong Port manage highly advanced operations that have positioned Singapore as a global hub for container transshipment, handling more than 37 million twenty-foot equivalent units (TEUs) per year. Furthermore, Singapore serves as a regional center for cruise tourism, welcoming over one million visitors annually through its international cruise terminal. Collectively, these indicators affirm Singapore's leading position as a smart maritime hub that leverages technology and innovation to promote the blue economy and sustainable development.

Figure (4) : Singapore's maritime sector



Source : (Orissa International and Intralink Limited, 2025, p. 3)

The sector's institutional framework is mainly built around two entities: the Maritime and Port Authority of Singapore (MPA) and PSA Corporation. Before independence in 1965, maritime operations were managed by the Singapore Harbour Board. In 1964, the Port of Singapore Authority (PSA) was established to handle port operations and regulatory tasks. Following institutional reforms in the late 1990s, PSA was restructured into PSA Corporation Ltd in 1997, while regulatory duties were transferred to the newly established MPA in 1996. Today, PSA International functions as a holding company wholly owned by Temasek Holdings, Singapore's sovereign wealth fund (Innovation Norway, 2017, p. 14).

Port operations are primarily managed by PSA Corporation Ltd and Jurong Port, with key terminals located in Tanjong Pagar, Keppel, Brani, Pasir Panjang, Sembawang, Jurong, and Tuas. (Dradjati Dewiatena & Nur Bahagia, 2023, pp. 658-659)

The Port of Singapore has shown strong and resilient performance across major indicators. Vessel arrival tonnage increased from 2.66 million GT in 2016 to 2.90 million GT in 2020, before a slight decline to 2.81 million GT in 2021. Bunker sales volumes remained stable between 48–50 million tonnes, maintaining Singapore’s leadership as a global bunkering hub.

The Singapore Registry of Ships grew from 88.0 million GT in 2016 to 97.3 million GT in 2019, reflecting its appeal for international ship registration. Container throughput also expanded steadily from 30.9 million TEUs to 37.5 million TEUs, driven by investments in automation and the Tuas Port expansion project. Total cargo throughput peaked at 630.1 million tonnes in 2018, dropped to 590.7 million tonnes in 2020 due to pandemic disruptions, and partially recovered to 599.0 million tonnes in 2021.

Overall, these performance indicators confirm the Port of Singapore’s position as one of the world’s most advanced, efficient, and resilient ports.

Table (3) : Port of Singapore performance

Performance Indicator	2016	2017	2018	2019	2020	2021
essel Arrival Tonnage(billion GT)	2.66	2.80	2.79	2.85	2.90	2.81
Bunker Sales Volume (million tonnes)	48.6	50.6	49.8	47.5	49.8	50.0
Singapore Registry of Ships(millionGT)	88.0	88.8	90.9	97.3	95.0	92.3
Container Throughput (million TEUs)	30.9	33.7	36.6	37.2	36.9	37.5
Cargo Throughput (million tonnes)	593.3	627.7	630.1	626.5	590.7	599.0

Source : (Dradjati Dewiatena & Nur Bahagia, 2023, p. 660)

4.3.Technological techniques used in the Port of Singapore :

Singapore’s ports have deployed key digital systems :VTIS, CITOS, PORTNET, Marinet, TradeNet, and TradeXchange to enhance port and supply chain interaction. VTIS ensures safety and efficiency in port waters, CITOS optimizes internal terminal resources, and PORTNET provides broad supply chain coverage for container shipping. While many systems target specific segments, integrating them could improve visibility, transparency, and reduce transaction costs, with advanced analytics enabling real-time operational insights.

The National Trade Platform (NTP), launched in 2017, is projected to save firms US\$453 million in annual man-hours through document digitization and process automation. In 2018, PSA increased its stake in CrimsonLogic to 45%, expanding its reach to the global shipping community via Global eTrade Services, linking 23 customs nodes. These strategic investments support the co-creation of next-generation platforms, integrating processes and boosting efficiency for shippers, government agencies, and other stakeholders. (Yim Yap & Siu Lee Lam, 2018, p. 2).

Table (4) : Information systems at the port of Singapore

	CITOS	PORTNET	TradeNet, TradeXchange	Marinet	VTIS	NTP
Emphasis	Container terminal operations	Container shipping lines & port users	International trade, global focus	Shipping community	Navigational safety	Innovation & trade,Singapore focus
Administrator	PSA	PSA	Crimson Logic/ PSA	MPA	MPA	Singapore Customs
Owner	PSA	PSA	IE Singapore 55%; PSA 45%	MPA	MPA	Singapore Customs
Port operator community	✓	✓	✓	✓	✓	✓
Shipping line	–	✓	✓	✓	✓	✓

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community						
Shipper community	–	✓	✓	✓	–	✓
Supply chain community	–	✓	✓	✓	–	✓
Port service provider community	–	✓	–	✓	✓	–
Trade facilitation community	–	✓	✓	–	–	✓
Government agencies	–	✓	✓	✓	✓	✓

Source : (Yim Yap & Siu Lee Lam, 2018, p. 2)

4.4.Singapore's transformation strategy :

Singapore has been advancing its maritime research and development in line with the Singapore R&D Roadmap 2030(Maritime Transformation). This roadmap is structured around five main strategic directions: developing a world-class Maritime intelligent next-generation port, managing sea space and maritime traffic efficiently, enabling smart fleet operations and autonomous vessels, enhancing maritime safety and security, and promoting environmental and energy sustainability. (ESCAP, 2024, pp. 18-19).

Figure (5): Five key trusts



Source : (ESCAP, 2024, p. 20)

In line with its transformation goals, Singapore is channeling major investments toward port automation, smart vessels, digital business systems, and low-carbon technologies. One notable initiative in this regard is PIER71, a partnership between the MPA and the National University of Singapore (NUS), established to encourage innovation and support maritime startups.

Sustainability has also become a core principle of the country's maritime and MarinTech strategy. As the world's largest bunkering hub, Singapore is intensifying its decarbonization efforts, collaborating with various stakeholders to build supply chains for zero-emission fuels, particularly green ammonia, hydrogen, and methanol. New regulations require all harbour craft operating locally to be either fully electric or net-zero capable, while expanding charging infrastructure for larger vessels equipped with rechargeable battery systems.

Moreover, the MPA continues to advance digitalisation within the maritime industry by deploying technologies such as artificial intelligence (AI) and digital twin systems to optimize route planning, safety, and emissions reduction. These efforts aim to enable just-in-time port arrivals, minimizing turnaround times and increasing operational efficiency. In 2024, strategic

collaborations were launched with Microsoft and Amazon Web Services to explore cloud-based, AI-driven, and data-analytic maritime solutions.

Complementing these initiatives, Singapore's Agency for Science, Technology and Research (A*STAR) founded the Centre for Maritime Digitalisation (C4MD) to translate computational modeling, simulation, and AI research into practical maritime applications. The centre seeks to enhance sustainability, safety, and efficiency throughout Singapore's maritime ecosystem. Furthermore, A*STAR's partnership with Seatrion Limited focuses on offshore energy innovation and the integration of AI to improve engineering processes and operational productivity within the MarinTech sector. (Orissa International and Intralink Limited, 2025, pp. 3-4)

4.5. The Tuas port project as a new generation of smart ports :

The Port of Singapore adopts the Next Generation Port (NGP) 2030 framework as a strategic plan guiding the modernization of its port system. The initiative covers the conceptualization, design, and implementation of the Tuas Terminal, the Tuas Maritime Hub, and advanced port operations. Its key objectives include optimizing port water management, strengthening safety and security measures, improving user experience, and reinforcing environmental protection and sustainability.

The development of Tuas Port stands as a flagship project. Construction of its first phase began in 2016, with a long-term plan to relocate all container terminal activities from the city center to Tuas by around 2040. Once completed, the port will become the world's largest fully automated container terminal, with a projected handling capacity of approximately 65 million TEUs per year.

Tuas Port, recognized as Singapore's Next Generation Port, integrates cutting-edge automation and smart technologies such as autonomous vehicles, drones, vessel tracking, real-time port arrival systems, and green technologies. These innovations are expected to create a fully intelligent and sustainable port ecosystem.

Additionally, vessels at Tuas Port will benefit from a multi-purpose platform allowing them to perform various tasks, such as document processing and bunkering, during waiting periods enhancing operational efficiency. The traditional email-based documentation system for port entry is being replaced by a single digital portal connecting all relevant government agencies, improving transparency and coordination.

Moreover, Singapore is pioneering blockchain-based solutions through the TradeTrust project, which aims to digitize the bill of lading and facilitate secure data exchange across maritime stakeholders, marking a significant step toward a fully digital and smart maritime economy. (ESCAP, 2024, pp. 18-21)

Figure (6): Singapore's next-generation port (NGP)



Source : (ESCAP, 2024, p. 19)

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Conclusion

This research sought to define the conceptual framework of both the blue economy and smart ports, clarify the relationship between the blue economy and the maritime transport sector, and highlight the role of smart ports in achieving its goals, based on Singapore's pioneering experience as an applied model. The research has reached a set of results that can be summarized as follows:

Today's Blue Economy highlights the importance of transitioning to a comprehensive and sustainable development model based on the rational use of marine resources while balancing the requirements of economic growth with the preservation of the marine environment. This model has proven its ability to enhance productivity, stimulate innovation, and promote social justice by diversifying maritime economic activities—ranging from maritime transport, fishing, and tourism to renewable energy, biotechnology, and digital logistics. It provides coastal countries with real opportunities to achieve sustainable economic growth and strengthen their global competitiveness.

Maritime transport is one of the key sectors of the Blue Economy, representing the main driver of international trade and an important source of economic growth and job creation. The historical evolution of ports from traditional to smart ports underscores the shift toward a more efficient and sustainable model founded on digitization and clean technologies. All data indicates that smart ports represent a strategic transformation in the maritime transport sector within the Blue Economy framework, aiming to integrate automation, digitization, and artificial intelligence to enhance operational efficiency and promote environmental sustainability. The success of this transformation relies on advanced communication infrastructure supported by 5G, the Internet of Things, big data, and blockchain technologies.

The Singaporean experience serves as a pioneering model that embodies the integration of technology and sustainability within a strategic vision for the Blue Economy. Singapore has successfully transformed its maritime sector into a leading economic driver through investments in digitization, innovation, and scientific research, as well as the adoption of effective policies promoting public–private cooperation. The Tuas Port project stands as a symbol of this transformation, combining full automation, clean energy, and integrated digital infrastructure, positioning Singapore as a global benchmark in smart port management and strengthening the competitiveness of a sustainable maritime economy.

A number of lessons can be drawn from the Singaporean experience, presented as the following recommendations:

- Adopting a comprehensive national strategy for maritime digital transformation based on the integration of Fourth Industrial Revolution technologies into port and supply chain management;
- Developing a smart model port, such as the Tuas Port project, to serve as a pilot platform for implementing modern technologies and enhancing the competitiveness of national ports;
- Establishing a flexible and stimulating legislative framework that keeps pace with digital transformation and ensures information security in electronic maritime transactions;
- Investing in scientific research and innovation by establishing specialized centers for maritime digital transformation, similar to the C4MD Center in Singapore;
- Promoting maritime innovation and entrepreneurship by supporting startups specializing in

maritime transport technology (MarinTech);

- Integrating environmental sustainability principles into maritime policies by shifting to clean energy and encouraging low-emission ships;
- Developing human resources in the maritime transport sector with specialization in artificial intelligence, data analysis, and cybersecurity.

The limitations of this research lie in its reliance on a descriptive-analytical approach based on the presentation and analysis of secondary data. This makes its findings dependent on the nature and accuracy of the data obtained from the sources used. Furthermore, the analysis was limited to Singapore's experience as a pioneering model of smart ports within the blue economy framework, without including a comparative study of other countries' experiences that could contribute to supporting the practical aspect of the research. Additionally, the research did not focus on measuring the impact of the shift toward smart ports on achieving the goals of the blue economy. These shortcomings can be addressed in future studies that explore this area more deeply.

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