PEOLPLE'S DEMOCRARTIC REPUBLIC of ALGERIA
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
MOHAMED KHEIDER UNIVERSITY OF BISKRA
FACULTY OF ECONOMICS, COMMERCE AND MANAGEMENT SCIENCES
DEPARTMENT OF COMMERCE SCIENCES

Thesis Title

Exploring the Role of Artificial Intelligence into Improving International Seaports Performance.

Study Case: Singapore, Rotterdam, Dubai

A Thesis Submitted to the Department of Commerce Sciences as Partial Fulfilment for the Master's Degree in Commerce Sciences. Option; Finance and International Trade

Submitted by: Achouri Sara **Supervised by:** Dr. Farid Benabid

Board of the Examiners

Farid Benabid	**Professor**	**University of Biskra**	**supervisor**
Abd Elhak Rais	**Professor**	**University of Biskra**	**Chairperson**
Kamilia Izzrech	**Assistant Professor**	**University of Biskra**	**Examiner**

Academic year 2023/2024

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Academic year 2023/2024

Appendices

Appendix 01:

الجمهورية الجزائرية الديمقراطية الشعبية

وزارة التعليم العالي والبحث العلمي

جامعة محمد خيضر-بسكرة بسكرة في:30-05-2024

كلية العلوم الاقتصادية والتجارية وعلوم التسيير

قسم العلوم التجارية

إذن بالطبع

أنا الممضي أسفله الأستاذ:بن عبيد فريد

الرتبــة:أستاذ التعليم العالي

قسم الارتباط (اداريا) :العلوم التجارية

أستاذ مشرف على مذكرة ماستر للطلبة (ة): عشوري سارة

الشعبة: العلوم التجارية

التخصــص: مالية وتجارة دولية

بعنــوان:

Exploring the role of Artificial Intelligence into improving international seaports performance. Study case: Singapore, Rotterdam, Dubai

ارخص بطبع المذكرة المذكورة.

الاستاذ المشرف **رئيس القسم**

Appendix 02:

ملحق بالقرار رقم ....1082.... المؤرخ في 27 ... 2020 ....

الذي يحدد القواعد المتعلقة بالوقاية من السرقة العلمية ومكافحتها

الجمهورية الجزائرية الديمقراطية الشعبية

وزارة التعليم العالي والبحث العلمي

مؤسسة التعليم العالي والبحث العلمي:

نموذج التصريح الشرفي

الخاص بالالتزام بقواعد النزاهة العلمية لإنجاز بحث

أنا الممضي أسفله،

السيد(ة): عشوري سارة الصفة: طالب، أستاذ، باحث طالبة

الحامل(ة) لبطاقة التعريف الوطنية رقم: 204335487 والصادرة بتاريخ 2019.03.05

المسجل(ة) بكلية / معهد العلوم الاقتصادية والتجارية قسم العلوم التجارية

والمكلف(ة) بإنجاز أعمال بحث (مذكرة التخرج، مذكرة ماستر، مذكرة ماجستير، أطروحة دكتوراه).

عنوانها: Exploring the Role of Artificial Intelligence into Improving International Seaport Performance Study Case: Singapore, Rotterdam, Dubai

أصرح بشرفي أني ألتزم بمراعاة المعايير العلمية والمنهجية ومعايير الأخلاقيات المهنية والنزاهة الأكاديمية المطلوبة في إنجاز البحث المذكور أعلاه.

التاريخ: 2024/06/04

توقيع المعني (ة)

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To my Creator:

My heartfelt and endless praises go to Allah for His countless blessings and guidance throughout my educational journey.

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Thank you sincerely,

Achouri Sara

Dedication

To the one I want to be with at the moment, I drew every possible route that would bring him happiness and fulfilment while I provided his joyful, satisfied face as a result of my efforts... May God have mercy on my father **(Salim Achouri).**

To the one who has been there for me through thick and thin, who has encouraged me and cheered me on, who has given me wise counsel and who has prayed for me constantly—my mother **(Karima Bergheul)** —may God grant her long life.

To my little sister **Hadjer Achouri**, who has bestowed upon me love and optimism, and encouraged me with every step I take.

To all my family members: "**Achouri** and **Bergheul**" from the oldest member, to the youngest member of them, may God protect them.

To my loved ones and my best friends (**Maram** and **houda**), and to all my friends (**Fatoum, Farah, Yasmine, Ines**).

Finally, in heartfelt dedication, I extend my deepest appreciation to myself for the unwavering determination, resilience, and countless sacrifices made throughout this journey. My relentless pursuit of excellence is a testament to my strength, courage, and unwavering commitment to personal growth. Here's to celebrating the resilience and perseverance within me.

SARA

Abstract

Abstract

International transportation, amidst international trade expansion, witnesses a pivotal shift fuelled by rapid advancements in artificial intelligence (AI). Recognizing the critical importance of efficient international seaports in this landscape, this study endeavours to tackle operational inefficiencies, security risks, and environmental impacts through cutting-edge AI solutions, driven by the imperative to enhance global trade and connectivity. In fact, the focus of this research is to investigate AI's role in enhancing international seaport performance, focusing on optimizing logistics, improving security, and promoting sustainability in key ports: Singapore, Rotterdam, and Dubai. The research method consisted of applying a descriptive analytical approach, the study assesses AI adoption and integration across various port types. By evaluating AI applications, the research provides insights into its impact on port operations. The findings from this research show that AI applications enhance port efficiency by streamlining cargo handling and bolstering security measures. Additionally, it contributes to sustainability by reducing energy consumption and emissions through optimized resource management. The main Conclusions drawn from this research are integrating AI into seaport operations yields substantial benefits in efficiency, security, and sustainability. Leveraging best practices from leading ports, such as Singapore, Rotterdam, and Dubai, offers insights for global port enhancement. This study provides strategic recommendations for effective AI implementation, advancing knowledge in maritime logistics and port management.

Keywords : International Transportation, International Trade, Seaports, Artificial Intelligence (AI).

Résumé

Le transport international, au milieu de l'expansion du commerce international, connaît un changement crucial alimenté par les avancées rapides de l'intelligence artificielle (IA). Reconnaissant l'importance critique des ports internationaux efficaces dans ce paysage, cette étude s'efforce de s'attaquer aux inefficacités opérationnelles, aux risques de sécurité et aux impacts environnementaux grâce à des solutions d'IA de pointe, motivée par l'impératif d'améliorer le commerce mondial et la connectivité. Cette recherche examine le rôle de l'IA dans l'amélioration de la performance des ports internationaux, en se concentrant sur l'optimisation de la logistique, l'amélioration de la sécurité et la promotion de la durabilité dans des ports clés : Singapour, Rotterdam et Dubaï. En utilisant une approche analytique descriptive, l'étude évalue l'adoption et l'intégration de l'IA dans différents types de ports. En évaluant les applications d'IA, la recherche fournit des informations sur son impact sur les opérations portuaires. L'IA améliore significativement l'efficacité portuaire en rationalisant la manipulation des marchandises et en renforçant les mesures de sécurité. De plus, elle contribue à la durabilité en réduisant la consommation d'énergie et les émissions grâce à une gestion optimisée des ressources. L'intégration de l'IA dans les opérations portuaires génère des avantages substantiels en termes d'efficacité, de sécurité et de durabilité. En tirant parti des meilleures pratiques des principaux ports, tels que Singapour, Rotterdam et Dubaï, cette étude offre des perspectives pour l'amélioration des ports mondiaux. Elle propose également des recommandations stratégiques pour une mise en œuvre efficace de l'IA, contribuant ainsi à l'avancement des connaissances dans la logistique maritime et la gestion portuaire.

Mots-clés : Transport Internationales, Commerce International, Ports, Intelligence Artificielle (IA).

ملخص

يشهد النقل الدولي، في ظل توسع التجارة الدولية، تحولاً حاسماً يدعمه التقدم السريع في مجال الذكاء الاصطناعي. ومع التعرف على الأهمية الحرجة للموانئ البحرية الدولية الفعّالة في هذا السياق، تسعى هذه الدراسة لمواجهة عدم الفعالية التشغيلية ومخاطر الأمن والتأثيرات البيئية من خلال حلول الذكاء الاصطناعي المبتكرة، مدفوعة بضرورة تعزيز التجارة العالمية والتواصل. تقوم هذه الدراسة بفحص دور الذكاء الاصطناعي في تعزيز أداء الموانئ البحرية الدولية، مع التركيز على تحسين الخدمات اللوجستية وتعزيز الأمن وتعزيز الاستدامة في الموانئ الرئيسية: سنغافورة وروتردام ودبي. من خلال استخدام نهج تحليلي وصفي، تقوم الدراسة بتقييم تبني ودمج الذكاء الاصطناعي في مختلف أنواع الموانئ. من خلال تقييم تطبيقات الذكاء الاصطناعي، توفر الدراسة رؤى حول تأثيرها على عمليات الموانئ. يعزز الذكاء الاصطناعي كفاءة الموانئ بشكل كبير من خلال تبسيط عمليات التعامل مع البضائع وتعزيز التدابير الأمنية. بالإضافة إلى ذلك، يساهم في الاستدامة من خلال تقليل استهلاك الطاقة والانبعاثات من خلال إدارة الموارد المُحسنة. يؤدي دمج الذكاء الاصطناعي في عمليات الموانئ إلى فوائد كبيرة في الكفاءة والأمن والاستدامة. من خلال الاستفادة من أفضل الممارسات في الموانئ الرئيسية، مثل سنغافورة وروتردام ودبي، تقدم هذه الدراسة رؤى لتحسين الموانئ على الصعيد العالمي. كما تقدم توصيات استراتيجية لتنفيذ الذكاء الاصطناعي بفعالية، مما يسهم في تقدم المعرفة في اللوجستيات البحرية وإدارة الموانئ.

الكلمات الرئيسية : النقل الدولي، التجارة الدولية، الموانئ البحرية ، الذكاء الاصطناعي.

Contents

CHAPTER TWO:THE PRACTICAL PART

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List of Tables

List of Abbreviation and Acronyms

(AI): Artificial Intelligence

(RUR): Rossum's Universal Robots

(ENIAC): Electronic Numerical Integrator and Computer

(ISP): list Processing language

(NPL): Natural language processing

(GPS): Global Positioning System

(CCTV): closed-circuit television

(IBM): International Business Machines Corporation

(AR): Augmented Reality

(MR): Mixed Reality

(VR): Virtual Realty

(PDM): Predictive maintenance

(ASCs): Automated Stacking Cranes

(AGVs): Automated Guided Vehicles

(PCS): Port Community System

(OCR): optical character recognition

(PoC): proof-of-concept

(IoT): Internet of Things

(PSA): Port Singapore Authority

(UAE): United Arab Emirates

(AITVs): Autonomous Internal Terminal Vehicles

(SPI): Smart Port Index

(ICT): Information and communication technologies

General Introduction

General Introduction

"Anything that could give rise to smarter-than-human intelligence—in the form of Artificial Intelligence, brain-computer interfaces, or neuroscience-based human intelligence enhancement – wins hands down beyond contest as doing the most to change the world. Nothing else is even in the same league."

-Eliezer Yudkowsky-

Since the beginning of the technological era, the world has witnessed immense developments in various technological fields. Technology has become an integral part of our daily lives, leading to a radical change in how we interact with the world around us. From the invention of the computer to the internet, there has been continuous and relentless progress. However, among all these innovations, artificial intelligence can be considered one of the greatest leaps in the history of technology.

Artificial intelligence has begun as a fictional idea in science fiction novels, but gradually transformed into a tangible reality affecting many aspects of our lives. From voice assistants in smartphones to self-driving cars, AI has significantly evolved over the years. This progress has not merely improved device performance but has fundamentally changed how machines handle information and make decisions.

With this immense advancement, the impact of AI on international trade becomes evident. In our current era, international trade has become more complex and intertwined, with technology playing a vital role in facilitating these processes. AI contributes to enhancing these trade relations by streamlining trade negotiations, optimizing logistics and supply chains, automating trade documentation.

In another equally important context, international transportation plays a crucial role in supporting and developing these trade relationships. International transport represents the main artery for the flow of goods and services between countries, contributing to enhancing international trade and cultural exchange. With technological advancement, the transportation sector has seen radical transformations, from intelligent transportation systems to the development of electric vehicles and self-driving aircraft. These advancements have not only made transport more efficient but also contributed to reducing environmental impact and promoting sustainability.

Thus, technological development, artificial intelligence, and international transportation are all interconnected elements that influence each other in complex and multifaceted ways. In this research, we will explore how these elements interact, their mutual impacts, and their role in shaping our shared future. Part of this research remains shrouded in mystery, inviting us to continue exploring this intricate and intriguing relationship.

Globalization has fuelled an exponential increase in maritime trade, making international seaports pivotal hubs for economic activity and global connectivity. However, the efficiency and effectiveness of these seaports are often hindered by various challenges ranging from operational bottlenecks to security concerns. In this context, the integration of artificial intelligence (AI) technologies emerges as a promising avenue for addressing these challenges and enhancing the performance of international seaports.

Problem Statement

The contemporary maritime industry faces multifaceted challenges, including optimizing logistical operations, ensuring port security, and minimizing environmental impact. Traditional approaches have struggled to adequately address these challenges, necessitating innovative solutions. Thus, our primary research question is: "**How can Artificial Intelligence be leveraged to enhance the efficiency, security, and sustainability of international seaports?**"

From this central inquiry, we derive several secondary questions:

1) How can AI optimize port logistics to streamline cargo handling processes and reduce turnaround times?
2) What AI-driven solutions can be implemented to enhance port security and mitigate risks such as smuggling and terrorism?
3) In what ways can AI contribute to minimizing the environmental footprint of seaport operations through energy efficiency and emissions reduction?
4) How can Algeria benefit from the experience of other countries in implementing artificial intelligence (AI) in its ports?

Hypotheses

Building upon the aforementioned questions, we formulate the following hypotheses:

General Hypothesis: AI integration into international seaport operations will lead to significant improvements in efficiency, security, and sustainability.

Secondary Hypotheses:

1) Implementation of AI-based predictive analytics will optimize cargo handling processes, resulting in reduced turnaround times.
2) AI-driven surveillance systems will enhance port security by detecting and preventing illicit activities more effectively than traditional methods.
3) AI-enabled optimization algorithms will minimize energy consumption and emissions by optimizing resource allocation and routing within seaport operations.
4) By leveraging the best practices and proven technologies from other countries, Algeria could enhance operational efficiency, security, and logistical management in its ports through the implementation of artificial intelligence.

Significance of the Study

The study holds significant implications for the maritime industry, port authorities, policymakers, and stakeholders. By elucidating the potential of AI in enhancing seaport operations, our research aims to inform strategic decision-making processes and facilitate the adoption of innovative technologies to address pressing challenges.

Objectives

- To evaluate the current state of AI adoption in international seaports.
- To identify key challenges and opportunities associated with integrating AI into seaport operations.
- To assess the impact of AI on port efficiency, security, and sustainability metrics.
- To propose recommendations for the effective implementation of AI solutions in international seaports.
- To contribute to academic literature by advancing knowledge on the role of AI in maritime logistics and port management.

Methodology

Our study adopts a descriptive-analytical methodology to examine the adoption of artificial intelligence (AI) in the ports of Singapore, Rotterdam, and Dubai, which encompass various types of ports, including container ports, bulk cargo ports, passenger ports, and oil and gas ports. By identifying key parameters, evaluating AI applications, and assessing their impact, we aim to gain a comprehensive understanding of AI integration in each port. This approach allows us to uncover how AI solutions address port-specific challenges, providing a detailed view of AI's effectiveness in enhancing port performance and facilitating insights into best practices for these leading international seaports.

Literature Review

During our research for this study, we have conducted extensive literature reviews, uncovering several themes closely related to our topic. These themes are elucidated below:

Study No. 1: Smartening up Ports Digitalization with Artificial Intelligence (AI): A Study of Artificial Intelligence Business Drivers of Smart Port Digitalization

Abu Ghazaleh (2023) delves into the pivotal role of artificial intelligence (AI) in revolutionizing port operations and driving digitalization initiatives forward. Recognizing AI as a transformative force capable of minimizing human error and expediting operations across sea, land, and air transportation sectors. The author emphasizes its significance within the broader context of digital transformation. Specifically, AI's potential to redirect human labour towards currently underutilized digital platforms within port environments is highlighted. Applying exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and structural equation modelling (SEM), the study scrutinizes the integration of AI within the operational management framework of port communities, aiming to identify opportunities for AI adoption and propose innovative AI-Ports initiatives. Through evaluating value-added core tasks in ports, the research seeks to assess the feasibility and benefits of AI integration, ultimately providing strategic insights to enhance port digitalization efforts and optimize operational efficiency within port communities (Abu Ghazaleh, M, 2023).

Study No. 2: Research on the Path of Artificial Intelligence to Empower Intelligent Port Upgrading and Transformation

Du (2023) explores the pivotal role of artificial intelligence (AI) in advancing the transformation of ports into intelligent systems, recognizing their critical position within the global transportation network and their impact on global trade and shipping. The study analyses the current application status and challenges of AI integration in promoting the development of smart ports, delving into typical applications such as container electronic tags, unmanned driving technology, and intelligent ship stowage. By providing practical examples, the research elucidates AI's transformative potential across various port operations. Additionally, optimization countermeasures are proposed to enhance the effectiveness of AI-driven initiatives within port environments, aiming to address challenges and promote efficiency and sustainability. Through its comprehensive analysis and practical insights, the study contributes to understanding how AI empowers the transition of ports into intelligent systems, ultimately facilitating more efficient and sustainable port operations (Du, X, 2023).

Study No. 3: AI-Powered Intelligent Seaport Mobility: Enhancing Container Drayage Efficiency through Computer Vision and Deep Learning

Lee et al. (2023) presents a conceptual paper addressing the challenges arising from rapid urbanization, particularly in transportation sectors. They propose a novel mathematical framework grounded in deep learning techniques to optimize smart mobility within seaport operations, thereby contributing to the development of intelligent cities. Through a comprehensive literature review, the authors underscore the benefits of merging artificial intelligence (AI) and computer vision (CV) technologies in parking facility management within seaports. Their innovative model utilizes live Closed-Circuit Television (CCTV) camera data to accurately identify parking spaces and lanes, facilitating efficient parking space allocation and enhancing container drayage efficiency. The framework aims to improve traffic management, optimize parking space allocation, and streamline container movement within seaports, laying the groundwork for sustainable and intelligent seaport systems. The study's insights provide valuable guidance for real-world applications, emphasizing the need to further explore AI and CV technologies in seaport logistics. Future research will concentrate on implementing and validating this framework in actual seaport environments, thereby advancing intelligent seaport operations and urban logistics networks (Lee, H., Chatterjee, I., & Cho, G, 2023).

Study No. 4: Application of Artificial Intelligence in Maritime Transportation

Chen et al. (2024) conducts a comprehensive examination of artificial intelligence (AI) applications in maritime transportation, with a primary focus on augmenting efficiency and safety within the maritime logistics and supply chain management domain. Against the backdrop of economic globalization, which has heightened complexities in maritime logistics, the study underscores the sophistication of AI technology, leveraging real-world scenarios, extensive training datasets, and robust computational capabilities. The authors highlight AI's pivotal role in bolstering maritime transportation efficiency, utilizing data from sensors deployed on ships and coastal structures to train AI models effectively. Various advanced AI techniques are explored to enhance efficiency, particularly in maritime safety and environmental protection realms. Noteworthy applications include AI-enabled ship automation control, collision avoidance, and optimization of ship trajectories to minimize fuel consumption and enhance safety.

The study further addresses ship detection, tracking, and identification using maritime surveillance images, with a keen focus on ship fleet management optimization, ship-port cooperation, energy consumption reduction, and autonomous port management. Emphasizing the growing significance of AI in achieving smart maritime shipping, the paper underscores its potential to streamline operations while addressing typical maritime traffic challenges. The authors conclude by discussing AI's future role in reducing carbon emissions and enhancing efficiency and safety in the era of smart maritime shipping (Chen, X., Ma, D., & Liu, R. W, 2024).

Comparison between our Study and the Previous Studies

This table presents a comparative analysis of the focus areas, specific applications, methodologies, and contributions of our study and the previous studies:

Table 1 Comparative Analysis of AI Studies in Port Operations

Aspect	**Our Study**	**Study No. 1**	**Study No. 2**	**Study No. 3**	**Study No. 4**
Focus Area	AI implementation in seaports for efficiency, security, and sustainability metrics	AI's role in revolutionizing port operations and driving digitalization initiatives forward	AI's impact on transforming ports into intelligent systems and challenges in AI integration	AI-powered intelligent seaport mobility through computer vision and deep learning	AI applications in maritime transportation for efficiency and safety
Specific Applications	Practical use of AI in seaports to optimize cargo handling, enhance security, and minimize energy	AI business drivers for smart port digitalization	Typical AI applications like container electronic tags and unmanned driving technology	Mathematical framework using AI and computer vision for efficient parking space allocation	AI-enabled ship automation control, collision avoidance, and optimization of ship trajectories
Methodology	Objectives include evaluating AI adoption, identifying	Likely focuses on AI business drivers through a strategic lens	May provide optimization countermeasures for AI-driven	Utilizes deep learning techniques for optimizing	Emphasizes AI technology leveraging real-world scenarios, extensive

	challenges, assessing impacts, proposing		initiatives in ports	smart mobility within seaports	training datasets, and computational capabilities
Contributions	Aims to inform strategic decision-making in the maritime industry and advance knowledge on AI	Highlights AI's transformative potential in redirecting human labour towards digital platforms	Offers practical examples and optimization measures for AI integration in smart port development	Focuses on enhancing container drayage efficiency through AI and computer vision technologies	Underscores AI's pivotal role in bolstering maritime transportation efficiency and safety

Source: prepared by the student Achouri Sara

Contents

To conduct this study effectively, we've structured our thesis as follows: a theoretical part comprising three topics and a practical part.

- **Chapter One: The Theoretical Part:**
- **Topic one:** Introduction to Artificial Intelligence (AI): This topic provides an overview of AI, from its definition to its applications in various sectors, highlighting its transformative potential.
- **Topic Two**: Ports in Global Trade and Transportation: This topic explores the crucial role of ports in global trade and transportation networks.
- **Topic Three:** AI Applications in Port Operations: Here, we examine various applications of AI in port operations, showcasing its impact on the maritime industry**.**
- **Chapter Two: The Practical Part:**

  Case Studies of AI Implementation in Ports: We delve into the practical use of AI in ports through case studies of three distinct ports (Singapore, Rotterdam and Dubai).

Supplemented by a general introduction and a general conclusion, our thesis is structured to provide a comprehensive exploration of the topic.

CHAPTER ONE:
THE THEORETICAL PART

CHAPTER ONE: THE THEORETICAL PART

Introduction

Globalisation has fuelled an exponential increase in maritime trade, making international seaports pivotal hubs for economic activity and global connectivity. However, the efficiency and effectiveness of these seaports are often hindered by various challenges, ranging from operational bottlenecks to security concerns. In this context, the integration of artificial intelligence (AI) technologies emerges as a promising avenue for addressing these challenges and enhancing the performance of international seaports.

In the first part of this chapter, we start by explaining the basics of Artificial Intelligence (AI). We cover the essential principles and methods of AI to understand its role and potential. Then, in the second part, we aim to talk about the basics of seaports, including what they are and how they work. Finally, in the third section, we explore how AI is used in seaports, showing how it's changing the way ports operate. By going step by step through these topics, we aim to give you a clear picture of how AI is impacting port operations.

TOPIC ONE:

Basic Concept about Artificial Intelligence

TOPIC ONE: Basic Concept about Artificial Intelligence

1.1 Introduction

In this section, we explore the foundational aspects of Artificial Intelligence (AI). We begin by defining AI and examining its background and history to understand its evolution. After that, we discuss the major subfields of AI, such as machine learning and natural language processing, and explore its various applications across different industries. Additionally, we highlight the advantages and disadvantages of AI, addressing both its potential benefits and inherent risks. Finally, we delve into the role of AI in transportation, illustrating how it is revolutionizing this crucial sector.

1.2. Definition of Artificial Intelligence

Definition 01: There are many definitions of Artificial Intelligence (AI). The definitions themselves depend on the meaning of “intelligence,” which is defined by Oxford dictionaries as “the ability to acquire and apply knowledge and skills” and by the Wiktionary free online dictionary as "capacity of mind, especially to understand principles, truths, facts, or meanings, to acquire knowledge and apply it to practice; the ability to learn and comprehend (mohamed M, 2023)."

Definition 02: AI is a field of computer science that studies how machines can imitate the intelligence of their human counterparts. Over the last decade, the term's definitions have become quite loose and refer to just about any computerized or automated function. However, the difference between an AI system and traditional software packages is the ability to make informed judgements and decisions by responding to patterns in data (Simanta Shekhar, Sarmah, 2019).

Definition 03: The term "artificial intelligence" refers to the technology that develops machines that can behave like humans without using any living organisms (Mijwil ,Maad M, 2015).

Thus, there are many definitions around, but most of them can be classified into the following four categories:

- systems that think like humans
- systems that act like humans
- systems that think rationally
- systems that act rationally

1.3 Artificial Intelligence Background

The field of Artificial Intelligence (AI) has been officially established by John McCarthy in 1956 as part of the Dartmouth Summer Research Project on AI. The goal has been to investigate techniques for designing machines to mimic specific aspects of intelligence, which has consistently propelled the field's progress. However, many of the technological concepts that now define AI has been already in existence prior to that event. Thomas Byes has developed a systematic approach to analysing the likelihood of events in the 18th century, while Gorge Poole has proved that methodical execution of Aristotle's logical thinking has been possible in the 19th century (mohamed M, 2023).

By the beginning of the 20th century, developments in experimental sciences have given rise to the field of statistics, which enables the drawing of trustworthy conclusions from data. The concept of constructing a machine capable of carrying out a series of instructions, which has fascinated innovators like Charles Babbage, has developed by the 1950s and led to the creation of the first electronic computer. Scientists have also built robots that could sense and act on their own (mohamed M, 2023).

Alan Turing, the founder of computer science, has introduced a formal model of computing that has had a profound impact on the field. In his seminal work, "Computing Machinery and Intelligence," he has contemplated the potential of computers designed to simulate intelligence and proposed methods for testing their capabilities and mechanisms for automated learning. However, Turing has lacked the necessary computational capacity to implement and put his ideas into practice (mohamed M, 2023).

There are several subareas of AI, some of which are currently more popular than others due to different factors. Search and planning involve the processes of logical thinking and decision-making in order to achieve a desired objective. The field of knowledge representation and reasoning focuses on transforming information into an organized manner, and machine learning is a framework that allows systems to improve their job performance by autonomously analysing relevant data (mohamed M, 2023).

The field of multi-agent networks addresses the interaction between intelligent systems and has gained significance in online marketplaces and transportation networks. The field of human-robot interaction perception has gained significant importance due to the coexistence of robots, computer systems, and humans. Machine perception has been crucial in the advancement of robotics and serves as a distinct and autonomous field of research.

In recent years, several variables have converged to accelerate AI development. Big data is crucial for facilitating the learning process of AI devices, and companies like Amazon, Google, Facebook, and Alibaba possess extensive data resources that empower their AI systems to gain a deeper understanding of their clients and deliver tailored services.

There is a growing trend toward improving computing capacity, with GPUs significantly accelerating the advancement of machine learning and deep learning. Sentient software offers remarkable opportunities for both organizations and individuals to create AI applications (mohamed M, 2023).

1.4 The History of Artificial Intelligence

To get knowledge about the historical development of artificial intelligence, it is imperative to go into earlier periods in history. During the Ancient Greek era, there is evidence of the implementation of diverse concepts regarding humanoid robots. Daedalus, a mythological figure who is believed to have ruled over the realm of wind and attempted to create humanoid beings, serves as an example of this. Philosophers' attempts to define the cognitive processes of the human mind have led to the emergence of modern artificial intelligence. The year 1884 holds significant importance in the field of artificial intelligence. Charles Babbage continues to work on developing a mechanical apparatus that can exhibit intelligent behaviour. Nevertheless, due to this research, he has concluded that he would be unable to create a machine capable of displaying intellectual behaviours equivalent to those of a human person, and he has halted his study (Mijwil, Maad M., 2015).

In 1950, Claude Shannon has proposed the idea that computers have had the capability to play chess. Progress in the field of artificial intelligence has been sluggish until the early 1960s. Artificial intelligence's inception Dartmouth College introduced the inaugural session on artificial intelligence in 1956. Marvin Minsky confidently has declared in his book "The Search for Artificial Intelligence" that he would resolve the challenge of modelling artificial intelligence within a single generation. During this period, we have introduced the initial artificial intelligence applications. Logical theorems and the chess game serve as the foundation for these applications. The programs have developed during this period differed from the geometric shapes used in IQ tests, suggesting the possibility of creating intelligent computers (Mijwil, Maad M., 2015).

1.4.1 Milestones for Artificial Intelligence History

In 1950, Alan Turing created a test to determine whether a machine is intelligent. This test shows the intelligence given to computers. The intelligence level of the machines that have passed the test at that time has been considered adequate. LISP (List Processing Language), developed by John McCarthy in 1957, is a functional programming language developed for artificial intelligence. One of the rather old and powerful programming languages, LISP is a language that allows you to create flexible programs that represent basic operations with list structure. Between 1965 and 1970, it could be called a dark period for artificial intelligence. The developments on artificial intelligence in this period are few to be tested. The hasty and optimistic attitude due to the unrealistic expectations that have emerged has led to the idea that it will be easy to uncover the machines with intelligence. But this period has been named as a dark period on behalf of artificial intelligence because it has not succeeded with the idea of creating intelligent machines by simply uploading data Between 1970 and 1975, artificial intelligence gained momentum (Mijwil, Maad M., 2015).

in artificial intelligence systems that have been developed and developed on subjects such as disease diagnosis, the basis of today's artificial intelligence has been established. During the period 1975-1980 they have developed the idea that they could benefit artificial intelligence through other branches of science such as psychology. Artificial Intelligence has begun to be used in large projects with practical applications in the 1980s. The next time the daylight is passed, the artificial intelligence has been adapted to solve real life problems. Even when the needs of users are already met with traditional methods, the use of artificial intelligence has reached to a much wider range thanks to more economical software and tools (Mijwil, Maad M., 2015).

1.4.2 Chronological History of Artificial Intelligence

- On May 1st, in a certain year, Alexander Heron, an individual from ancient times, has constructed automatons that utilised mechanical mechanisms powered by water and steam.
- In **1206**, Ebru İz Bin Rezzaz Al Jezeri, a trailblazer in the field of cybernetic science, successfully has developed water-powered machines that could be controlled automatically.

- In **1623**, Wilhelm Schickard has created a mechanical calculator that has been capable of performing all four basic arithmetic operations.
- In **1672**, Gottfried Leibniz has created a binary counting method that serves as the fundamental concept for modern computers.
- From **1822** to **1859**, Charles Babbage has been involved in the development of a mechanical calculator. Ada Lovelace is recognised as the pioneer of computer programming due to her significant contributions in working with Babbage's punched cards on his machines. Lovelace's work encompasses the study and development of algorithms.
- In **1923**, Karel Capek initially has proposed the concept of robots in the theatrical play called "Rossum's Universal Robots" (RUR).
- In **1931**, Kurt Gödel has presented his theory of deficiency, which is now commonly referred to as Gödel's theory.
- In **1936**, Konrad Zuse has created a programmable computer called the Z1, which has had a memory capacity of 64K.
- In **1946**, the ENIAC (Electronic Numerical Integrator and Computer), which has weighed 30 tonnes and occupied an entire room, has become operational.
- In **1948**, John von Neumann has proposed the concept of a self-replicating programme.
- In **1950**, Alan Turing, the pioneer of computer science, has introduced the notion of the Turing Test.
- In **1951**, the initial programmes for artificial intelligence have developed for the Mark 1 device.
- In **1956**, Newell, Shaw, and Simon have established the Logic Theory-LT programme, which has aimed to solve mathematical difficulties. The system is considered to be the inaugural artificial intelligence system. The following text:

- Late **1950s** to early **1960s**: Margaret Masterman et al. has designed a schematic network for machine translation.
- In **1958**, John McCarty from MIT has developed the LISP (list Processing language) programming language.
- In **1960**, JCR Licklider has discussed the interaction between humans and machines in his work.

- In **1962**, Unimation has been founded as the pioneering business in the production of robots for industrial applications.
- In **1965**, the development of an artificial intelligence programme called ELIZA has been initiated.
- In **1966**, Stanford University has created the first animated robot named "Shakey".
- In **1973,** DARPA initiates the development of protocols known as TCP/IP.
- In **1974**, the Internet has been initially utilised.
- In **1978**, Herbert Simon has been awarded the Nobel Prize for his ground-breaking work on Artificial Intelligence known as the Limited Rationality Theory.
- In **1981**, IBM manufactured the initial personal computer.
- In **1993**, the production of Cog, a robot with a human-like appearance, has commenced at MIT.
- In **1997**, the supercomputer Deep Blue successfully has defeated the renowned chess player Kasparov.
- In**1998**, Furby, the inaugural artificial intelligence player, has been introduced to the market.
- In **2000**, a robot dubbed Kismet has been launched. This robot is capable of using gestures and imitating movements in order to communicate.
- In **2005**, the research of Asimo, the most advanced robot in terms of artificial intelligence and human-like abilities and skills, has been unveiled.
- In **2010**, Asimo has been programmed to respond to commands using brain signals (Mijwil ,Maad M, 2015).

1.5 Major Subfields of Artificial Intelligence

Artificial Intelligence is a broad field of study that includes many theories, methods, and technologies, as well as the following major subfields:

1.5.1 Machine Learning: automates analytical model building. It uses methods from neural networks, statistics, operations research, and physics to find hidden insights in data.

"Machine learning is the process of teaching a computer to perform a task rather than programming it to do so step by step. At the end of training, a machine-learning system will be able to make accurate predictions when given data" (Athanasios, 2023).

1.5.2 A Neural Network: is a type of machine learning that is made up of interconnected units (like neurons) that process information by responding to external inputs and relaying information between each unit. Neural networks are mathematical models that draw inspiration from the structure of the brain. Each neuron within a neural network is a mathematical function that takes in data via an input, transforms that data into a more amenable form, and then spits it out via an output (Athanasios, 2023).

1.5.3 Deep Learning: uses huge neural networks with many layers of processing units, taking advantage of advances in computing power and improved training techniques to learn complex patterns in large amounts of data. Common applications include image and speech recognition (Athanasios, 2023).

1.5.4 Computer Vision: relies on pattern recognition and deep learning to recognise what's in a picture or video. When machines are capable of processing, analysing, and understanding images, they can capture pictures or videos in real time and interpret their surroundings. CV helps systems understand and interpret the visual world in a way that can elicit appropriate action. It trains computers to interpret and understand the visual world (Athanasios, 2023).

1.5.5 Natural Language Processing (NLP): is the ability of computers to analyse, understand, and generate human language. Natural language interaction, or NLP, allows humans to communicate with computers using normal, everyday language. (Athanasios, 2023)

1.6 Applications of Artificial Intelligence

AI has big role in: transportation, robots, health, education, commination, public safety and security, entertainment, and employment.

1.6.1 Smarter Cars: In 2001, GPS has been introduced for personal vehicle for car navigation devices, and from this, it has become a basic part of the transportation infrastructure. Nowadays, vehicles are equipped with sensors. An average automobile in the US is predicted to have seventy sensors including gyroscopes, accelerometers, ambient light sensors, and many sensors are used. Automobiles built 2000 sensor for the better quality and service of cars (sachin shankar, vinayak pujari, 2020).

1.6.2 AI in Social Media: social media sites like Facebook, Twitter, and Snapchat contain billions of user profiles, which require to be stored and managed during a very efficient way. AI can organize and manage massive amounts of knowledge. AI can analyse many data to spot the newest trends, hashtag, and requirement of various users (sachin shankar, vinayak pujari, 2020).

1.6.3 AI in Robotics: Artificial Intelligence has a remarkable role in Robotics. Usually, general robots are programmed such they will perform some repetitive tasks, but with the assistance of AI, we will create intelligent robots which may perform tasks with their own experiences without pre-programmed. Humanoid Robots are best examples for AI in robotics, recently the intelligent Humanoid robot named as Erica and Sophia has been developed which can talk and behave like humans (sachin shankar, vinayak pujari, 2020).

1.6.4 AI in E-commerce: AI is providing a competitive edge to the e-commerce industry, and it's becoming more demanding within the e-commerce business. AI helps shoppers to get associated products with recommended size, colour, or maybe brand (sachin shankar, vinayak pujari, 2020).

1.6.5 AI in Education: From fifteen years, AI has been considered an advance in the education field. Applications are used by educators and learners today. Robots have been popular educational devices. In the 1980s, in the MIT Lab, the Lego Mind Storms kits has been developed for the purpose of education. Some robots, like Ozobot and Cubelets, teach and help learners and children (sachin shankar, vinayak pujari, 2020).

1.6.6 AI in Safety and Security: AI is used only when necessary. And deployment is very carefully done, AI is also helpful for removing some of the bias inherent in human decision-making. The term AI is also helpful in Cybersecurity, and machine learning is making an impact. The CCTVs are deployed almost everywhere in the world today tend to be more useful for helping solve crimes and preventing them (sachin shankar, vinayak pujari, 2020).

1.7 Advantages of Artificial Intelligence

Artificial Intelligence (AI) presents numerous advantages across various domains. By substituting humans with robots, AI reduces human labour and reallocates human attention to more critical tasks. It serves as a cost-effective labour force, expediting tasks and enhancing profitability. Unlike humans, AI-driven machines can operate continuously without the need for breaks or refreshments. AI systems can be reprogrammed to function for extended periods without experiencing boredom or exhaustion, significantly increasing operational efficiency. In industries such as mining and fuel exploration, AI and robotics enhance human safety by undertaking hazardous tasks (sachin shankar, vinayak pujari, 2020).

AI also mitigates human errors through the application of specialized algorithms that facilitate decision-making based on pre-existing data, leading to greater accuracy and precision. This automation of repetitive activities enables humans to focus on developing their creative potential. Leading organizations and websites utilize AI-powered digital assistants to interact with users, thereby reducing the necessity for human resources. Advanced chatbots are so sophisticated that they can be indistinguishable from human interlocutors (sachin shankar, vinayak pujari, 2020).

Moreover, integrating AI with other technologies enhances machine decision-making and execution efficiency, often surpassing human capabilities. Commonly used AI-powered applications, such as Apple's Siri, Windows' Cortana, and Google's OK, deliver results more rapidly than humans, further demonstrating AI's capacity to improve productivity and performance across various sectors (sachin shankar, vinayak pujari, 2020).

1.8 Disadvantages of Artificial Intelligence

Despite its numerous advantages, Artificial Intelligence (AI) also presents several significant disadvantages and risks. The development and maintenance of AI machines are expensive, requiring substantial financial and temporal investment. Repairing and rebuilding robotic systems can be time-consuming and costly, necessitating human intervention, which further escalates expenses and resource allocation (sachin shankar, vinayak pujari, 2020).

A critical societal concern is the potential for AI to cause severe unemployment by replacing human jobs. This problem necessitates finding alternative human roles that AI cannot perform or considering drastic systemic changes, such as adopting a communist regime. Additionally, if AI technology falls into the wrong hands, it can easily lead to destructive outcomes, instilling fear among the populace (sachin shankar, vinayak pujari, 2020).

The convenience offered by AI applications may lead to human complacency, potentially impeding future generations' development by reducing the need for human effort and creativity. As AI increasingly handles repetitive tasks, human involvement diminishes, posing a significant problem for employment standards. Organisations are inclined to replace minimally qualified individuals with AI robots, which can perform tasks more efficiently but lack the human element crucial for team dynamics (sachin shankar, vinayak pujari, 2020).

Although AI systems excel in efficiency, they cannot replicate the human connection essential for effective team management. Specifically programmed machines can only perform specific tasks; beyond these parameters, they often malfunction or produce irrelevant outputs, which is a significant drawback. This limitation underscores the irreplaceable value of human judgement and emotional intelligence in various professional settings (sachin shankar, vinayak pujari, 2020).

Machines can perform only those tasks that they're designed or programmed to try to do; anything beyond that, they have a tendency to crash or give irrelevant outputs, which might be a serious backdrop (sachin shankar, vinayak pujari, 2020).

1.9 The Role of Artificial Intelligence in Transportation

Artificial Intelligence (AI) has become a crucial element in the modernization of the transportation sector, offering solutions to various challenges such as increasing travel demand, CO2 emissions, safety concerns, and environmental degradation. The integration of AI techniques in transport aims to enhance efficiency, safety, and sustainability in urban mobility and traffic management systems (Abduljabbar et al., 2019).

1.9.1 AI in Traffic Management and Safety

AI has revolutionized traffic management by transforming traditional traffic sensors into smart agents capable of detecting accidents automatically and predicting future traffic conditions. Techniques like Artificial Neural Networks (ANNs), Genetic Algorithms (GAs), and Simulated Annealing (SA) have been applied to optimize traffic flow and reduce congestion (Abduljabbar et al., 2019). For instance, ANNs are used for road planning and incident detection, providing more accurate and reliable predictions of traffic conditions and accidents (Abduljabbar et al., 2019).

1.9.2 AI in Public Transportation

Public transportation systems have benefited significantly from AI applications. AI techniques improve route planning and scheduling, enhance passenger information systems, and optimize the use of public transport fleets. This has led to increased efficiency and reduced waiting times for passengers, contributing to the sustainability of urban transport systems (Abduljabbar et al., 2019).

1.9.3 Autonomous and Connected Vehicles

One of the most promising applications of AI in transport is the development of autonomous and connected vehicles. These technologies aim to enhance road safety and reduce traffic accidents by enabling vehicles to communicate with each other and with traffic management systems. Trials of self-driven cars and autonomous buses in countries like Finland, Singapore, and China demonstrate the potential of AI to transform personal and public transportation (Abduljabbar et al., 2019).

1.9.4 AI Techniques in Transport Planning

Transport planning involves complex decision-making processes that benefit from AI's ability to analyse large datasets and identify patterns. AI techniques such as ANNs, GAs, and SA are used to design optimal road networks, predict traffic patterns, and manage transportation infrastructure more effectively. These methods help planners address the increasing travel demand and environmental impacts associated with urban growth (Abduljabbar et al., 2019).

1.9.5 Challenges and Future Directions

Despite the significant advancements, AI applications in transport face challenges such as data quality, computational complexity, and the integration of AI systems with existing infrastructure. Future research aims to address these issues by developing more sophisticated AI algorithms and enhancing the interoperability of AI systems across different transport modes (Abduljabbar et al., 2019).

1.10 Conclusion

We have covered the basic concepts of Artificial Intelligence, starting with its definition and historical background, and moving through its major subfields and applications. The study also has been discussing the advantages and disadvantages of AI, providing a balanced view of its potential and challenges. Lastly, the chapter has explored the transformative role of AI in transportation, highlighting its impact on this essential industry. Through this comprehensive overview, we have established a solid foundation for understanding the multifaceted nature of AI and its growing significance in various fields.

TOPIC TWO:
Basic Concepts about Seaports

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2.1 Introduction

In this section, we delve into the fundamental aspects of seaports. We start by exploring the history of ports to understand their development over time. Following this, we intend to define what a port is and discuss the various classifications of ports. Then, we explain the seaport concept in detail, emphasizing their crucial role in global trade and connectivity. Additionally, we highlight the importance of ports, focusing on their economic and logistical significance. Lastly, we outline the various services provided by ports, illustrating their multifaceted operations.

2.2 History of the Ports

Ports have been pivotal in the development of civilizations, serving as gateways for trade, cultural exchange, and technological advancements. The history of ports is rich and multifaceted, encompassing various periods and regions, and influenced by numerous economic, social, and technological factors (Palmer, 2000).

❖ **Early History of Ports**

Ports have existed since ancient times, facilitating trade and interaction between different civilizations. Early ports, such as those in the Mediterranean, have played crucial roles in the economic and cultural exchanges of the ancient world. The ports of Phoenicia, Greece, and Rome has been instrumental in the spread of goods, ideas, and cultures across the region (Broeze, 1997).

❖ **Medieval and Early Modern Ports**

During the medieval period, ports have continued to thrive as centres of commerce and cultural exchange. The rise of maritime republics such as Venice and Genoa exemplify the significance of ports in medieval trade networks. In the Early Modern period, European seaports have become even more critical as Europe began to explore and colonize other parts of the world. Ports like Lisbon, Antwerp, and Amsterdam have emerged as major hubs of international trade (Bird, 1963; Polónia, 2006).

❖ **Industrial Revolution and Modernization**

The Industrial Revolution has marked a significant turning point in the history of ports. The advent of steam power, industrial manufacturing, and the expansion of global trade networks have necessitated the modernization of port infrastructure.

This period has witnessed the construction of new docks, warehouses, and transportation links to support increasing trade volumes. The ports of Liverpool and London are prime examples of this transformation, adapting to the demands of industrial and maritime advancements (Jarvis, 1999).

- **20th Century Developments**

The 20th century has brought further changes to ports with the introduction of containerization and other technological advancements in shipping. Container ports have emerged, fundamentally altering the logistics of global trade. This period also has witnessed the rise of major port cities in Asia, such as Singapore and Hong Kong, which have become critical nodes in the global supply chain (Hayuth & Hilling, 1992).

- **Comparative Studies and Port Competition**

Comparative studies of ports, such as the analysis of competition between Antwerp and Rotterdam, highlight the dynamic nature of port development. These studies examine how ports adapt to economic pressures and technological changes, offering insights into the factors driving port success and decline (Loyen, Buyst, & Devos, 2003).

- **Interdisciplinary Approaches**

The study of ports has increasingly become interdisciplinary, incorporating insights from geography, economics, urban studies, and social history. This approach has enriched our understanding of ports not just as physical infrastructures but as complex entities influencing and influenced by various socio-economic factors (Broeze, 1997; Tull, 1997).

The history of ports is a testament to their enduring importance in global commerce and cultural exchange. From ancient harbours to modern container terminals, ports have continually evolved, reflecting broader changes in technology, economy, and society. The study of port history, therefore, offers valuable perspectives on the interconnectedness of the world and the forces shaping our economic and cultural landscapes (Williams, 2014).

2.3 Definition of Port

- **Definition 01:** At its most basic, a port is a place: an established landing point for the loading and unloading of sea cargo (Palmer, 2020).

- **Definition 02:** A port is a location on a coast or shore containing one or more harbours where ships can dock and transfer people or cargo to or from land. Port locations are selected to optimize access to land and navigable water, for commercial demand, and for shelter from wind and waves (G.S Dwarakish, Akhil Muhammad Salim, 2015)**.**

- **Definition 03:** Ports are one of the primary components of the general transportation sector and are nowadays linked to the expanding world economy. Ports are basically a means of integration into the global economic system (G.S Dwarakish, Akhil Muhammad Salim, 2015)**.**

A port is a strategically located area on a coast or shore with facilities for docking ships to transfer cargo and passengers. The design optimizes access to land and water, meets commercial demands, and provides shelter from environmental elements. Ports play an important role in the transportation sector and the global economy because they facilitate international trade and economic integration.

2.4 Port Classification

Classification is a necessary and basic step to identify and separate ports from each other, through which it is possible to differentiate between the different functions of ports in different dimensions. This study classifies ports based on several factors, including 1) port usage, 2) geographical location, 3) maritime transportation system using the port, 4) type of water corridor, 5) functional role of the port, 6) role of the port in the transportation network and transfer, 7) the length of the operation period, 8) the length of the service period during the day, 9) the type of port ownership, 10) the usability of the port, and 11) the coverage area of the port, all of which have been investigated in the previous dimensions (Abdoreza Sheikholeslami, 2024).

2.4.1 Port Classification Based on Port Usage

Seaports are divided into eight general groups according to the type of use of the port and the purpose of its use, and the basic activity in the port will be different accordingly (Abdoreza Sheikholeslami, 2024).

A passenger port serves both passenger transportation and water access. Only special passenger transportation services, such as boarding and disembarking, and general or comprehensive maritime transportation fleet services are available in these ports, along with passenger fleet docks.

A cargo port serves as a hub for the transportation of cargo and provides access to waterways for the movement of goods. Only the cargo fleet docks at these ports, where they provide special services for the transportation of goods, including loading and unloading, maintenance, packaging, and comprehensive services of the maritime transportation fleet.

A container port serves as a hub for the transportation of goods. Only the container fleet docks at these ports, where they provide services for loading, unloading, and storing containers.

A military port serves as a port for military access to the sea, facilitating the transportation of equipment and military forces through water corridors. Only the military fleet docks in these ports, and only the naval fleet provides military services and general services there.

A Fishing Port serves as a hub for fishing activities and offers specialised services such as maintaining marine animals, providing fishing equipment, and providing general services for the maritime transportation fleet. Only fishing vessels dock in these ports.

Extractive Port: This type of port facilitates the extraction of oil from wells or salts from the sea while also offering services such as drilling equipment, maintenance, and general maritime fleet services. In these ports, only a special naval fleet docks.

A Research Port: depending on the type of activity, provides a variety of services, including aquatic maintenance equipment, water surveying equipment, waterway release equipment, and general maritime fleet services. becomes in these ports, only a special naval fleet dock.

Complex Port: depending on the type, a complex port can be a combination of the seven previously mentioned ports, carrying out more than one maritime activity (Abdoreza Sheikholeslami, 2024).

2.4.2 Port Classification Based on Port Geographic Location

Seaports may be located in various geographical locations due to the expansion of waterways and the development of maritime transportation over time; therefore, we can classify the ports into seven general groups based on their geographical location.

A Coastal Port is one that is located near the coast of a river, sea, lake, or ocean and provides a water connection to land.

Seaport is a port that is located in the sea and far from the land and provides the possibility of providing services or activities in that place.

Island Port is a port located on the coast of the island that provides a water connection with the island.

A Dry Port is a port that is located within the territories and gradually transfers maritime operations to a place far from the sea. These ports usually provide comprehensive services for transportation, storage, packaging, aggregation, and distribution of goods. In times of need, dry ports serve as a complementary element to coastal ports, offering a suitable space for extensive activity and the development of transportation services.

A Floating Port is a large maritime transportation fleet known for its high level of port service, which moves in the sea depending on the need.

Polar Ports are ports situated in areas susceptible to sea surface freezing. These ports offer special stopping and accommodation services, route clearing operations, and relief services.

Subsea Port is a subsea port, and it is located at a lower level than the sea level to access the sea water level and provides services such as the top of the sub-surface fleet and transmission lines in order not to occupy the water level (Abdoreza Sheikholeslami, 2024).

2.4.3 Port Classification Based on Port Functional Role According

Due to the development and evolution of ports over time, each of the ports used in maritime transportation may be placed in one of the generations of the port evolution model. Therefore, the port evolution models allow for the separation and classification of ports by generation (Abdoreza Sheikholeslami, 2024).

Ancient port is a port that has been built in the past and known as one of the first points of the formation of the maritime transportation network; it is called the ancient port. These ports may have been taken out of service due to their inappropriate location or the preservation of their historical context, and a new port might replace them, or they might be updated and upgraded over time and continue to be used.

Access port is the most basic type of port, serving solely as a gateway to maritime transportation. Special services are offered in these ports. They only provide the ability to stop and dock, and neither the fleet nor the user receive this service.

A commercial port is a location where trade and commerce activities occur due to water connections with various locations, and it serves as the hub for commercial activities in the region. In these ports, the exchange role of the port is particularly important in the movement of cargo and passengers.

Industrial ports are those where, in addition to transporting cargo and passengers, they also foster industrial activities. By employing people in related industrial units, these ports are able to produce industrial products, which is why they are known as industrial ports.

A Key Port is a port that sits at the intersection of significant maritime lines and plays a crucial role in global communication. In these ports, the relative location of the network is very important.

A Hub Port serves as an operational core in the region and offers comprehensive maritime transportation services.

A Smart Port is characterised by its modern technology, which allows it to control fleet movement and plan its trips through smart network monitoring systems. The problem of making ports smart is still being developed and updated; therefore, the exact criteria for distinguishing and identifying smart ports need more study and investigation in the coming years.

A Multimodal Port, or a maritime-based common terminal, is a multimodal transportation network where maritime transportation serves as the primary collector.

A port-city is a port that either has become a significant factor in urban development in its vicinity due to the high volume of various activities in its location over time, or the port, also known as a port city, is located close to a city and serves as both a city and a port (Abdoreza Sheikholeslami, 2024).

2.4.4 Port Classification Based on Port Role in Maritime Transportation

Network in addition to the general duties of the port as a maritime transportation terminal, each port plays a specific role in the maritime transportation network, which causes a difference in their performance in the network. These roles include:

The term "port of access" refers to a port that sits in the final layer of the maritime transportation network and solely serves to create access and directly meet demand (Abdoreza Sheikholeslami, 2024).

A feeder port, also known as a distributor, is a port that is responsible for distributing the traffic flow that originates from the main axis of the collector. This flow is then distributed from the hub port to the lower-level ports.

Hub port is the largest operational port in the maritime transportation network, receiving the largest volume of traffic flow and serving as the network's operational core. The main collecting axes, which play the most role in the movement in the network, are connected to these ports, and as a result, these ports are going to have the highest level of movement, the lowest level of direct access, and the highest level of water access.

Interchange port is a common or multi-purpose transportation terminal, or a port in the same location as terminals of other types of transportation, that serves the role of cargo and passenger exchange in the multimodal transportation network.

Logistics centre port is a port where many cargo, passenger, and maritime transportation fleet services are performed due to the provision of comprehensive maritime services and the high storage capacity of the fleet and travel cargoes, and activities such as shipbuilding and maintenance factories in Once established, we refer to it as a network backup port.

Complementary port: if existing restrictions prevent the development of an operational port and the volume of its demand flow exceeds the supply capacity, ports will be built nearby to accommodate a portion of the demand flow. It is referred to such a port as a complementary port.

The central port serves as the hub for managing, coordinating, controlling, and supervising the operation of the maritime transportation network. It is also the location of the network's primary planning, policy-making, economic, and administrative activities. The use of the word "port" for this centre is because the only maritime transportation infrastructure is ports, and this centre can be built in an area even far from the sea (Abdoreza Sheikholeslami, 2024).

2.4.5 Port Classification Based on Port Operational Duration Ports

can be divided into four sub-categories based on the length of the overall operation period and duration of use.

A permanent port is one that has been in continuous operation since its construction and may continue to do so in the future.

Temporary port is a port that is operated for a limited and specific period, and then it is removed from the operational plan of the network. After the completion of the exploitation period, these ports may undergo demolition or remain unaltered.

Periodic port is a port with regular operating lengths and regular breaks. For example, we can mention polar ports that operate at certain times of the year.

Emergency port is a port that starts to operate during crisis conditions, and after the crisis is resolved, its operation is stopped. However, due to the possibility of the crisis occurring again, its infrastructure remains intact (Abdoreza Sheikholeslami, 2024).

2.4.6 Port Classification Based on Port Usability

The most important factor after the availability of the port in planning trips is the ability to use the port because the use of the port services is possible only in the form of defined authorised groups. Therefore, ports can be classified accordingly (Abdoreza Sheikholeslami, 2024).

Closed port is one that only the owner can use for personal use. Usually, ports that are designed for a specific purpose are known as closed ports.

Controlled port is a port that only certain groups can use. Typically, these ports establish ownership and rights of use for specific groups.

All people, owners of goods and services, and ship owners can use a free port in exchange for service fees. Usually, ports that have a high capacity to provide services and the supply of port services in the region are limited, allowing different users to directly use these services, such as international ports or ports located in free zones (Abdoreza Sheikholeslami, 2024).

2.3.7 Port Classification Based on Port Coverage Zone

Each of the ports in the maritime transportation network operates in a certain area for access and communication; therefore, it is necessary to distinguish the coverage area of the ports in identifying their performance.

Dedicated port is a port that is designed for a specific maritime route and has a specific coverage area.

Local port is a port whose all trips are defined in a small area of a few cities.

A national port is one where all voyages are within the country.

A regional port is one whose voyages are defined within the boundaries of neighbouring countries.

International port is a port that travels in all open waters (Abdoreza Sheikholeslami, 2024).

2.5 Seaport Concept

The concept of seaports has evolved significantly in response to the changing global landscape, particularly in terms of their organisation and structure. Within this context, the port has primarily evolved across four generations. Defining the concept of a seaport and classifying it is of utmost importance. From a comprehensive perspective, a seaport serves as a hub for the interchange of commodities and vessels between the sea and land. It is a specific geographical location designed to accommodate ships and facilitate the transfer of goods (Arbia Hlali , Sami Hammami, 2017).

According to Paul Tourret, a port, in its conventional sense, is a complex of breakwaters, harbours, and quays that are designed to accommodate various types of vessels and cargo. In addition to its terminological definition, a seaport can be defined from various perspectives, including economic, geographical, legal, and institutional. More specifically, the definition of a port has been addressed in several ways (Arbia Hlali , Sami Hammami, 2017).

2.5.1 The Economic Conception

The economist Bauchet defines a port as "the location where ships are sheltered, goods pass through, and may also be transformed." This description highlights the three fundamental roles of a port. The first is to define the port function itself. The ship's port serves as its residence. Current ships' immense size and impressive capabilities obscure their initial purpose. A port facilitates the essential operations for transferring products or persons between different modes of transportation, such as from a ship to a land-based mode or vice versa.

Ports and shipping are the primary tools of global commerce. The volume of international trade, sea cargo transportation, port handling, and the size of the world fleet all increase proportionately. Various authors, including Bauchet and Vigarié, have substantiated this mutual reliance both practically and theoretically.

Global exports have experienced significant growth since the end of World War II. Maritime trade is increasingly becoming the predominant method of commerce. The proliferation of maritime transport has been essential in facilitating the global spread of international trade(Arbia Hlali , Sami Hammami, 2017).

Furthermore, these two ports functions can also accommodate commercial and industrial activities. Commercial activities are essential for conducting all operations related to the transit of vessels and merchandise in the port. The ship's actions include both preparation and execution of the stopover. Handling the products involves completing customs clearance processes before taking them out of the terminal.

Economically speaking, a port is a complex system that combines tangible and intangible elements to efficiently transport ships and cargo. Port infrastructure consists of both real and intangible components, including port superstructures and other tools or equipment.

Indeed, the port utilises several components to effectively provide services to ships and cargo. Shipbuilding infrastructure primarily comprises essential heavy infrastructure that enables ships to approach a maintained station in the docks and docking stations where ships berth throughout the port execution period. Afterwards, specialised equipment, known as superstructure or tooling, loads and unloads items from ships docked to the ground and secured in place (Arbia Hlali , Sami Hammami, 2017).

2.5.2 The Geographic Conception

The geographer favours a definition that highlights the specificity of the place "port" not in relation to the functions that are carried out there but in relation to the rest of the earth's surface. For example, Vigarié defines the seaport as an area of contact between the two domains, the land traffic and the maritime traffic, whose role is to ensure a solution of continuity between two transport schemes adapted to crossing two spaces with different characteristics (Arbia Hlali , Sami Hammami, 2017).

The geography words (1992) define it as "a place of transhipment of persons or goods between land and water", an interface between sea and land, between maritime circulation space and land circulation space. It is therefore "a plane or line of contact between two systems or two distinct sets" (Arbia Hlali , Sami Hammami, 2017).

2.5.3 The Institutional Conception

The institutional regime of ports depends on how they are defined and the kind of traffic they receive. According to J.G. Matons, the competent administrative authority specifically designates a port as a place on the coast for the purpose of seaborne trade. The port is an institution, with or without a legal personality, responsible for exercising public works, police, or other powers in the geographical and legal space. In the same sense, B. Steck defines ports as “service companies, at the centre of the logistical chain that organises world trade, to allow the flow of traffic, even capturing and raising it. To adapt to changes in the global economy, particularly those influenced by technological dynamics, ports need to provide a growing range of services that require specific equipment that undergoes constant renewal (Arbia Hlali , Sami Hammami, 2017).

The port serves as a hub for economic activity and a hub for exchanges. Both goods and people circulate. Thus, one distinguishes between a port and its various activities, which are more or less developed according to the economic activity and the stakes of the region. These activities have an impact on the port's structure and vicinity (Arbia Hlali , Sami Hammami, 2017).

2.6 The Importance of Sea Ports

Ports play a crucial role in the development of a nation, serving as hubs for trade, transportation, and economic activities. They are not just points of entry and exit for goods but also vital centres for economic growth, regional development, and globalization.

❖ **Economic Significance**

Ports are significant contributors to a nation's economy. They facilitate international trade by enabling the import and export of goods. Efficient port operations reduce the cost of trade, which can lower the prices of imported goods and make exports more competitive. This, in turn, can boost a country's GDP and create jobs both directly in port-related activities and indirectly in associated industries (Dwarakish & Salim, 2015). Ports are essential for industries that rely on raw materials from abroad and need to export finished products, making them critical for manufacturing and industrial sectors (Mukherjee, 2001).

❖ **Infrastructure and Development**

The development of port infrastructure is often linked with broader economic development. Ports require substantial investment in infrastructure, such as docks, storage facilities, and transportation links like railways and highways. These investments can stimulate local economies by creating jobs and fostering the growth of ancillary services such as logistics, warehousing, and customs clearance (Sánchez et al., 2002). Modern ports equipped with advanced technology can handle larger volumes of cargo more efficiently, reducing turnaround times and increasing throughput (Ferrari, 2011).

- **Global Trade and Connectivity**

Ports are vital nodes in the global supply chain. They facilitate the movement of goods across international borders, connecting producers with global markets. This connectivity enhances a country's participation in global trade networks, contributing to economic integration and competitiveness (Tovar et al., CCRP Working Paper No.7). Efficient ports can attract more shipping lines and increase trade volumes, which can lead to further economic benefits such as increased foreign direct investment and improved balance of payments (Berköz, 1999).

- **Employment and Social Impact**

Ports generate significant employment opportunities, both directly and indirectly. Direct employment includes jobs in port management, cargo handling, and ship services. Indirect employment is created in related sectors such as transportation, logistics, and manufacturing. The presence of a port can lead to the development of industrial clusters in its vicinity, providing jobs and contributing to regional economic development (Ferrari, 2011).

Additionally, ports support social functions by providing employment to a large number of people, which can improve living standards and reduce poverty in surrounding areas (Mukherjee, 2001).

- **Environmental and Technological Aspects**

Modern ports are increasingly focusing on sustainability and environmental protection. The impact of port activities on the environment, such as pollution from ships and cargo handling operations, is a growing concern. Ports are adopting green technologies and practices to minimize their environmental footprint, such as using cleaner fuels, improving waste management, and implementing energy-efficient operations (Oliveira, 2008). Moreover, technological advancements are making ports more efficient. Automation and digitization are helping to streamline operations, reduce costs, and improve safety (Kowalczyk, 2012).

In conclusion, ports are indispensable for the economic development of a nation. They facilitate trade, contribute to GDP growth, create jobs, and support regional development. The efficient functioning of ports is crucial for integrating a country into the global economy and enhancing its competitiveness. Investments in port infrastructure and technology, along with sustainable practices, are essential for maximizing the economic benefits while minimizing the environmental impact (Dwarakish & Salim, 2015).

2.7 Sea Port Services

❖ **Understanding Port Services**

Before diving into specifics, it's crucial to grasp the essence of port services. These encompass a wide array of offerings within a port, catering to ships, cargo, and various economic entities. Their primary aim is to facilitate the smooth transportation of goods from their origin to their final destination.

Ports serve as pivotal geographic locations where passengers and goods transit. They act as meeting points between maritime vessels and different land transport modes. Moreover, they serve as vital control centres for the exchange of essential computerized data to ensure the seamless movement of ships and cargo (Thommerel, M, 2022).

Some ports are intricately connected to industrial-port zones, serving as interfaces between ports and industries, thereby linking to hinterlands or inland regions where goods originate and are destined.

❖ **Unveiling Port Services: An Overview**

Port services can be broadly categorized into three groups: (Thommerel, M, 2022).

1 - Services for Ships

Ship-related services within ports are diverse, ranging from equipment maintenance to administrative support. Key services include:

- **Piloting**: Providing expert guidance to ship captains navigating in and out of ports.
- **Towing**: Assisting ships with manoeuvres such as berthing and departure using powerful tugboats.
- **Bunkering and Water Supply**: Furnishing ships with fuel and water for various onboard needs.

2 - Cargo Services

These services revolve around the handling and transportation of goods, facilitated by port facilities:

- **Handling**: Loading and unloading goods from ships and transporting them within the port.
- **Stuffing and Stripping**: Packing and unpacking cargo containers.
- **Customs Clearance and International Transportation**: Facilitating import/export procedures and international cargo movement.

3 - Additional Offerings

Apart from ship and cargo services, ports offer supplementary services, including:

- **Security and Illumination**: Ensuring safety and providing lighting within the port area.
- **Infrastructure Rental and Utilities**: Offering rental spaces and utilities such as water, electricity, and communication services.
- **Transportation Infrastructure**: Providing quality road and rail links for efficient cargo movement.

4- Towards Port Digitalization

Ports are increasingly embracing digitalization to enhance efficiency and competitiveness. This entails:

- **Port IT Systems:** Utilizing digital platforms like Port Community Systems (PCS) to streamline information exchange among stakeholders.
- **Smart Container Solutions:** Integrating sensor-equipped containers to monitor environmental conditions and enhance supply chain transparency.
- **Automation Initiatives:** Implementing automation to streamline operations and minimize manual intervention, albeit cautiously due to cybersecurity concerns.

2.8 Conclusion

We have examined the basic concepts of seaports, beginning with their history and development. We have provided a clear definition of ports and discussed their different classifications. We also have explained the seaport concept, emphasizing their vital role in global trade and connectivity. Furthermore, we have highlighted the importance of ports in economic and logistical contexts and outlined the diverse services they offer. This comprehensive overview has established a foundational understanding of seaports and their pivotal role in the maritime industry.

TOPIC THREE:
Applications of Artificial Intelligence in Seaports

TOPIC THREE: The Applications of AI in Seaports

3.1 Introduction

In this topic, we explore a diverse array of applications where Artificial Intelligence (AI) is transforming operations within seaports. From autonomous handling equipment to remote logistic tracking, port community systems (PCS), predictive analytics and planning, to other innovative AI applications. Each section delves into how advanced technologies are revolutionizing the maritime industry.

3.2 Autonomous Handling Equipment

Autonomous handling equipment stands at the forefront of innovation in sea port operations, revolutionizing the way cargo is handled and transported within port terminals. These cutting-edge systems, devoid of direct human intervention, encompass a range of machinery and vehicles meticulously designed to streamline loading, unloading, and container movement processes (Dávid, A, 2019).

At its core, autonomous handling equipment embodies efficiency, safety, and cost-effectiveness. By harnessing advanced technologies such as artificial intelligence (AI), sensors, and machine learning algorithms, these systems operate seamlessly, maximizing productivity while minimizing the risk of human error (David, A. et el, 2014).

Imagine towering Automated Stacking Cranes (ASCs) autonomously navigating through port yards, swiftly retrieving and precisely stacking containers with unmatched precision. These robotic marvels optimize space utilization within terminals, ensuring every square meter is utilized to its fullest potential, thereby boosting throughput capacity and enhancing operational efficiency (AGERSHOU, H, 2004).

Complementing ASCs are fleets of Automated Guided Vehicles (AGVs), tirelessly shuttling containers between quayside, storage areas, and transportation hubs. These driverless vehicles navigate with finesse, guided by onboard sensors or infrastructure-based guidance systems. Their tireless operation, unaffected by fatigue or time constraints, ensures seamless cargo flow around the clock, facilitating just-in-time logistics and meeting the demands of a dynamic maritime industry (AGERSHOU, H, 2004).

The significance of autonomous handling equipment extends beyond mere efficiency gains. These systems usher in a new era of safety, mitigating the risks associated with manual operation in hazardous environments. By removing human operators from the equation, ports can significantly reduce the likelihood of accidents and injuries, safeguarding both personnel and valuable assets (Galieriková, A., Sosedová, J, 2018).

Moreover, the adoption of autonomous equipment presents a compelling business case, offering substantial cost savings over traditional labour-intensive methods. With reduced labour costs and optimized resource utilization, port operators can achieve greater profitability while maintaining a competitive edge in the global trade landscape (David, A. et el, 2014).

Yet, amidst the promise of autonomy lie challenges and considerations. The integration of autonomous systems demands meticulous planning and coordination, necessitating seamless interoperability with existing port infrastructure and IT systems. Regulatory compliance, cybersecurity, and workforce implications loom large, underscoring the need for robust governance frameworks and proactive risk management strategies (Galieriková, A., Sosedová, J, 2018).

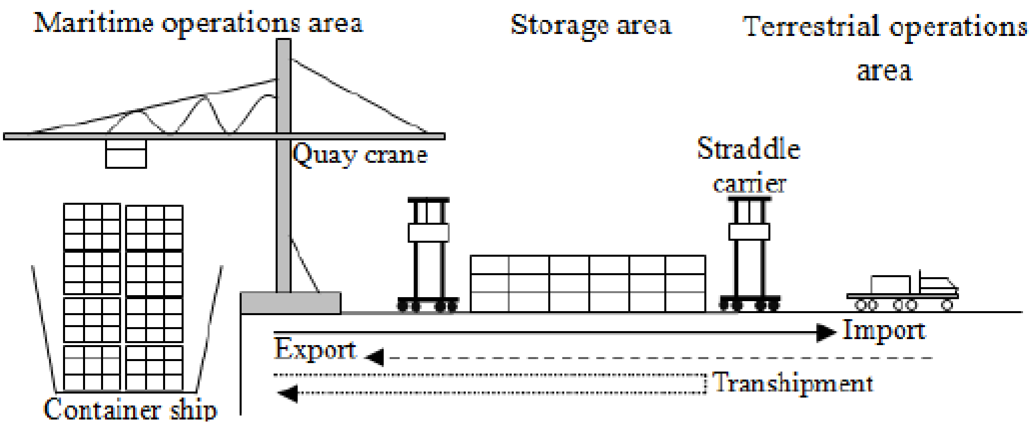

Figure 1 : Overview of Container Handling Processes (Najib, M., Boukachour, J., & El Fazziki, A, 2013)

In essence, autonomous handling equipment epitomizes the convergence of technology and maritime logistics, reshaping the paradigm of port operations for generations to come. As ports embrace automation to navigate the complexities of a rapidly evolving industry, the transformative potential of autonomous handling equipment emerges as a beacon of progress, driving efficiency, safety, and sustainability across the maritime ecosystem.

3.3 Remote Logistic Tracking

To track remote logistics in sea ports, several online platforms offer advanced container tracking solutions. These platforms provide real-time visibility, automated notifications, and comprehensive shipping management tools. Here are some key features of the platforms mentioned in the search results:

- **CCL Logistics & Technology**: offers a Transport Management System called my CCL for managing and tracking sea freight, providing end-to-end supply chain control with the support of Freight Forwarding experts (CCL Logistics & Technology, 2024).
- **GoComet**: provides a single-window container tracking solution for ocean, air, road, and freight shipments, enabling real-time automated notifications and hassle-free integrations with TMS and ERP systems (GoComet, 2024).
- **Terminal49**: offers a modern API and a dashboard for tracking all containers, automating cargo tracking, reducing errors, and enhancing schedule management with precise ETAs and Last Free Days to minimize demurrage charges (Terminal49, 2024).
- **OpenTrack**: provides container tracking technology for ocean and rail cargo, ensuring complete visibility with standardized data from major carriers, ports, terminals, and rail carriers, along with integrated inland rail visibility and white label portals for customer experience enhancement (OpenTrack, s.d.).

These platforms offer a range of features such as automated alerts, standardized data, API integrations, and tools to enhance operational efficiency, reduce costs, and improve supply chain visibility in seaports.

3.4 Port Community Systems (PCS)

In its role as a digital freight platform, a Port Community System (PCS) possesses the adaptability to evolve into a bespoke entity, tailored to capitalize on prevailing opportunities and established stakeholder connections within a port community. Within this dynamic framework, a myriad of specific applications seamlessly converges to form an integrated system: (Port Community System | Port Economics, Management and Policy, 2020)

Figure 2 : Port Community System (Port Community System | Port Economics, Management and Policy, 2020)

Vessel call management within a Port Community System (PCS) orchestrates the intricate ballet of maritime arrivals and departures. Here, a carrier initiates the process by submitting a request for berth and anchorage, which is swiftly processed by the terminal operator. Concurrently, providers of port services, including pilotage, towage, and mooring, are also notified of the impending vessel call, ensuring all necessary arrangements are in place for a seamless docking experience. Moreover, pertinent public authorities, such as the port authority, customs, and port police, are promptly alerted, facilitating regulatory compliance and security protocols. This synchronized approach ensures efficient vessel operations while fostering collaboration among stakeholders and regulatory bodies within the port community (Port Community System | Port Economics, Management and Policy, 2020).

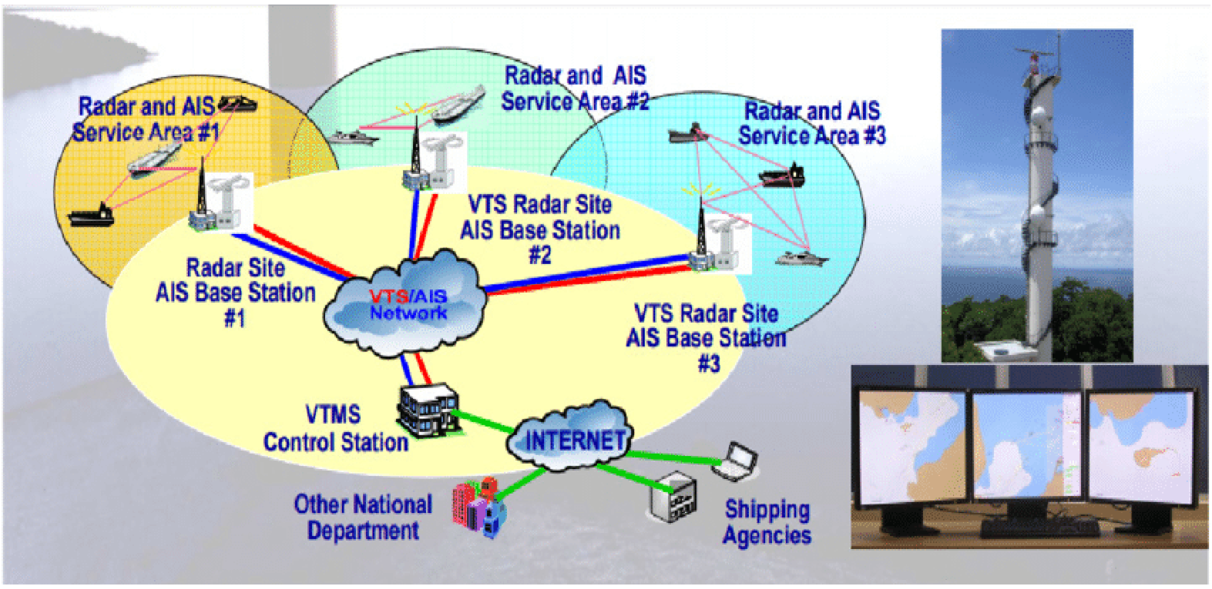

Figure 3 :Vessel Traffic Management System (Sarkodie and al, 2018)

Within the framework of container handling management in a Port Community System (PCS), carriers, including shipping companies and trucking firms, engage seamlessly with terminal operators through a standardized interface. This streamlined interaction eradicates the complexities associated with disparate terminal information systems, ensuring smooth communication and operation. Concurrently, the cargo manifest is promptly shared with both the carrier and the terminal operator, facilitating a synchronized flow of information. Moreover, regulatory agencies such as customs and the port authority receive the cargo manifest simultaneously, enabling automated cross-referencing processes. This integration expedites the clearance of cargo for import or export, significantly reducing processing times. By harmonizing data exchange and regulatory compliance procedures, container handling management within the PCS enhances efficiency and expedites the movement of goods through the port community (Port Community System | Port Economics, Management and Policy, 2020).

Gate management within a Port Community System (PCS) entails the electronic oversight of inbound and outbound movements at terminal gates, significantly enhancing operational efficiency. This process primarily caters to freight forwarders, shipping lines, trucking firms, and terminal operators, streamlining the flow of goods through the port community. By leveraging electronic documentation, including transport contracts, release orders, and admittance orders, gate management consolidates inland logistical operations into a single electronic document. When provided in advance, typically within a 24-hour window, this electronic documentation enables pre-clearance of all processes, minimizing administrative delays and expediting cargo movement. Consequently, physical pick-up or delivery becomes the sole remaining step, allowing for seamless execution. The implementation of such electronic gate management systems often results in a significant increase in gate throughput capacity, sometimes doubling or more, without necessitating additional infrastructural investments aside from automatic gate processing equipment. This transformative approach optimizes resource utilization, reduces congestion, and enhances overall operational efficiency within the port community (Port Community System | Port Economics, Management and Policy, 2020).

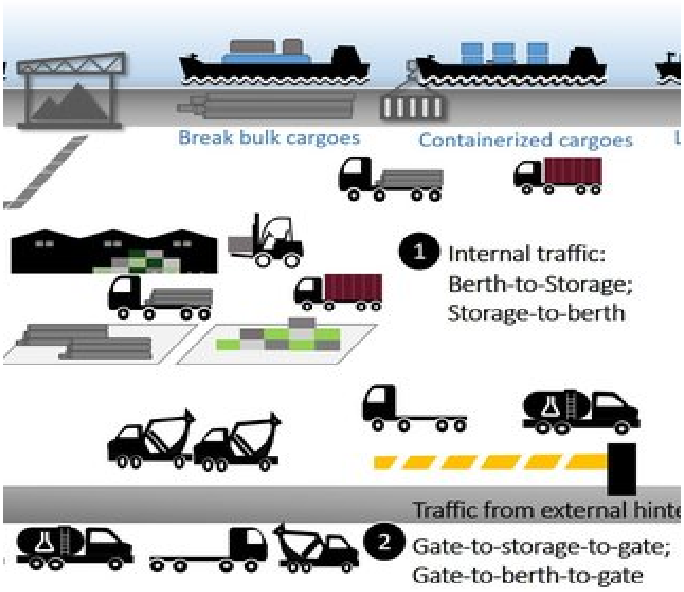

Figure 4 : Layout of lanes at outbound gate

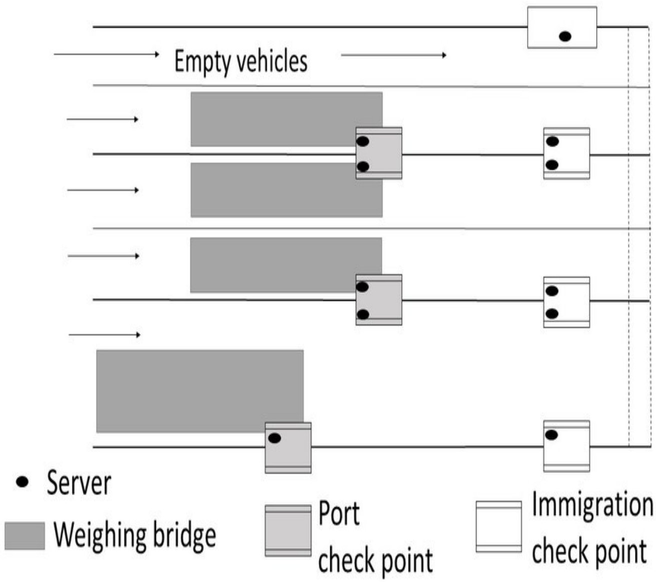

Figure 5 : Maritime port optimization at a glance

Source: (KULKARNI, Ketki; TRAN, Khiem Trong; Hai WANG; and LAU, Hoong Chuin, 2017)

Security and control mechanisms within a Port Community System (PCS) are designed to automate and enhance the secure utilization of port facilities, particularly focusing on cargo access. Leveraging technologies like optical character recognition (OCR) for license plates and container IDs, alongside real-time observation, discrepancies in cargo documentation are swiftly identified for manual verification, ensuring procedural integrity. Additionally, the integration of scanning devices such as radiation detection and RFID further bolsters security measures, augmenting existing infrastructure. By optimizing resource utilization and refining security protocols, the PCS not only ensures the efficient operation of port facilities but also fortifies against potential threats, ensuring the safety and integrity of cargo handling processes within the port community (Port Community System | Port Economics, Management and Policy, 2020).

The culmination of the aforementioned functionalities within a Port Community System (PCS) facilitates comprehensive tracking capabilities through seamless IT integration. This enables continuous monitoring of container loads across the port community, beginning from their unloading at containerships, through the clearance process at terminal gates, until their final delivery. This holistic tracking mechanism empowers stakeholders with real-time visibility into the movement of goods, fostering enhanced supply chain management practices and optimizing asset utilization within the port community. By leveraging advanced tracking technologies, the PCS ensures greater transparency and efficiency throughout the cargo handling process, ultimately contributing to the seamless flow of goods and the overall operational success of the port ecosystem (Port Community System | Port Economics, Management and Policy, 2020).

3.5 Predictive Analytics and Planning

Predictive analytics and planning represent a transformative facet within the Port Community System (PCS), enabling proactive decision-making and resource allocation. By harnessing historical data and real-time insights, predictive analytics algorithms forecast future trends and operational patterns within the port community. This predictive capability empowers stakeholders to anticipate demand fluctuations, optimize resource utilization, and mitigate potential bottlenecks before they occur. Furthermore, predictive analytics inform strategic planning initiatives, facilitating the development of efficient workflows and infrastructure investments. Through predictive analytics and planning, the PCS not only enhances operational efficiency but also fosters resilience and adaptability within the dynamic maritime environment (Predictive Analytics for Port Optimization – INGENIOUS, s.d.).

The following table illustrates instances of IoT, edge processing, and analytics applications within maritime logistics, particularly in port operations. Many of these use cases are encompassed within the ingenious project, ranging from remote control of Automated Guided Vehicles (AGVs) through tactile IoT to tracking resources in sea and hinterland transport, as well as employing predictive analytics for asset management and operational planning. However, this article specifically delves into the utilization of predictive analytics within ports and the broader multimodal logistics environment, aiming to enhance schedule estimation and related planning processes (Predictive Analytics for Port Optimization – INGENIOUS, s.d.).

Table 2 2 Examples of IoT, Edge Processing, and Analytics Applications in Maritime Logistics within Port Operations

	Sea	Port	Hinterland
Autonomous & remote-controlled vehicles	MASS (Maritime Autonomous Surface Ships)	AGV (Automated Guided Vehicles)	Autonomous trucks
Monitoring, situational awareness	Vessel and container tracking, smart fairways	Cargo and resource tracking and monitoring, digital twins	Automatic gate monitoring systems, vehicle tracking
Predictive asset management	Predictive engine health and energy management	Predictive machinery health management	Predictive engine health and energy management
Scheduling, optimization	ETA (Estimated Time of Arrival) predictions, JIT (Just In Time) arrivals	Cargo operations prediction, RTA (Requested Time of Arrival)	ETA, JIT

In this context, predictive analytics refers to the utilization of past and present data, coupled with statistical analyses, computational models, and algorithms, to forecast future events within maritime logistics. The necessity for predictive analytics arises from the need to anticipate various factors crucial for efficient operations. These factors encompass the timing and duration of events and processes, such as vessel arrival times or cargo handling durations, as well as resource requirements like bunkering and tug assistance. Additionally, predictive analytics aids in forecasting future courses of action, such as vessel destinations and routes. Access to such predictive insights is essential for planning operations effectively. However, the challenge persists due to the unreliable availability and insufficient sharing of data among stakeholders in the logistics chain who stand to benefit from this information. This lack of data reliability and sharing is exemplified by common issues encountered in vessel scheduling, as outlined in this blog post (Predictive Analytics for Port Optimization – INGENIOUS, s.d.).

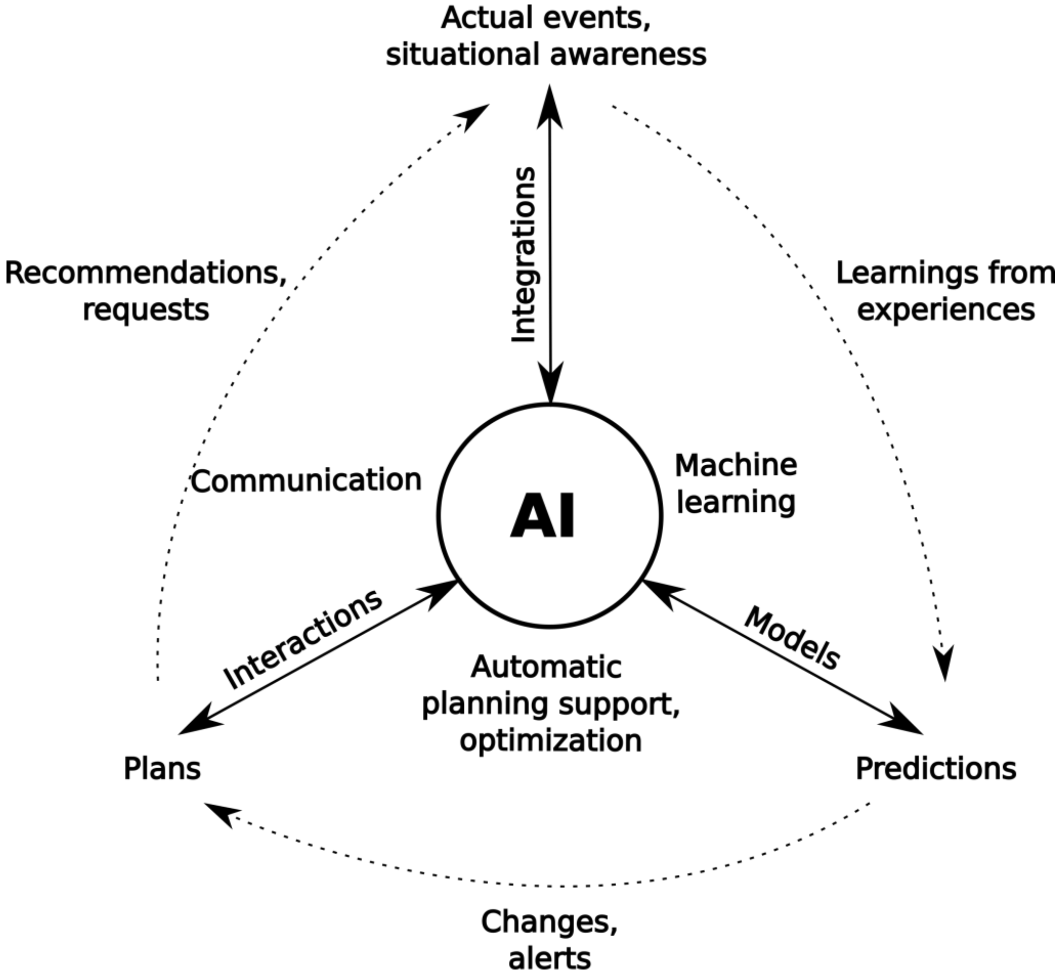

Figure 6 Predictive Analytics for Port Optimization Model (Predictive Analytics for Port Optimization – INGENIOUS, s.d.).

3.6 Other Applications of Artificial Intelligence in Sea Ports

Shipping, constituting approximately 90% of global trade, has long served as the lifeblood of the world economy (OECD, 2020). Yet, this industry, renowned for its conservatism, is undergoing a significant shift. Maritime enterprises, once reliant on conventional methodologies and wary of technological innovation, are now recognizing the value of technology and embracing digital transformation (Pham Mai Ngan, 2023).

Among the array of technological advancements, Artificial Intelligence (AI) emerges as particularly promising, offering solutions to streamline various facets of maritime trade. From unmanned vessels and port operations to document processing and environmental conservation, AI applications hold the potential to revolutionize maritime operations comprehensively (Pham Mai Ngan, 2023).

3.6.1 Autonomous Ships

With human error implicated in over 75% of marine accidents (Allianz, 2019), autonomous vessels present a solution to enhance safety and relieve humans of perilous tasks at sea. Equipped with radar, GPS, sensors, cameras, and operated by AI systems, crewless ships facilitate data gathering, route planning, and hazard avoidance. Moreover, with crew-related expenses constituting up to 30% of voyage costs (CBInsights, 2018), unmanned ships promise significant financial benefits for shipping carriers.

The development of the world's first fully autonomous ferry by Rolls-Royce and Fin ferries in 2018, and the impending trans-Atlantic journey of the Mayflower Autonomous Ship utilizing IBM's AI technology, signify the accelerating pace of technological advancement in this domain.

3.6.2 Virtual Assistants

In December 2019, shipping giant Maersk introduced Captain Peter, a virtual assistant within its revamped Remote Container Management platform. Captain Peter assists customers along their cargo journey, monitoring container conditions and notifying deviations.

In the maritime realm, virtual assistants facilitate shipment tracking, booking deliveries, amending orders, and providing immediate assistance or guidance. These AI-powered assistants adapt to users' preferences and communication styles, thereby reducing human involvement in daily vessel operations (Pham Mai Ngan, 2023).

3.6.3 Document Processing

Maritime enterprises contend with extensive paperwork, including bills of lading, commercial invoices, and packing lists. Manual processing of such documents is not only time-consuming and costly but also error-prone. AI solutions mitigate these challenges by learning and accurately extracting information from thousands of document formats, reducing data entry efforts and inaccuracies (Pham Mai Ngan, 2023).

3.6.4 Safety Enhancement

Enhancing voyage safety is paramount in the shipping industry, and AI holds significant promise in this regard. By analysing weather patterns, port conditions, and technical anomalies, AI guides seafarers in making informed decisions, thereby averting unforeseen stoppages and incidents. AI-powered image recognition systems minimize marine collisions by identifying objects in the vicinity and alerting operators during poor visibility conditions. Additionally, AI-enabled navigation systems create optimal routes based on incident records and enable real-time tracking of vessels (Pham Mai Ngan, 2023).

3.6.5 Environmental Sustainability

Despite its environmental friendliness compared to other modes of transport (ABB, 2019), the maritime industry is committed to reducing its ecological footprint. AI aids in this endeavour by predicting optimal routes, thereby minimizing fuel consumption and carbon emissions. Furthermore, many autonomous ships are designed to be fully electric or harness power from renewable sources like solar and wind, promising a positive impact on the planet's health (Pham Mai Ngan, 2023).

While the adoption of AI in the maritime industry has been gradual compared to other sectors, the tide is shifting as shipping companies recognize the imperative of technological innovation for competitiveness. It is only a matter of time before AI becomes an integral component of maritime workflows, driving efficiency, safety, and sustainability across the industry.

3.7 Conclusion

In conclusion, the infusion of AI across various aspects of seaport operations signifies a transformative leap forward for the maritime industry. With advancements ranging from autonomous handling equipment to predictive analytics, AI is reshaping traditional paradigms, fostering efficiency, safety, and sustainability. As sea ports embrace these innovations, they pave the way for enhanced performance, streamlined processes, and increased competitiveness, heralding a new era of maritime excellence and progress.

Conclusion of the Chapter

In conclusion, the rapid growth of maritime trade has elevated international seaports to vital nodes for global connectivity and economic activity. Despite their importance, seaports encounter challenges that impede their efficiency, from operational bottlenecks to security issues. However, integrating artificial intelligence (AI) offers a promising solution to enhance seaport performance. This chapter has introduced the basics of AI, outlined seaport fundamentals, and explored AI's transformative role in port operations. Through these discussions, we've highlighted AI's potential to revolutionize seaport management, setting the stage for further exploration in subsequent chapters.

CHATPTER TWO:

THE PRACTICAL PART

Introduction

In this chapter, our goal is to delve deeper into the use of AI in port operations around the world. To achieve this, we have selected three distinct ports—Singapore, Rotterdam, and Dubai—as case studies. By focusing on these diverse ports, we aim to gain a comprehensive understanding of the various applications of AI in port management and operations across different geographical and operational contexts. Through comparative analysis, we seek to uncover insights that illuminate the evolving landscape of AI adoption in the maritime industry.

1. Port of Singapore

1.1 Definition

The Port of Singapore, located in Singapore, it serves as a pivotal international seaport and a crucial junction in global transportation networks. Its competitive edge, attributed to its resources, operations, and information technology, is widely recognized. The research paper "Significance of the Port of Singapore against the Country's Economic Growth" explores the port's contribution to Singapore's economic development. Furthermore, the port's service quality significantly influences customer satisfaction within the port sector. Studies examining ship collision frequency in port fairways underscore its importance in global shipping operations. The port's conceptual framework and service characteristics are also scrutinised in theoretical studies, emphasising its pivotal position in the global maritime industry (Mindur, M, 2020).

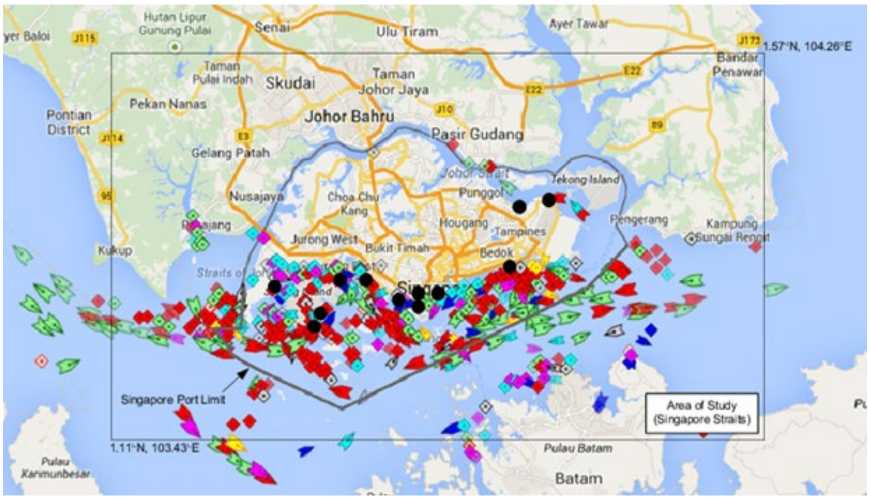

Figure 7 Outline map of ship traffic density at Singapore ports *(Leong S. C et al, 2014)*

1.2 Applications of AI Used in Port Operations in Singapore

1.2.1 Smart Data Modules Deployment (SAFER Project)

The Smart Data Modules Deployment (SAFER Project) within Singapore's port operations represents a strategic initiative focused on the introduction and implementation of sophisticated smart data modules (T. H. Hwee, 2017). These modules are integral components of the SAFER Project, meticulously designed to elevate automation capabilities and precision in managing pivotal maritime tasks. With a firm foundation in advanced data analysis tools and cutting-edge algorithms, the SAFER Project endeavours to revolutionize operational efficacy and safety standards within the port ecosystem. Through the strategic integration of AI technologies, the SAFER Project aspires to orchestrate a paradigm shift in port performance optimization and the seamless facilitation of maritime operations, thereby reaffirming Singapore's position as a global leader in maritime excellence (United Nations Economic and Social Commission for Asia and the Pacific, 2021).

1.2.2 Automated Movement Detection

Automated Movement Detection represents a pinnacle of technological advancement within Singapore's port infrastructure. This sophisticated system integrates cutting-edge AI technologies to meticulously monitor and analyse movements occurring within the port's expansive domain. Through a network of sensors, cameras, and advanced algorithms, it swiftly identifies and tracks various activities, including vessel arrivals and departures, cargo handling operations, and personnel movements (Maritime and Port Authority of Singapore, 2023).

At its core, Automated Movement Detection serves as a sentinel, tirelessly vigilant in safeguarding the integrity and security of port operations. By automating the surveillance and analysis of these movements, it not only enhances operational efficiency but also fortifies the port's defences against potential security threats or disruptions (Lim, G. J., Cho, J., Bora, S., Biobaku, T., & Parsaei, H, 2018).

Moreover, this system plays a pivotal role in optimizing resource allocation, facilitating seamless navigation, and expediting logistical processes within the port environment. Its ability to provide real-time insights and alerts enables port authorities to make informed decisions swiftly, ensuring the smooth and uninterrupted flow of maritime activities (United Nations Conference on Trade and Development, 2022).

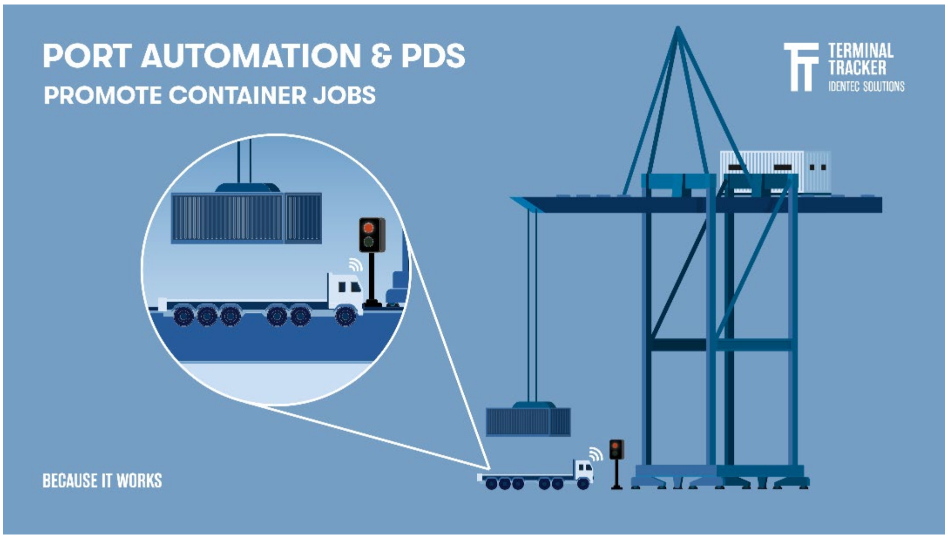

Figure 8 Port Automation with PDS (Automation and PDS: Who is using IT? , 2022)

In essence, Automated Movement Detection stands as a testament to Singapore's commitment to innovation and excellence in port management. Its integration of AI technologies underscores the nation's relentless pursuit of efficiency, security, and reliability in maritime operations, further solidifying its position as a global leader in the maritime industry (Siemens, 2017).

1.2.3 Infringement Analytics

Infringement Analytics constitutes a cornerstone of Singapore's port management strategy, embodying a sophisticated approach to monitoring and mitigating operational irregularities. This advanced system harnesses the power of AI-driven analytics to scrutinize port activities meticulously, identifying any deviations from established protocols or regulations (Tham Wai Wah, 2018).

Through the utilization of sophisticated algorithms and data analysis techniques, Infringement Analytics swiftly detects and evaluates potential infringements such as unauthorized access, safety breaches, or compliance violations. By leveraging real-time data feeds and historical patterns, it provides port authorities with actionable insights and alerts, enabling them to intervene promptly and mitigate risks (Tham Wai Wah, 2018).

1.2.4 Pilot Boarding Detection

Pilot Boarding Detection epitomizes Singapore's commitment to precision and safety in maritime operations, employing advanced technologies to monitor and manage pilot boarding activities with unparalleled accuracy. This sophisticated system integrates state-of-the-art AI algorithms and sensor networks to detect and track the boarding of pilots onto vessels navigating Singapore's waters (Maritime and Port Authority of Singapore, 2020).

By leveraging real-time data analysis and pattern recognition, Pilot Boarding Detection swiftly identifies and verifies pilot embarkation, ensuring the seamless and secure transfer of pilots to and from vessels. This capability enhances navigational safety, minimizes turnaround times, and optimizes port efficiency, ultimately contributing to the overall reliability and reputation of Singapore's maritime services (Maritime and Port Authority of Singapore, 2020).

1.2.5 Next-Generation Port Operations

Next-Generation Port Operations in Singapore epitomize a forward-looking approach to port management, integrating cutting-edge technologies to redefine industry standards and enhance operational efficiency. This strategic initiative leverages a combination of AI, automation, and data analytics to optimize port processes, streamline logistics, and improve overall performance (the Singapore Shipping Association, 2019).

By embracing next-generation technologies, Singapore's ports can anticipate and adapt to evolving industry demands, ensuring competitiveness on the global stage. These advancements facilitate real-time monitoring, predictive maintenance, and dynamic resource allocation, enabling ports to operate with unprecedented agility and responsiveness (the Singapore Shipping Association, 2019).

1.2.6 Vessel Movement Monitoring

Vessel Movement Monitoring stands at the forefront of Singapore's maritime infrastructure, embodying a sophisticated approach to overseeing and managing the intricate dance of vessels within its waters. This comprehensive system integrates cutting-edge AI algorithms and sensor networks, providing real-time tracking and analysis of vessel movements. Its primary goal is to ensure navigational safety, operational efficiency, and regulatory compliance. Through continuous monitoring and analysis, Singapore's vessel movement monitoring system enables proactive decision-making, allowing authorities to anticipate and mitigate potential risks such as collisions, congestion, or unauthorized entries into restricted areas (T. H. Hwee, 2017).

By leveraging data-driven insights, port authorities can optimize traffic flow, minimize delays, and enhance overall port productivity. Moreover, vessel movement monitoring plays a pivotal role in supporting emergency response efforts, facilitating swift and coordinated actions in the event of accidents or incidents at sea. Through fostering transparency and collaboration among stakeholders, Singapore's vessel movement monitoring system reinforces the nation's commitment to maritime safety, security, and environmental protection, solidifying its position as a global leader in maritime excellence (T. H. Hwee, 2017).

Figure 9 Diagram of a typical Vessel Monitoring System (Susanto, H., & Wibisono, G., 2019*)*

1.2.7 Big Data Integration (Tuas Port)

Big Data Integration at Tuas Port marks a transformative leap in Singapore's port infrastructure, representing a visionary approach to harnessing vast volumes of data for operational optimization. This ambitious initiative, denoted as (PSA Singapore, 2018), involves the seamless integration of big data analytics with port operations at Tuas, the world's largest automated container terminal. By leveraging advanced AI technologies and sophisticated data analytics tools, Tuas Port aims to unlock invaluable insights from the wealth of information generated within its ecosystem. This includes data related to vessel movements, cargo handling operations, logistical flows, and environmental factors. Through real-time analysis and predictive modelling, Tuas Port can anticipate demand fluctuations, optimize resource allocation, and enhance overall port efficiency. Moreover, big data integration enables Tuas Port to adapt dynamically to evolving market trends and operational challenges, ensuring agility and resilience in an increasingly complex global trade landscape.

Furthermore, the strategic vision denoted as (Maritime Information Services Ltd, 2018) behind Big Data Integration at Tuas Port extends beyond operational optimization to encompass broader goals of innovation and sustainability. By harnessing the power of data-driven insights, Tuas Port seeks to drive innovation across the maritime sector, fostering the development of new technologies, business models, and operational paradigms. This includes initiatives such as robotic automation, IoT-enabled logistics, and predictive maintenance, which promise to revolutionize port operations and redefine industry norms. Moreover, Big Data Integration at Tuas Port is intricately linked to Singapore's broader sustainability agenda, with a focus on reducing carbon emissions, enhancing environmental stewardship, and promoting sustainable growth. By leveraging data analytics to optimize energy consumption, minimize waste, and mitigate environmental impact, Tuas Port aims to set new standards for eco-friendly port operations. In essence, the integration of big data analytics at Tuas Port represents a pivotal step towards realizing Singapore's vision of a smarter, greener, and more resilient maritime ecosystem.

1.2.8 Fully Automated Crane Systems

Fully Automated Crane Systems herald a new era of efficiency and precision in Singapore's port operations, exemplifying the nation's commitment to technological innovation and operational excellence. These state-of-the-art systems represent a paradigm shift in container handling, eliminating the need for manual intervention and maximizing productivity. By integrating advanced AI algorithms, sensor technology, and automation, Fully Automated Crane Systems optimize the loading and unloading of containers with unparalleled speed and accuracy. This transformative technology does not only reduce labour costs but also minimize human error, resulting in smoother operations and faster turnaround times (Lee, J, 2019).

Moreover, the implementation of Fully Automated Crane Systems aligns with Singapore's broader strategic vision for port modernization and competitiveness. By leveraging automation to streamline container handling processes, Singapore's ports can accommodate growing trade volumes, improve port throughput, and maintain their status as global trade hubs.

Additionally, Fully Automated Crane Systems enhance safety by minimizing the risk of accidents and injuries associated with manual crane operations (Lee, J, 2019).

Furthermore, the deployment of Fully Automated Crane Systems underscores Singapore's leadership in embracing disruptive technologies to drive economic growth and sustainability. These systems pave the way for a more efficient and environmentally friendly port ecosystem by optimizing energy consumption, reducing emissions, and minimizing environmental impact. In essence, Fully Automated Crane Systems represent a cornerstone of Singapore's efforts to revolutionize port operations, enhance competitiveness, and pave the way for a smarter, greener future in maritime logistics.

1.2.9 Blockchain-based Cargo Tracking and Tracing

The successful completion of a proof-of-concept (PoC) trial exercise of blockchain-based cargo tracking and tracing in early 2018 has marked a significant milestone. This trial, which has utilized the IBM blockchain platform, has aimed to explore various aspects of logistics management, including real-time track and trace, transparent execution of logistics booking processes, regulatory compliance, and participant permission access control (Maritime Information Services Ltd, 2018).

By leveraging blockchain technology, the trial demonstrated the potential for enhancing both physical and digital connectivity within the supply chain ecosystem. It has emphasized the importance of collaboration among stakeholders in the Singapore port industry to drive improvements in efficiency and transparency along the global supply chain (U. D. Ani, N. Daniel, F. Oladipo, and S. E.Adewumi, 2018).

Overall, the successful PoC trial has highlighted the potential benefits of blockchain technology in revolutionizing logistics and supply chain management, paving the way for further exploration and implementation of blockchain solutions in the industry (U. P. D. Ani, H. (Mary) He, and A. Tiwari, 2017).

1.2.10 Robotic Arms for Container Handling

Robotic Arms for Container Handling stand as a pinnacle of innovation within Singapore's port operations, showcased prominently at the Intelligent Port of the Future Exhibition by PSA Singapore. From January 10th to January 14th, 2018 at Pasir Panjang Terminal Building 3, this exhibition serves as a platform to unveil PSA's visionary approach to the future of port logistics, highlighting the transformative potential of technology and innovation in reshaping traditional job roles. Among the array of cutting-edge technologies on display, robotic arms emerge as a game-changer in container handling processes. These precision-engineered robotic arms revolutionize the labour-intensive task of twist lock handling during container loading and unloading operations alongside the quay cranes. By seamlessly integrating automation into port operations, these robotic arms optimize efficiency, minimize downtime, and enhance safety standards. Furthermore, PSA's commitment to workforce development is evident through initiatives aimed at upskilling employees to effectively collaborate with mechanization, empowering them to assume more value-added responsibilities while harnessing the assistance of robotic arms. This strategic integration of robotic technology underscores Singapore's position as a trailblazer in maritime logistics, showcasing its unwavering dedication to leveraging innovative solutions to drive operational excellence and maintain global competitiveness in the dynamic landscape of port management (PSA Corporation Limited, 2018).

1.2.11 IoT-fitted Amphibious Drones

IoT-fitted Amphibious Drones in Singapore exemplify a cutting-edge fusion of technology and innovation within maritime logistics. These drones, equipped with Internet of Things (IoT) capabilities, represent a revolutionary approach to surveillance, delivery, and security operations in port environments. Deployed alongside on-ground IoT sensor networks, these drones autonomously navigate through software-controlled flight plans, offering a myriad of enterprise use cases. From facilitating ship-shore or shore-ship deliveries to providing terminal security surveillance, these drones offer a faster, more cost-effective method of data collection and analysis. Moreover, they play a crucial role in inspections, ranging from structural assessments of port equipment to comprehensive evaluations of port infrastructure. With the potential to operate over land and water, including the capability to land on water to inspect wharf side fenders, IoT-fitted Amphibious Drones are poised to revolutionize port operations, enhancing efficiency, safety, and environmental sustainability in the bustling maritime ecosystem of Singapore (Bouari, M, 2018).

1.2.12 Simulation for Equipment Maintenance

PSA intends to utilize data analytics extensively in Singapore's future port, focusing on optimizing various facets like equipment specialist performance, crane maintenance, and the implementation of simulation models. These models are instrumental in simulating container port operations, enabling PSA to predict and analyse potential scenarios for enhanced operational efficiency. Through leveraging data analytics, PSA aims to improve the performance of equipment specialists, ensure proactive maintenance of cranes, and simulate port operations effectively, thereby laying the groundwork for a more efficient and innovative port environment in Singapore (PSA Corporation Limited, 2018).

2. Port of Rotterdam

2.1 Definition

The Port of Rotterdam is one of the largest and busiest seaports in Europe, situated in the city of Rotterdam, Netherlands. It serves as a vital gateway for international trade, handling various types of cargo including containers, bulk goods, and petroleum products. The port's strategic location at the mouth of the Rhine-Meuse-Scheldt River delta gives it access to the hinterland of Europe, making it a key hub for maritime transportation. With extensive infrastructure and modern facilities, the Port of Rotterdam plays a crucial role in facilitating global supply chains and contributing to the economic prosperity of the Netherlands and the wider region (Port of Rotterdam, 2019).

2.2 Applications of AI Used in Port Operations in Rotterdam

2.2.1 Real-time Analytics

Real-time analytics in the port of Rotterdam involves the continuous monitoring and analysis of various aspects of port operations using sensors, cameras, and other IoT devices. Data collected from these sources, such as ship movements, container statuses, weather conditions, and traffic patterns, is processed in real-time using advanced analytics algorithms. This processing includes cleaning, aggregating, and analysing the data to extract meaningful insights and identify patterns. The insights generated by real-time analytics algorithms provide valuable information for decision-making in port operations. Port authorities and stakeholders can use this information to make timely decisions to improve efficiency, safety, and overall port performance. Additionally, real-time analytics enables predictive capabilities, allowing for the identification of potential bottlenecks, equipment failures, or optimization opportunities before they occur, further enhancing the port's operational effectiveness (Port of Rotterdam, 2019).

2.2.2 IoT-Enabled Operational Platform

In early 2018, the port of Rotterdam, in partnership with IBM, has embarked on a multi-year digitalization initiative with the goal of leveraging IoT and cloud management technologies to revolutionize the port's operational environment and establish itself as the 'world's smartest port'. As part of this initiative, an IoT-driven project has been launched to create a digital twin of the port of Rotterdam, effectively replicating all its operations and conditions, including ship movements. This digital twin system has aimed to harness a variety of data sources, including information from smart quay walls and sensor-fitted buoys, to gain insights into the status of berthing terminals, weather conditions, and water conditions. By utilizing this data, the port has intended to enhance efficiency through real-time tracking of operations, conducting test scenarios, and predicting the best possible docking times for ships based on their characteristics. This initiative has represented a significant step towards optimizing port operations and maximizing efficiency through the integration of advanced digital technologies (M. Murison, 2018).

2.2.3 Decision Support Tool

As part of its digital transformation initiative, the port of Rotterdam developed a decision support tool to assist in the management of incoming ships and port operations. Integrated into the IoT-enabled operational platform, this tool utilizes real-time data collected from various sources, such as sensors, cameras, and weather stations, to provide insights and recommendations for decision-making. Port authorities and stakeholders can leverage the decision support tool to make informed decisions regarding ship berthing, cargo handling, and resource allocation based on current conditions and predictive analytics. By harnessing advanced algorithms and machine learning capabilities, the tool aims to optimize port operations, reduce congestion, and enhance overall efficiency. Ultimately, the decision support tool plays a critical role in enabling the port of Rotterdam to achieve its goal of becoming the 'world's smartest port' (Port of Rotterdam, 2019).

2.2.4 Optimization of Berthing and Departure Times

The port of Rotterdam is actively pursuing strategies to optimize the berthing and departure times of ships as part of its overarching digital transformation initiative. Leveraging advanced technologies and data-driven approaches, the port aims to streamline the process of ship arrivals and departures to improve operational efficiency and reduce congestion. By implementing real-time monitoring systems and predictive analytics, the port can better anticipate vessel arrivals, assess berth availability, and coordinate ship movements accordingly. This proactive approach enables the port to minimize wait times for vessels, optimize berth utilization, and enhance overall port productivity. Additionally, by optimizing departure times, the port can facilitate faster turnaround times for ships, leading to increased throughput and improved customer satisfaction. Through continuous innovation and collaboration with industry partners, the port of Rotterdam is committed to becoming a leader in optimizing berthing and departure times, driving sustainable growth and competitiveness in the global maritime industry (S. Berns, R. Dickson, I. Vonck, and J. Dragt, 2017).

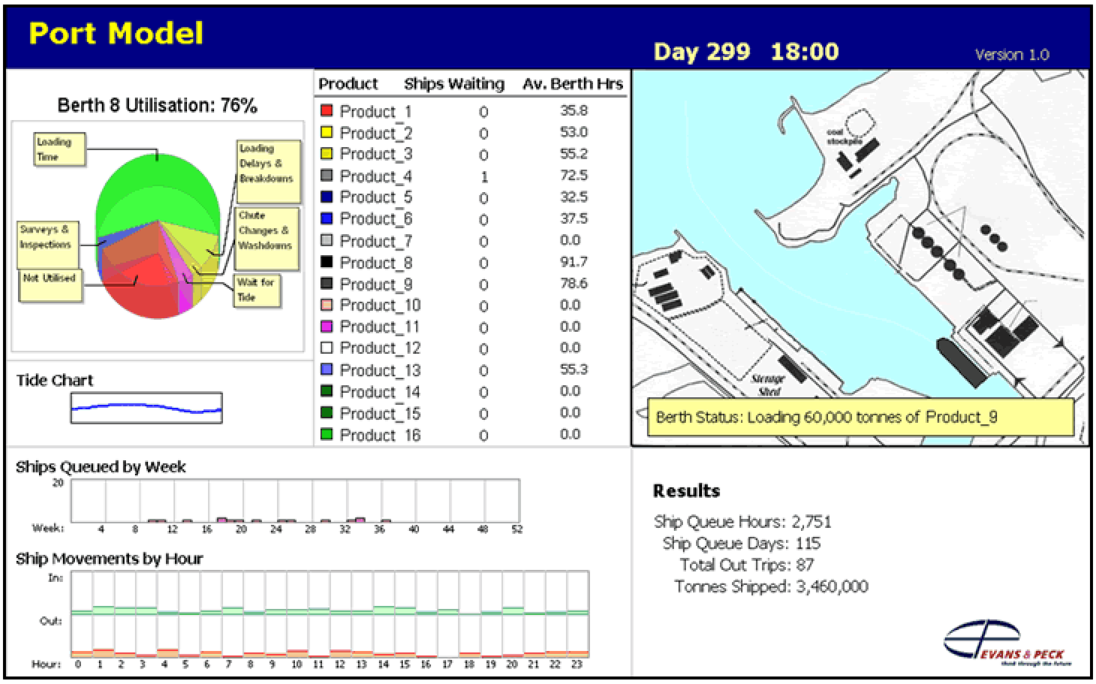

Figure 10 Simulating Port Berth Capacity with Any Logic source: Model developed and published by Evans & Peck Australia.

2.2.5 Digital Twin Development

In pursuit of its digital transformation goals, the port of Rotterdam is actively engaged in the development of a sophisticated digital twin of its operations. This ambitious endeavour aims to create a comprehensive virtual replica of the entire port environment, encompassing all facets of its operations and conditions. Central to this initiative is the integration of IoT technologies, which enable the collection of real-time data from various sources such as smart quay walls and sensor-fitted buoys. By harnessing this wealth of data, the digital twin can accurately simulate and mirror the dynamic activities within the port, including ship movements, cargo handling processes, and environmental factors. This holistic representation serves as a valuable tool for port operators and stakeholders, facilitating enhanced decision-making, operational planning, and performance optimization. Through the continuous refinement and expansion of its digital twin, the port of Rotterdam aims to unlock new levels of efficiency, resilience, and sustainability, solidifying its position as a global leader in maritime operations (Service, T. N, 2018).

2.2.6 Data Processing

Data processing plays a pivotal role in the digital transformation journey of the port of Rotterdam. With the influx of data from various sources such as IoT sensors, smart quay walls, and sensor-fitted buoys, the port leverages advanced processing techniques to extract valuable insights and drive informed decision-making. This involves the aggregation, cleaning, and analysis of large volumes of data to uncover patterns, trends, and correlations relevant to port operations. Through the application of data processing algorithms and analytics tools, the port can effectively manage and interpret complex datasets in real-time. Furthermore, data processing enables the port to optimize operational processes, enhance resource allocation, and improve overall efficiency. By harnessing the power of data processing, the port of Rotterdam is able to unlock new opportunities for innovation, performance improvement, and sustainable growth in the maritime industry (Harbour Master's Division Privacy Statement, 2022).

2.2.7 Safety and Reliability

Ensuring safety and reliability is paramount in the digital transformation efforts of the port of Rotterdam. By harnessing advanced technologies such as IoT, AI, and real-time analytics, the port aims to enhance safety protocols, mitigate risks, and uphold stringent operational standards. Through continuous monitoring of key parameters such as ship movements, weather conditions, and environmental factors, the port can proactively identify potential hazards and take preventive measures to safeguard operations. Additionally, the implementation of predictive maintenance strategies allows for early detection of equipment failures, minimizing downtime and reducing the likelihood of accidents. Moreover, by integrating safety protocols and reliability measures into its digital infrastructure, the port can uphold its commitment to ensuring the well-being of personnel, protecting valuable assets, and maintaining the integrity of maritime operations. Overall, safety and reliability remain core priorities in the port of Rotterdam's digital transformation journey, driving continuous improvement and resilience in its operations (Boer, S., Konter, J., & Meijer, A. K, 2009).

3. Port of Dubai

3.1 Definition

The ports of Dubai are integral components of the United Arab Emirates' (UAE) maritime infrastructure, strategically positioned near the Strait of Hormuz. Among these ports, Port Jebel Ali stands out as a major global maritime hub, ranking as the 9th busiest port worldwide and the busiest in the Middle East. With its extensive container terminals and robust infrastructure, Port Jebel Ali facilitates trade routes connecting Asia, the Middle East, Northern Africa, and Europe, contributing significantly to Dubai's economic prosperity (Ajay Menon, 2020).

Another noteworthy port in Dubai is Mina Rashid, renowned for its transition from a commercial port to a vibrant passenger and cruise terminal. Managed by DP World, Mina Rashid is undergoing redevelopment to cater to the burgeoning cruise tourism sector, signalling Dubai's commitment to diversifying its maritime offerings and enhancing its global appeal as a tourist destination. Together, these ports underscore Dubai's pivotal role in global trade and tourism, serving as vital conduits for economic growth and connectivity in the region (Ajay Menon, 2020).

3.2 Applications of AI Used in Port Operations in Dubai

3.2.1 Jebel Ali Terminal 4

The Jebel Ali port in Dubai, operated by DP World, has forged a contractual alliance with DGWorld, a specialist in autonomous vehicles, robotics, and AI, to furnish the port with a fleet of Autonomous Internal Terminal Vehicles (AITVs). This collaboration is geared towards enhancing the overall efficiency of the terminal while streamlining the existing fleet size. Integrating AI algorithms into container movement and dock management aligns with DP World's strategy to usher in digitalization and cutting-edge technologies as the new norm in traditional port operations and supply chains, paving the way for the future of trade. The introduction of AITVs is anticipated to unlock new potential for efficient and cost-effective automation of current container terminals, complemented by the extensive utilization of advanced AI-based software solutions. The contract encompasses all associated integrations into the existing operational processes and infrastructures. (DP World UAE Region FZE. , 2023).

3.2.2 Intelligent Surveillance Systems

Dubai ports utilize intelligent surveillance systems that integrate AI to analyse real-time data from various sources such as security cameras, motion sensors, and intrusion detection systems. This enables swift response to security incidents and better risk management. Mirasys India, a leading provider of AI video analytics and surveillance solutions, has transformed port security by introducing AI video analytics to enhance port security and safety (Mirasys India, 2023). Digi fort, a provider of intelligent video monitoring software, offers advanced features such as license plate recognition, automated alerts, alarms, and pre-configured actions, statistical graphs, and integration with third-party systems (Digifort, 2024). Suraj Informatics provides smart intelligent video surveillance systems that are an essential part of a global security strategy, offering video analytics solutions for security and business intelligence [3]. These intelligent surveillance systems help Dubai ports to ensure safety and security by analysing real-time data and providing proactive actions for programmed behavioural situations with automatic event and alarm generation, along with valuable statistical information for business intelligence application (Digifort, 2024).

3.2.3 Demand and Capacity Prediction

Port operators in Dubai utilize AI models to forecast future demand regarding maritime traffic and port capacity. By employing these AI models, operators can anticipate the upcoming demand, enabling them to plan and allocate resources and infrastructure efficiently to meet the growing demand in a timely manner (Almeida, F, 2023).

3.2.4 Predictive Maintenance Systems

AI-based predictive maintenance systems are increasingly crucial for monitoring the condition of port equipment and forecasting maintenance requirements. These systems leverage advanced machine learning algorithms to scrutinize performance data and identify anomalies, enabling operators to proactively plan maintenance activities and minimize unexpected downtime. The pivotal components of AI-based predictive maintenance systems encompass data collection, analysis, anomaly detection, and maintenance scheduling. Data collection involves gathering historical and real-time data from diverse sources like sensors, maintenance records, and operational data. Subsequently, data analysis entails cleaning, normalizing, and aggregating the data to uncover patterns and trends. Anomaly detection is pivotal for identifying deviations from normal behaviour, which may signal potential failures or issues. Maintenance scheduling encompasses recommending preventive or corrective maintenance tasks, scheduling maintenance activities, and issuing alerts to maintenance teams when necessary. Effective communication and integration are paramount for ensuring that insights derived from the system translate into actionable steps. This involves interactions with various stakeholders, including maintenance personnel and management, as well as alignment with enterprise systems such as ERP and asset management software. User interface and reporting tools play a major role in rendering insights accessible to maintenance staff and decision-makers (Ucar, A., Karakose, M., & Kırımça, N, 2024).

These tools offer data visualization, dashboards, and reporting capabilities, facilitating comprehension of complex data patterns and informed decision-making. Recent advancements and future trends in AI-based predictive maintenance encompass the integration of advanced machine learning algorithms, edge and cloud computing for real-time analysis and data storage, predictive analytics with big data, XAI for transparency, IoT sensor integration, digital twin, AR, VR, MR, and extended versions, big data and analytics, autonomous maintenance systems, energy-efficient AI-based PDM, trustworthy AI algorithms, and human-centric AI interfaces. In conclusion, AI-based predictive maintenance systems play an increasingly vital role in monitoring port equipment and predicting maintenance needs. These systems employ advanced machine learning algorithms to analyse performance data and detect anomalies, empowering operators to proactively manage maintenance activities and minimize downtime. Effective communication and integration, user interface and reporting, and recent advancements and future trends are pivotal aspects of these systems (Ucar, A., Karakose, M., & Kırımça, N, 2024).

3.2.5 Smart Container Management

Artificial Intelligence (AI) is increasingly utilized in port operations to optimize container positioning, taking into account factors like final destination, delivery schedules, and specific cargo requirements. This optimization reduces vessel waiting times and enhances overall port efficiency. AI-driven solutions offer precise supply chain planning strategies, fostering agility and sustainability in port operations. Throughput's AI-powered software suite empowers marine businesses to navigate unprecedented market constraints and overcome bottlenecks, thus facilitating smoother marine trade. Additionally, AI-driven demand sensing and segmentation have uncovered potential additional revenue opportunities exceeding $2 million in incremental sales alone for major port operators. AI facilitates accurate ETA forecasting, revolutionizing various aspects of port operations including administrative tasks, berth allocation, workforce management, infrastructure maintenance, and resource planning.

Automation of vessels, trucks, and certain port management systems is made possible by AI, enhancing efficiency and safety. Ports leverage digital AI technologies for system automation, safety enhancements, vessel routing optimization, reduced turnaround and container dwell times. Furthermore, AI optimizes port and shipping operations, diminishing waiting times, congestion, and environmental impact while promoting sustainability. By improving operational efficiency and effectiveness, AI ensures ports and shipping companies remain competitive in the dynamic global market (Ucar, A., Karakose, M., & Kırımça, N, 2024).

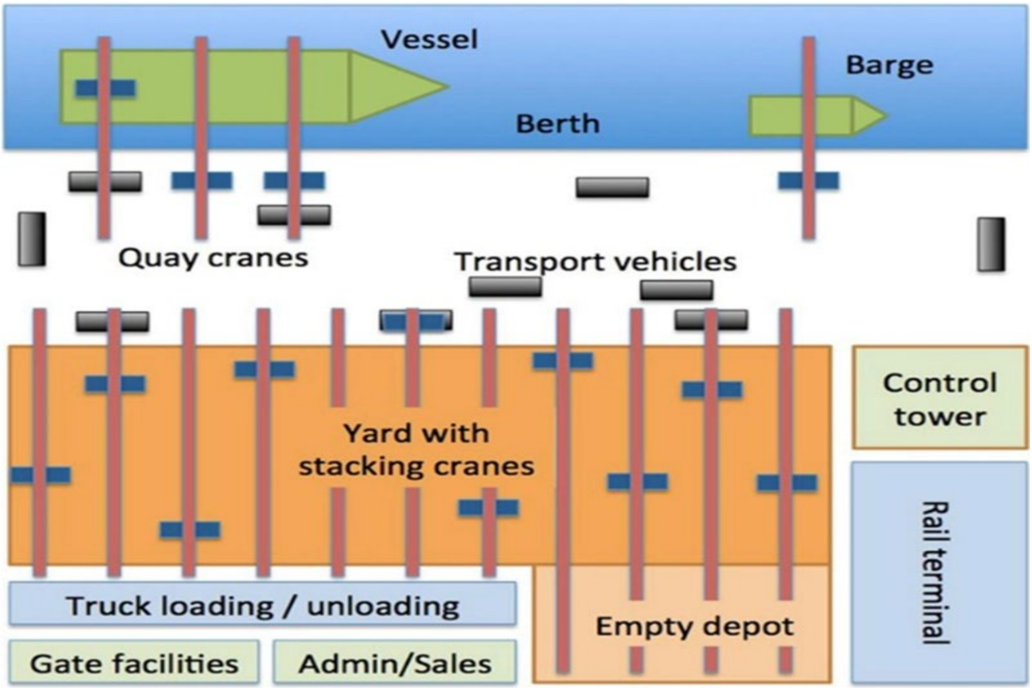

Figure 11 op-view of container terminal *(Parolas, I, 2016)*

4.Analysis of the Strengths and Weaknesses of Singapore, Rotterdam, and Dubai’s Ports

4.1 The port of Singapore

The port of Singapore, being a crucial international seaport, possesses various strengths and weaknesses that impact its operations. Let's analyse these aspects:

- **Strengths:**

- Strategic Location: the port of Singapore's strategic location at the crossroads of major shipping routes in Asia provides it with a competitive advantage in terms of connectivity and accessibility to global markets.
- Technological Advancements: Singapore's port operations leverage cutting-edge technologies such as AI-driven analytics, automated movement detection, and infringement analytics to enhance efficiency, safety, and security.
- Operational Excellence: the port's commitment to excellence in governance, safety standards, and regulatory compliance is evident through initiatives like Pilot Boarding Detection and Next-Generation Port Operations.
- Innovation and Collaboration: Singapore's focus on innovation and collaboration within the maritime ecosystem, as seen in initiatives like Big Data Integration at Tuas Port, fosters sustainable growth and resilience.

- **Weaknesses:**

- Dependency on Global Trade: the port of Singapore's reliance on global trade makes it vulnerable to fluctuations in the global economy and trade patterns, impacting its throughput and revenue.
- Security Concerns: despite advanced security measures, the port faces challenges in ensuring complete security against potential threats such as unauthorized access or safety breaches.
- Environmental Impact: the port's operations, including vessel movements and cargo handling, may have environmental implications such as emissions and waste generation, necessitating sustainable practices.
- Competition: intense competition from other major seaports in the region poses a challenge to the Port of Singapore in maintaining its position as a leading maritime hub.

By addressing these weaknesses and leveraging its strengths, the Port of Singapore can further enhance its competitiveness, sustainability, and resilience in the global maritime industry.

4.2 The Port of Rotterdam

Let's analyse the strengths and weaknesses of the port of Rotterdam:

❖ **Strengths:**

- Strategic Location: the port of Rotterdam's strategic location at the mouth of the Rhine-Meuse-Scheldt River delta provides it with access to the hinterland of Europe, making it a key hub for maritime transportation.
- Technological Innovation: Rotterdam's focus on digital transformation and initiatives like real-time analytics, IoT-enabled operational platforms, and digital twin development enhances operational efficiency and decision-making.
- Infrastructure and Facilities: the port's extensive infrastructure and modern facilities enable it to handle various types of cargo efficiently, contributing to the economic prosperity of the Netherlands and the region.
- Operational Efficiency: Rotterdam's emphasis on optimizing berthing and departure times through digital twin development and data processing techniques enhances throughput and customer satisfaction.

❖ **Weaknesses:**

- Environmental Impact: the port's operations, including ship movements and cargo handling, may have environmental implications such as emissions and pollution, necessitating sustainable practices and environmental management.
- Competition: intense competition from other major seaports in Europe and globally poses a challenge to the Port of Rotterdam in maintaining its position as one of the largest and busiest seaports.
- Security Concerns: ensuring comprehensive security against potential threats and unauthorized access remains a challenge for the port, requiring continuous investment in security measures and protocols.
- Dependency on Global Trade: Like other major ports, Rotterdam's reliance on global trade exposes it to fluctuations in the global economy and trade patterns, impacting its operational volumes and revenue.

By addressing these weaknesses and leveraging its strengths in strategic location, technological innovation, infrastructure, and operational efficiency, the Port of Rotterdam can enhance its competitiveness, sustainability, and resilience in the global maritime industry.

4.3 The Port of Dubai

Let's analyse the strengths and weaknesses of the ports in Dubai, focusing on Port Jebel Ali and Mina Rashid:

- **Strengths:**
  - Strategic Location: port Jebel Ali's strategic location near the Strait of Hormuz and its extensive container terminals facilitate trade routes connecting Asia, the Middle East, Northern Africa, and Europe, contributing significantly to Dubai's economic prosperity.
  - Technological Advancements: Dubai ports utilize intelligent surveillance systems, AI models for demand prediction, and predictive maintenance systems to enhance security, operational efficiency, and maintenance practices.
  - Diversification and Development: Mina Rashid's transition from a commercial port to a vibrant passenger and cruise terminal reflects Dubai's commitment to diversifying its maritime offerings and enhancing its global appeal as a tourist destination.
  - Collaboration and Innovation: Partnerships with technology providers for autonomous vehicles, robotics, and AI solutions demonstrate Dubai's commitment to embracing digitalization and cutting-edge technologies in port operations.
- **Weaknesses:**
  - Environmental Impact: the ports in Dubai, like other major ports, face challenges related to environmental impact from operations, including emissions, waste generation, and pollution, necessitating sustainable practices and environmental management.
  - Security Vulnerabilities: despite advanced surveillance systems, ensuring comprehensive security against evolving threats and unauthorized access remains a challenge for Dubai ports, requiring continuous investment in security infrastructure and protocols.
  - Dependency on Global Trade: Dubai ports' reliance on global trade exposes them to fluctuations in the global economy and trade patterns, impacting operational volumes and revenue.
  - Competition: Intense competition from other global ports and maritime hubs poses a challenge to Dubai ports in maintaining their position as key players in the region and enhancing their competitiveness.

By addressing these weaknesses and leveraging their strengths in strategic location, technological advancements, diversification, and collaboration, the ports in Dubai can enhance their competitiveness, sustainability, and resilience in the global maritime industry.

5. Points of Similarities

There are several points of resemblance between the ports of Singapore, Rotterdam, and Dubai based on the information provided:

- AI Applications: all three ports have implemented AI technologies in their operations to enhance efficiency, safety, and decision-making processes. They utilize AI for tasks such as predictive maintenance, demand prediction, optimization of container movements, and automation of port operations.
- Strategic Partnerships: the ports have established strategic partnerships with technology providers and experts in AI, robotics, and autonomous vehicles to drive innovation and digital transformation in port operations. These collaborations aim to leverage AI solutions for optimizing processes and improving overall performance.
- Focus on Data Analytics: Singapore, Rotterdam, and Dubai ports emphasize the importance of data analytics in harnessing the power of AI. They leverage real-time data from IoT sensors, smart technologies, and digital twins to make informed decisions, optimize operations, and enhance productivity.
- Emphasis on Operational Excellence: AI adoption in the ports reflects a shared commitment to achieving operational excellence through the integration of advanced technologies. By utilizing AI for tasks such as berth optimization, vessel routing, and workforce management, the ports aim to streamline processes and improve overall efficiency.
- Sustainability Initiatives: the ports demonstrate a common focus on sustainability by using AI to reduce environmental impact, optimize energy consumption, and promote eco-friendly practices. AI-driven solutions help in minimizing emissions, congestion, and environmental footprint while enhancing sustainability in port operations.

By aligning their strategies in AI adoption, data analytics, partnerships, operational excellence, and sustainability initiatives, the ports of Singapore, Rotterdam, and Dubai showcase a collective effort towards leveraging AI technologies to drive innovation and efficiency in maritime operations.

6. Points of Differences

Points of difference in the adoption of AI in the ports of Singapore, Rotterdam, and Dubai include:

- Focus Areas: while all three ports leverage AI for various applications such as predictive maintenance and demand prediction, they may prioritize different areas for AI implementation based on their specific operational needs and strategic objectives. For example, Singapore may focus more on automation and efficiency in container handling, Rotterdam on real-time analytics for decision-making, and Dubai on security and surveillance systems.
- Technology Providers: the ports may collaborate with different technology providers and AI solution vendors based on their expertise and offerings. This can lead to variations in the types of AI technologies, algorithms, and platforms implemented in each port, influencing the scope and impact of AI adoption in their operations.
- Scale of Implementation: the scale and extent of AI adoption can differ among the ports, with some ports investing more heavily in AI infrastructure and capabilities than others. This can result in variations in the sophistication of AI applications, the level of automation achieved, and the overall impact on operational efficiency and performance.
- Regulatory Environment: differences in regulatory frameworks and policies related to AI adoption in the maritime industry may influence the pace and extent of implementation in each port. Compliance requirements, data privacy regulations, and governance structures can shape the approach to AI deployment and integration in port operations.
- Cultural Factors: organizational culture, leadership priorities, and workforce readiness for AI adoption can vary across the ports, impacting the speed of implementation, acceptance of AI technologies, and the ability to drive change and innovation through AI initiatives. Cultural factors play a significant role in shaping the success of AI adoption in port operations.

By considering these points of difference in focus areas, technology providers, scale of implementation, regulatory environment, and cultural factors, the ports of Singapore, Rotterdam, and Dubai demonstrate unique approaches to AI adoption in their efforts to enhance efficiency, safety, and sustainability in maritime operations.

7. Container Traffic: Global Comparison

To compare the three ports of Singapore, Rotterdam, and Dubai, we can look at several factors such as their container traffic:

Table 3 Comparison of Key Statistics for Major Global Ports (Kerriou, A, 2023)

Trafic de conteneurs des principaux ports mondiaux en 2022				
Rang	Port	Pays	Trafic (EVP)	2022 / 2021 (%)
1	Shanghai	CN	47 300 000	+ 0,6 %
2	Singapour	SG	37 289 600	- 0,8 %
3	Ningbo - Zhoushan	CN	33 350 000	+ 7,3 %
4	Shenzhen	CN	30 040 000	+ 4,4 %
5	Qingdao	CN	25 670 000	+ 8,3 %
6	Guangzhou	CN	24 600 000	+ 1,7 %
7	Busan	KR	22 071 862	- 2,8 %
8	Tianjin	CN	21 020 000	+ 3,7 %
9	Hong Kong	CN	16 573 000	- 6,9 %
10	Rotterdam	EU	14 455 000	- 5,5 %
11	Jebel Ali	AE	13 970 000	+ 1,7 %
12	Anvers	EU	13 500 000	- 5,2 %
13	Port Kelang	MY	13 223 928	- 3,6 %
14	Xiamen	CN	12 430 000	+ 3,2 %
15	Tanjung Pelepas	MY	10 512 806	- 6,1 %
16	Los Angeles	US	9 911 159	- 7,2 %
17	New York / New Jersey	US	9 493 664	+ 5,7 %
18	Kaoshiung	TW	9 491 575	- 3,7 %
19	Long Beach	US	9 133 657	- 2,7 %
20	Laem Chabang	TH	8 741 079	+ 2,6 %
				©upply

With the information we discussed previously regarding the different ports, along with the table above, we can note the following points:

- Singapore is the largest port in terms of container traffic, handling over 37 million TEUs (twenty-foot equivalent units) in 2021.

- ❖ Rotterdam is the second-largest port in Europe, with a container traffic of 14.46 million TEUs in 2022.
- ❖ Dubai is the largest port in the Middle East, with a container traffic of 13.97 million TEUs in 2022.

To sum up, Singapore is the largest port in terms of container traffic, followed by Rotterdam and Dubai. These three ports are among the world's largest and most important, playing a crucial role in global trade and logistics.

8. Smart Port Index: Global Comparison

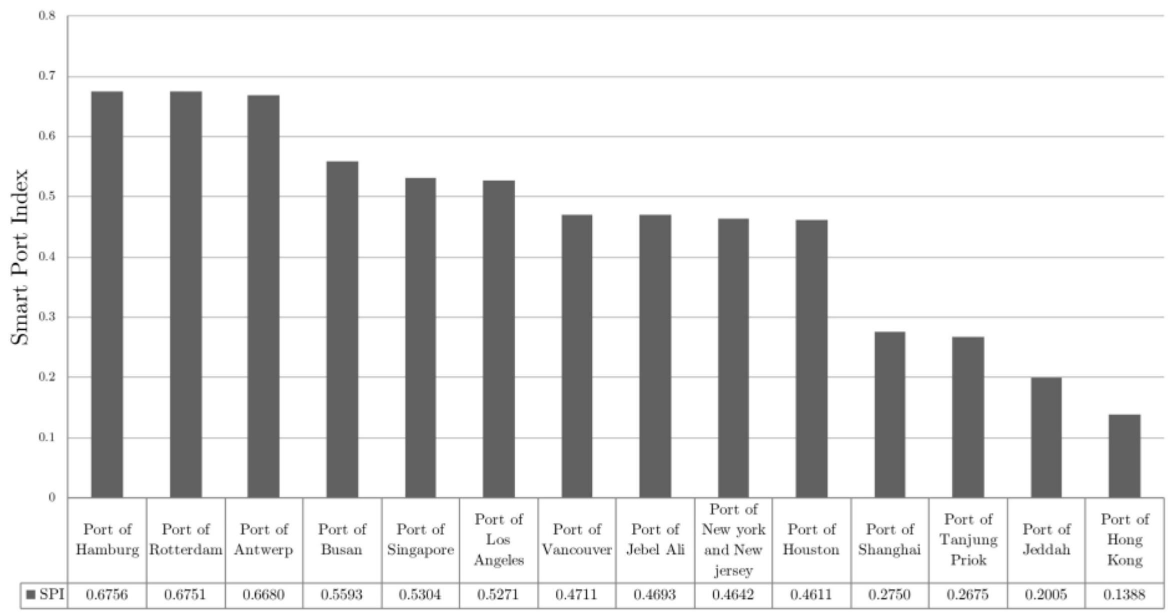

Figure 12 Comparison of Smart Port Index for 14 ports (Molavi, A., Lim, G. J., & Race, B, 2019)

Based on the Smart Port Index (SPI) values provided in the sources, the ranking of the ports in terms of smartness is as follows:

- Port of Rotterdam: SPI value of 0.6751
- Port of Singapore: SPI value of 0.5304
- Port of Jebel Ali (Dubai): SPI value of 0.4693

Therefore, based on the SPI values, the Port of Rotterdam is the smartest port among the three, followed by the Port of Singapore and then the Port of Jebel Ali (Dubai).

9. The Status of Algeria's Ports in the Use of AI Technologies

9.1 Efforts to Digitize the Algerian Port Sector

As part of efforts to modernize port infrastructure in Algeria and integrate Information and communication technologies (ICT), several initiatives have been undertaken:

The establishment of a dedicated platform for the "Algerian Port Electronic Data Interchange System" facilitates communication among private transport stakeholders, including shipping companies, freight brokers, railways, stevedores, port authorities, customs, and other participants. Officially launched on June 7, 2021, this platform ensures connectivity with the customs management information system, acting as an electronic gateway for logistics chain actors. Its management and oversight are carried out by the Port Authority, in collaboration with the public company SARPOR (الجريدة الرسمية، 2021).

Efforts have been made to set up electronic platforms aimed at facilitating export operations, particularly for agricultural and textile products, as well as improving traceability and transparency in port logistics. These electronic platforms aim to enhance port efficiency and logistics by providing information on the origin, destination, and transit logistics of goods. Additionally, two other electronic platforms have been established in the ports of Djendjen and Oran (مخلوف، 2021).

These initiatives demonstrate Algeria's efforts to modernize its port infrastructure and integrate information and communication technologies to improve efficiency and transparency in the sector.

9.2 The Digitization Applications Used in Certain Algerian Ports

- **Port of Annaba**

The Port of Annaba has implemented an electronic single window model for electronic information exchange. However, this system does not encompass all stakeholders due to a lack of coordination with other government entities and the absence of electronic signature activation in Algeria, which poses a significant obstacle. Additionally, many sectors in Algeria remain undigitized. The Annaba port complex has also launched an electronic platform accessible through a dedicated web portal for port users at [https://www.annaba-port.com] (قوارطية و عبداوي، 2021).

The container complex is managed using information systems, with staff utilizing information and communication technologies, having internet access, and each employee possessing a professional email address for communication and document and data exchange. The company uses software that uploads all information about the ship and cargo, prepares the loading or unloading costs, automatically generates the final invoice, and produces daily statistics. Additionally, two X-ray scanners are available on transport trucks for enhanced security and efficiency (قوارطية و عبداوي، 2021).

- ❖ **Port of Skikda**

The establishment uses a range of software, including the QMS (Quality Management System) program for IT and quality, the BI (Business Intelligence) FINANCE program dedicated to accounting operations used by the financial department, the HR system for human resources information, and the DEP (Digital Enterprise Platform) 185 system for invoice recording and business operations. The port also has secure internal networks used exclusively within the establishment. It includes:

The Local Network: An internal intranet specific to the establishment that allows communication and information transfer between multiple buildings within the establishment. It is distinguished by its ease of use and offers services such as communication and information transfer, as well as data search and manipulation.

The 5116210 Network: Consisting of specific accounts for each employee connected to the intranet, used for information exchange between branches of the establishment or subsidiaries. It cannot be used outside the establishment's boundaries and offers advantages in terms of security and speed.

The Extranet: An external communication network used for information exchange with other institutions (شلابي، 2019).

Additionally, the Skikda port establishment has launched an online payment service via credit or debit card, being the first port institution to offer this service through its website: [https://www.port-skikda.dz]. This initiative is part of the SARPI (Passenger and User Assistance and Reception System) service complex's guidelines. The service aims to facilitate transactions for economic partners, allow virtual access to invoices, and provide a digital dimension to administrative operations in ports. This service enables sending invoices by email to stakeholders for payment at any time without needing to travel. This service was launched on March 1, 2022. The port also has two laser scanners (2019 ،شلابي).

9.3 Obstacles of Applying Technological Techniques in The Algerian Ports

Regarding the use of information and communication technologies in transportation, these services are not widely prevalent in Algeria, being confined to a few areas. Moreover, the adoption of such systems is far from universal due to the Advanced Technology Readiness Index (ATRI) in Algeria, developed by UNCTAD (United Nations Conference on Trade and Development). This index reflects the national capacities to use, adopt, and adapt technology. A value close to **1** indicates that the country is ready to utilize and adopt advanced technologies, while a value close to **0** suggests lesser readiness. This index calculation is based on several sub-indicators:

Here is the table reorganized with the `Category Label` in rows and the years in columns:

Table 4 Algeria's Index Values by Category (2017-2021)

Category Label	2017	2018	2019	2020	2021
Global Index	0.3	0.4	0.4	0.4	0.4
ICT	0.3	0.3	0.4	0.4	0.4
Competencies	0.4	0.4	0.4	0.4	0.5
Research and Development	0.3	0.3	0.3	0.3	0.3
Industrial Activity	0.3	0.3	0.4	0.3	0.3
Access to Financing	0.4	0.5	0.6	0.6	0.6

Source: (UNCTAD) https://unctadstat.unctad.org/datacentre/dataviewer/US.FTRI

- **Representative Comment**

The table titled "Algeria's Index Values by Category (2017-2021)" presents the indices for various categories related to Algeria's technological and industrial capabilities over five years. These categories include the Global Index, ICT, Competencies, Research and Development, Industrial Activity, and Access to Financing. The data reveals fluctuations and trends in these areas, providing a snapshot of Algeria's progress in digital and economic development from 2017 to 2021.

- **Analytical Comment**

The table displays key trends associated with digitization efforts in Algerian ports. The **Global Index** remains relatively low, ranging from 0.3 to 0.4 during these years. It indicates a moderate level of overall technological readiness. The **ICT** (Information and Communication Technologies) specific index followed a similar trend, starting from 0.3 in 2017 and 2018 and improving to 0.4 from 2019 to 2021, suggesting limited but slightly improving ICT adoption. **Competencies** has witnessed a slight improvement from 0.4 in 2017 to 0.5 in 2021; it indicates a modest increase in the skills and abilities required to utilise technology.

Research and development (R&D) remain static at 0.3 from 2017 to 2021; it reflects minimal progress in innovation and technology development. Industrial activity has fluctuated between 0.3 and 0.4, with 0.3 in 2017, 2018, 2020, and 2021, and improving to 0.4 in 2019, demonstrating inconsistency in integrating technology into industrial processes. **Access to financing** has been notably higher and improving, starting from 0.4 in 2017, increasing to 0.5 in 2018, and reaching 0.6 from 2019 to 2021, suggesting better availability of funds for technology-related investments.

To sum up, the trends in the table reflect Algeria's ongoing efforts to improve its technological and industrial capabilities. These efforts are directly relevant to the digitization applications in Algerian ports, as enhanced ICT (Information and communication technologies) integrate Information and communication technologies infrastructure, stable competencies, and better access to financing create a conducive environment for implementing digital solutions in port operations. However, fluctuations in R&D and Industrial Activity indices suggest that sustained efforts and consistent investments are necessary to fully realize the benefits of port digitization.

9.4 Algeria's International Modernisation

Algeria is striving to modernize its port facilities by introducing information and communication technologies to reduce international transportation costs and better leverage the benefits of maritime transport to promote foreign trade.

Algerian ports do not fully utilise information and communication technologies (ICT) in their operations, except in a few administrative areas. The adoption of these systems remains limited, as evidenced by Algeria's Advanced Technology Readiness Index (ATRI), with values not exceeding 0.4 in most categories from 2017 to 2021. This reflects a moderate level of overall technological readiness and highlights the need for greater investment and integration of advanced technologies to enhance port operations and efficiency.

Although Algeria seeks to adopt a new port management policy to adapt to global economic developments, it lags behind in this effort. Therefore, additional efforts are needed to create an environment conducive to the adoption of technological systems and to benefit from the experience of leading countries in this field.

Conclusion

In Conclusion, our comparative study of the Port of Singapore, Port of Rotterdam, and Port of Dubai underscores the multifaceted nature of AI integration in port operations. While each port exhibits unique approaches and priorities in leveraging AI technologies, they collectively demonstrate a shared commitment to enhancing efficiency, sustainability, and competitiveness. Despite differing strategic emphases, common challenges such as data interoperability and cybersecurity highlight the need for collaborative solutions and knowledge exchange within the maritime community. As these ports navigate the complexities of AI adoption, they stand poised to unlock new opportunities for innovation and growth, shaping a more resilient and interconnected global port ecosystem for the future.

General Conclusion

General Conclusion

In the theoretical part of this study, we delved into the foundational concepts and theoretical frameworks surrounding the integration of artificial intelligence (AI) in international seaports. By exploring the motivation behind leveraging AI solutions in seaport operations, we have highlighted the significance of addressing operational inefficiencies, security risks, and the environmental impact to enhance global trade and connectivity. Through a comprehensive literature review and analysis of existing research, we have gained insights into the potential benefits and challenges associated with AI adoption in seaport management.

Transitioning to the practical part, our focus shifted towards examining real-world implementations of AI solutions in three key international seaports: Singapore, Rotterdam, and Dubai. Through case studies and comparative analyses, we have evaluated the effectiveness of AI applications in optimizing logistics, improving security measures, and promoting sustainability within these ports. By drawing parallels and identifying best practices from leading ports, we have aimed to provide strategic recommendations for enhancing seaport operations on a global scale.

Furthermore, we have explored the specific case of Algeria, examining the current landscape of AI adoption in its ports and assessing potential opportunities for improvement. By contextualizing our findings within the Algerian maritime industry, we sought to provide actionable insights and recommendations tailored to the unique challenges and opportunities present in the country's port infrastructure.

In conclusion, our study underscores the transformative potential of AI in revolutionizing international seaport operations. By bridging theoretical insights with practical case studies and addressing the specific context of Algeria, we contribute to advancing knowledge in maritime logistics and port management, ultimately aiming to foster more efficient, secure, and sustainable seaport ecosystems worldwide.

Testing the Validity of Hypotheses

General Hypothesis

The general hypothesis of "AI integration into international seaport operations will lead to significant improvements in efficiency, security, and sustainability" has been confirmed in this research. Furthermore, integrating AI into seaport operations yields significant improvements in efficiency, security, and sustainability. In Singapore, AI-driven predictive analytics has transformed cargo handling at the Port of Singapore, optimizing resource allocation and reducing turnaround times. Rotterdam has enhanced port security with AI-driven surveillance systems, detecting illicit activities more effectively. Dubai's Jebel Ali Port has minimized energy consumption and emissions using AI-enabled optimization algorithms, contributing to sustainability goals. These examples demonstrate the tangible benefits of AI integration in international seaport operations.

Secondary Hypotheses

The first secondary hypothesis is implementation of AI-based predictive analytics will optimize cargo handling processes, resulting in reduced turnaround times. Our study confirms this hypothesis. To elaborate, Singapore's Port has implemented AI-based predictive analytics to optimize cargo handling processes, resulting in reduced turnaround times. By analysing historical data and predicting future demand patterns, the port authorities have been able to optimize resource allocation and streamline operations, leading to notable reductions in turnaround times.

The second hypothesis is AI-driven surveillance systems will enhance port security by detecting and preventing illicit activities more effectively than traditional methods. The findings of the research support this hypothesis. Further, in Rotterdam, AI-driven surveillance systems have been deployed to enhance port security. Through real-time monitoring and analysis using advanced AI algorithms, port authorities have been able to detect and prevent illicit activities more effectively than traditional methods, leading to a significant improvement in port security outcomes.

AI-enabled optimization algorithms will minimize energy consumption and emissions by optimizing resource allocation and routing within seaport operations is the third hypothesis. this hypothesis has been proved in this research. To elaborate, Dubai's Jebel Ali Port has employed AI-enabled optimization algorithms to minimize energy consumption and emissions. By optimizing resource allocation and routing within the port, Jebel Ali has achieved notable reductions in energy consumption and emissions, contributing to its sustainability goals.

By leveraging the best practices and proven technologies from other countries, Algeria could enhance operational efficiency, security, and logistical management in its ports through the implementation of Artificial Intelligence is the fourth hypothesis.

This research partially proves the hypothesis by emphasizing the importance of using information and communication technologies to modernize ports in Algeria, although Artificial Intelligence is not explicitly mentioned.

Recommendations

Based on the preceding findings and in order to implement key methods to facilitate transportation, we propose the following recommendations:

Port of Singapore

- It is suggested to diversify service offerings to reduce dependency on global trade and stabilize revenue streams.
- It is proposed to implement cutting-edge security technologies to enhance protection against potential threats.
- It is recommended to adopt sustainable practices and invest in green technologies to minimize environmental impact.

Port of Rotterdam

- It is proposed to invest in renewable energy and carbon capture technologies to reduce emissions and pollution.
- It is recommended to form strategic alliances to enhance supply chain efficiency and mitigate competitive pressures.
- It is suggested to continuously upgrade security measures and conduct regular audits to ensure comprehensive protection.

Port of Dubai

- It is recommended to implement comprehensive environmental management systems to address emissions and waste generation.
- It is suggested to upgrade security infrastructure with advanced surveillance and access control technologies.
- It is proposed to diversify services and revenue streams to reduce dependency on global trade fluctuations.

Ports of Algeria

- It is recommended to progress towards port digitization through a gradual digital transition. This does not imply a complete overhaul of existing infrastructure but rather its adaptation to ongoing advancements, along with establishing communication among all stakeholders in the port community to ensure operational continuity.

- It is recommended that all companies in the supply chain should digitize their operations and provide their teams with appropriate technologies. Smart management will leverage the efficiency, productivity, speed, control, and visibility gains offered by digitization.
- It is suggested to conduct workshops for discussion on the development and modernization of ports on a large scale.
- It is recommended to enhance port connectivity to the land transport network to improve logistics chain efficiency, leveraging the country's geographical location.
- It is proposed to invest in information and communication technologies to modernize Algerian ports, considering them as essential elements of national infrastructure.

Future Research Prospects:

We propose further exploration into the following research areas:

- Towards Smarter Airports: Leveraging Artificial Intelligence for Enhanced International Travel Operations.
- Improving Cross-Border Supply Chains with AI: Case Studies from Leading Multinational Corporations
- Artificial Intelligence for Enhanced Global Trade Security: Tackling Smuggling and Fraud

"I believe AI is going to change the world more than anything in the history of humanity. More than electricity."

- Kai-Fu Lee-

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