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The Transformative Potential of Artificial Intelligence in the Maritime Transport and its Impact on Port Industry

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ABSTRACT

Purpose: *Artificial intelligence (AI) has been recognized as a critical force in the maritime industry, transforming port operations to meet the needs of the digital age. A paradigm change is taking place in the marine industry, which is a crucial component of global economic systems and international trade. Ports are leading the way in this transformation, using cutting-edge digital and AI capabilities to introduce a new age of operating strategies that provide improved efficiency, accuracy, and security.*

Approach/Design/Methodology: *Providing a historical summary of AI's evolution since the 1950s, the paper emphasizes its vital role in driving technical innovation and changing marine operations. Considerable attention is devoted to the ethical aspects of AI implementation in marine environments, promoting conscientious and ethical use. The article examines how AI improves marine operations, port, and port operation, in efficiency, accuracy, and security. It also addresses data management, financial issues, and ethical issues related to AI applications. The researchers employed a qualitative research technique to examine the transformative capacities of AI in the maritime industry and its impact on port operations with the support of SWOT Analyses. To gather primary data, a survey was conducted with industry professionals, including port officials, maritime specialists, and providers of AI technology.*

Findings: *This study contributes to a better understanding of the role that AI plays in current marine activities through the SWOT analyses outcomes. The article emphasizes the profound ability of AI to bring about significant changes in port operations through the Positive Aspects as Operational Efficiency, Safety and decision making. It discusses the potential advantages and difficulties associated with AI implementation. The article offers useful insights for industry executives and regulators, underlining the need for strategic and ethical AI integration in maritime port operations.*

Key-words:
Artificial Intelligence, Maritime industry, Port, Port operations

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INTRODUCTION

The maritime sector is an essential pillar in international trade and global economic frameworks, currently witnessing a paradigm shift (Dwarakish & Salim, 2015). Ports are at the forefront of this evolution, with state-of-the-art digital and Artificial Intelligence (AI) tools ushering in a new era of operational approaches, promising heightened efficiency, precision, and security (De La Peña Zarzuelo et al., 2020).

AI delves into developing computer mechanisms capable of executing intricate tasks, akin to human abilities, without being explicitly directed. It intertwines algorithms, programming prowess, extensive data acquisition, and advanced tech features to produce systems that evolve and engage with their surroundings, facilitating decision-making and problem resolution (Haenlein & Kaplan, 2019). Given its capacity to simulate human-like thought processes, AI's relevance in the maritime realm is soaring (Haenlein & Kaplan, 2019). AI's footprint in ports encompasses facets like digital linkage, traffic orchestration, automation, and self-regulating apparatus. Consequently, AI platforms are adept at reasoning, problem-solving, and decision-making, making waves in processes like cargo management, navigational frameworks, and upkeep procedures.

However, embedding AI into the fabric of any sector is not without its set of complications. Predicaments range from multifaceted data handling and monetary investments to reservations about AI's dependability and precision (Shaheen, 2021). Simultaneously, moral debates concerning AI's part in decisive actions, data discretion, and potential exploitation emerge (Zhuo et al., 2023). The infusion of AI and automated tools in port mechanisms also beckons a revaluation of labor dynamics, with a spotlight on altered industry skill prerequisites, influencing job prospects and educational trajectories.

To fathom AI's essence and influence in the maritime sphere, a holistic exploration of its current manifestations, advantages, obstacles, and moral repercussions is mandated. This document endeavors to present a thorough scrutiny of these facets, building on established studies and insights.

The primary intent of this exploration is to furnish pivotal knowledge for industry frontrunners, regulatory entities, and scholarly investigators, empowering them with the information to craft judicious choices and sculpt efficacious blueprints for capitalizing on AI within port functionalities.

By securing a well-rounded grasp of how AI molds the maritime domain, stakeholders can devise apt strategies for AI assimilation, confront associated hurdles, and stimulate enlightened policy dialogues. Subsequent sections embark on a literature evaluation, methodological approach, detailed analysis, and actionable suggestions to highlight AI's transformative capacity in modern maritime functions.

LITERATURE REVIEW

The researchers focus on how digitalization and AI are reshaping the maritime industry. The review unfolds in a structured manner, covering key themes from the overall impact of digital advances in maritime transport to the specific roles of Smart Ports and AI in port operations. The researchers tackled challenges and opportunities these technologies bring, including financial and cultural implications. Weaving within different research studies, aiming to fill gaps in current knowledge and highlighting the study with unique contribution to understanding the evolving maritime landscape, with comprehensive view of where the industry stands and where it is heading with these technological advancements.

The concept of AI was introduced in the 1950s (McCarthy et al., 2006). AI is the ability of a machine to mimic intelligent human behavior and perform tasks that require human intelligence. Over the years, AI has experienced periods of excitement and large investments, followed by periods of disappointment and low investments, known as the "AI winter"; however, recent advances in computing power, declining costs of data storage, cloud computing, and the availability of big data have contributed to the resurgence of AI; AI has been used in various areas, including computer vision, natural language processing, and machine learning, and has the potential to have a significant impact on society (Toosi et al., 2020; Marquis et al., 2021; Zhang, 2023).

The maritime domain has experienced significant shifts due to digitalization, profoundly altering maritime transport and industry practices. Enhanced information exchange among stakeholders, refined vessel functioning, and more efficient maintenance

protocols have been realized thanks to digital advances. Moreover, the advent of digitalization has provided a boost to cargo tracking and traceability and has streamlined decision-making processes (Babica et al., 2020, De La Peña Zarzuelo et al., 2020; Bentyn, 2023). These enhancements have led to heightened operational efficiency, notable cost reductions, and enhanced safety standards.

For sustained growth and ensuring stable port services, it is imperative that Smart Ports seamlessly embed Internet of Things (IoT) functionalities; while automation trends in maritime settings are on the rise, the sector has not progressed at the pace of its counterparts like aerospace or automotive. Emphasis is now placed on AI, machine learning, and both horizontally and vertically harmonized solutions within advanced ports (De La Peña Zarzuelo et al., 2020; Kougias et al., 2021; Hirata et al., 2022; Noto et al., 2023; Ayoub et al., 2023). Additionally, digital evolution has paved the way for innovations in the maritime sphere, including the exploration of unmanned vessels and the adoption of blockchain techniques for heightened security and clarity. Thanks to digital platforms, real-time route optimization, refined ship functions, and better data acquisition and interpretation have become possible (Babica et al., 2020, De La Peña Zarzuelo et al., 2020; Kougias et al., 2021). Moreover, the digital era has unveiled collaborative opportunities and novel monetization prospects for maritime stakeholders (Babica et al., 2020).

Port functions in the maritime realm have been deeply influenced by digital transformation, introducing benefits like enhanced effectiveness, adaptability, and economic viability (Fruth & Teuteberg, 2017; Haenlein & Kaplan, 2019; Ayoub et al., 2023). By digitizing port operations, processes can be more streamlined, allowing for proficient data handling, superior port operation oversight, and smoother stakeholder communication, culminating in more swift and efficient vessel servicing (Fruth & Teuteberg, 2017; Y. Li et al., 2023; Shaykhulova et al., 2023). Additionally, the digital overhaul has potential in curbing both time and financial constraints by minimizing extensive paperwork and physical labor (Fruth & Teuteberg, 2017; Solmaz, 2021, Tardo et al., 2022; Shaykhulova et al., 2023).

According to studies by Munim et al. (2021), Babica et al. (2019), and Fruth and Teuteberg (2017), while digitalization has assumed paramount importance in port operations, it brings forth challenges. These encompass the demand for secure and efficient data protocols, the absence of consistent regulations, and the imperative for system interoperability.

To navigate these obstacles, ports would be wise to adopt diverse, innovative strategies. Firstly, developing new technologies that are tailored to their specific needs (Nguyen et al., 2023); Secondly, create uniform regulations and standards across the industry, for interoperability and efficiency (Rahman et al., 2023); Thirdly, consider investing in open-source technologies, which are more cost-effective (Clemente et al., 2023); Finally, ports should also strive to create partnerships with other organizations and industry stakeholders for collaboration and knowledge sharing. By using these strategies, ports can ensure that digitalization of maritime port operations is successful and helps to improve overall operational efficiency (Munim et al., 2021).

The evolution of maritime port infrastructures has carved an engaging trajectory that deeply influenced AI's progression. Contemporary research endeavors, as underscored by the works of scholars like Chen et al. (2023), Hirata et al. (2022) and Munim et al. (2020), point out that port advancements have catalyzed the inception of AI through avenues like automation, sophisticated robotics, and intelligent infrastructures. To be precise, the infusion of robotics and automated solutions has ameliorated core port tasks such as efficient cargo maneuvering, stockpile administration, and vessel traffic supervision. This pivotal integration of AI within port systems has bolstered their operational prowess, driving them towards heightened efficiency and economical functionality. Moreover, leveraging AI has granted ports the capability to garner precise and trustable intel about their operations, paving the way for strategy optimization. Undoubtedly, the narrative of maritime port evolution resonates deeply with AI's meteoric ascent, fostering an environment where ports thrive on efficiency and cost-effectiveness.

Transitioning to a digital framework within maritime transport is not devoid of hurdles. Priadi (2022) underscores that this digital metamorphosis in maritime logistics necessitates a substantial financial commitment. Initial outlays for requisite hardware, software, allied services, and personnel training could be daunting for certain enterprises. Further complicating this transition is the imperative demand for robust data protection and safeguarding proprietary business intelligence, hindering many from wholeheartedly embracing digitalization. Additionally, the lack of seamless interaction among diverse platforms and systems might stifle digital integration. Coupled with the substantial upkeep costs of these digital systems, especially under constrained fiscal allocations, it is apparent that digitalizing maritime avenues demands both immense commitment and capital infusion, as articulated by Priadi (2022).

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In their exploration, Zerbino et al. (2019) delve into the cultural intricacies linked with knowledge handling in ports enhanced by Port Community Systems (PCS). They posit that superimposing PCS onto ports ushers in a distinct array of cultural nuances demanding attention for successful fruition. Introduction of avant-garde tech can inadvertently convolute pre-existing operational dynamics, potentially culminating in coordination lapses and communication disparities amongst the workforces.

Highlighting a case study centered on the Mediterranean port, Zerbino et al. (2019) illustrated how refined analytics can empower professionals to distill pivotal insights, eventually shaping strategies to condense docking durations and uplift port competence. Such implementations bear paramount importance, especially for Mediterranean harbors grappling with escalating vessel counts and their expanding dimensions. This analytical prowess furnishes a paradigm for peers to replicate, affirming the premise that maritime logistics can witness leaps in efficiency through analytical applications.

The maritime arena is witnessing transformative strides due to Big Data and AI, as elaborated by Kougias et al. (2021). Their in-depth examination elucidates the role of these technologies in amplifying maritime efficiency, safety, and profitability metrics. For instance, harnessing Big Data and AI facilitates a deep dive into sensor data from ship hulls, preemptively identifying and neutralizing potential glitches. Furthermore, AI serves as a beacon, enhancing navigation, optimizing operations, and bolstering safety through instantaneous environmental analytics and risk forecasts.

The bibliometric scrutiny of Big Data and AI within maritime domains elucidates their multifaceted applications and the burgeoning academic fascination. This exploration accentuates the exigency to concentrate investigative and developmental zeal on leveraging these groundbreaking tech avenues, propelling the maritime industry to harness their expansive potential optimally. Additionally, as the industry continues to evolve, future research should also focus on the potential impacts of these technologies on safety, efficiency, and compliance related aspects in the maritime industry (Munim et al., 2020).

The literature presents a contrast between the promising benefits of digitalization and AI in maritime operations and the significant challenges they bring. It balances the perspectives of technological advancement and efficiency with the complexities of financial and cultural integration. The review identifies a gap in research related to the long-term cultural and financial impacts of AI and digitalization in maritime operations. It also highlights the need for more focused studies on the implications of AI for safety, efficiency, and compliance in the maritime sector.

This paper contributes to literature by offering a holistic view of the advancements and challenges in the implementation of AI and digital technologies in maritime ports. It extends the understanding of AI's role in this sector, emphasizing the need for strategic and ethical considerations in its deployment. This review not only synthesizes existing research but also identifies areas for future exploration and underscores the importance of a balanced approach to technological integration in maritime operations.

METHODOLOGY

In this research, the researchers employed a qualitative approach, using a structured survey to explore the transformative potential of AI in the maritime industry and its impact on port operations. This survey, conducted over a period of three months, targeted a range of industry professionals, including port authorities, maritime experts, and AI technology providers. The aim was to engage with these experts to gain in-depth insights into the current use of AI, the challenges encountered, and potential future implications, leading to a comprehensive SWOT analysis.

Participants of the survey were carefully selected using a purposive sampling method1, ensuring a diverse representation of stakeholders within the industry. This included a balanced mix of professionals from various sectors and levels of expertise, aiming for a sample size of approximately 100 respondents to provide a broad perspective.

Secondary data were also gathered from academic journals, industry reports, and relevant publications to supplement the survey responses. This data served as a foundation for understanding existing knowledge and research on AI in the maritime sector. For analyzing the qualitative data from the survey, thematic analysis was employed, systematically organizing and categorizing responses to identify key themes and patterns. Descriptive statistics were used to quantitatively analyze the survey data, presenting an overview of

1 Purposive sampling encompasses a collection of non-probability sampling methods wherein units are deliberately chosen based on their possession of specific characteristics deemed necessary for inclusion in the sample. Purposive sampling involves the deliberate selection of units for specific reasons.

the participants' perspectives.

Throughout this study, researchers maintained strict adherence to ethical standards, ensuring informed consent from participants and confidentiality of their responses. Researchers recognize potential limitations such as participant availability and subjective interpretation of qualitative data. Despite these, researchers are committed to rigorously conducting this study, aiming to significantly contribute to the knowledge base on AI in the maritime industry.

The SWOT framework is a universally accepted and effective instrument in strategic delineation. It offers a blueprint for evaluating both internal and external dynamics that might notably determine the success of a venture, enterprise, or plan. Undertaking a SWOT analysis tailored to AI's role in maritime port functions allows the researchers to accomplish the following:

- Identify Strengths: By exploring the advantages and benefits that AI brings to the maritime industry, which can gain a deeper understanding of why it is crucial for future development (Ceyhun, 2019).
- Recognize Weaknesses: By highlighting the limitations or challenges associated with implementing AI technology in the maritime setting that can take a realistic view of areas that require attention and improvement (Mouzakitis et al., 2022).
- Uncover Opportunities: By discovering potential areas where AI can further contribute to the maritime industry, such as emerging trends or unmet needs, that can capitalize on untapped potential (Ceyhun, 2019; Munim et al., 2020).
- Acknowledge Threats: By examining external challenges or risks that may hinder the successful implementation of AI in maritime operations, which can proactively address and mitigate potential obstacles (Munim et al., 2020).

This extensive SWOT analysis helps make smart decisions and create effective strategies. It helps the researchers enhance strengths, address weaknesses, seize opportunities, and anticipate AI integration into the marine fabric. The SWOT framework is a useful tool for this investigation (Stan & Nedelcu, 2015).

Through these aspects, the SWOT framework provides a clear and comprehensive view of the terrain, encouraging wise decision-making and rigorous blueprinting. It forms a strategic compass to highlight the positives, address the gaps, capitalize on the opportunities, and avoid the risks of integrating AI into maritime and port domains (Stan & Nedelcu, 2015).

ANALYSIS AND RESULTS

According to the methodology followed in this research; SWOT analysis is an appropriate and valuable methodology for this study. Figure 1 presents the main outcomes of the SWOT analyses. Accordingly, researchers delved into a detailed SWOT analysis to explore the strengths, weaknesses, opportunities, and threats associated with AI's role in modern seaport operations.

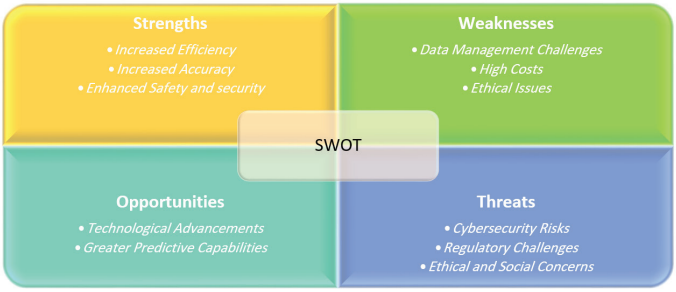

Fig. 1. Main outcomes of the SWOT analysis
Source: Authors

Strengths

1. *Increased Efficiency*: AI provides sophisticated algorithms and machine learning models that can process large amounts of data quickly and accurately, greatly enhancing the efficiency of maritime port operations. Automation, powered by AI, reduces the time needed for tasks such as cargo handling and offers greater precision, minimizing errors.

2. *Increased Accuracy*: AI's predictive capabilities help in forecasting and mitigating potential operational disruptions. Machine learning algorithms learn from data over time, and the more data they process, the more accurate their predictions and decisions become, minimizing the margin for human error.

3. *Enhanced Safety and security:* Real-time analytics offered by AI technologies can detect and predict potential risks in the port and in the maritime environment. By identifying faults or malfunctions early, maritime ports can take necessary precautions to avoid incidence and accidents, thus enhancing safety and security measures.

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Weaknesses

1. *Data Management Challenges*: AI systems are dependent on large amounts of data. Managing and ensuring the quality of this data can be challenging. Incorrect or incomplete data can negatively affect the AI system's performance and decision-making capabilities.

2. *High Costs*: Implementing AI technologies requires significant investment in hardware, software, and personnel training. The ongoing maintenance of these systems can also lead to high costs, which may be challenging for smaller ports or those with limited budgets.

3. *Ethical Issues*: As AI systems make more decisions, the ethical implications become more complex. Issues related to privacy, accountability, transparency, and consent can pose serious challenges if not properly addressed.

Opportunities

1. *Technological Progress:* The swift progression in AI tech presents maritime ports with avenues for continuous enhancement in their functionalities and offerings. Breakthroughs in AI, combined with areas like IoT and robotics, stand to redefine the maritime realm.

2. *Enhanced Forecasting Abilities:* The capability of AI to sift through colossal data volumes can unveil essential foresights, facilitating maritime ports to shift from being merely responsive to predictively strategic.

Threats

1. *Digital Security Concerns*: A heightened dependency on digital modalities may heighten vulnerabilities for maritime ports against cyber intrusions. Such jeopardies can imperil the privacy, veracity, and accessibility of systems and information, inducing considerable operational hiccups.

2. *Regulatory Challenges:* The rapid advancement of AI technology can often outpace regulatory frameworks. Compliance with diverse and evolving regulations can pose a significant challenge for maritime ports.

3. *Ethical and Social Concerns:* The wider use of AI in port operations can potentially displace jobs, leading to social implications. Careful management is needed to balance the benefits of automation with the potential social impacts.

In brief, the adoption of AI offers numerous benefits to maritime ports, it is crucial to address the associated weaknesses and threats. A balanced and careful approach, considering all these factors, will be essential to ensure sustainable and ethical application of AI in the maritime industry.

As shown on the chart in Figure 2, the survey data were gathered from 32 stakeholders, each bringing a unique perspective on the implementation and impacts of AI in port operations. The distribution of participants by job role was as follows: Port Managers and Directors, who are pivotal in making strategic decisions regarding AI integration, constituted 19% of the respondents.

AI Technology Providers, essential for insights into the practicalities and technological aspects of AI, represented 16%. Maritime Experts and Consultants, offering a comprehensive view of AI's influence on industry practices, accounted for 22%. Operations Supervisors made up 18%, providing valuable feedback on the day-to-day operational shifts attributed to AI. Logistics and Supply Chain Managers, who shed light on the efficiency and transparency gains in logistics due to AI, formed 10% of the sample. Maintenance or Engineering Managers, critical for discussing the implementation specifics and infrastructure challenges, comprised 9%. The remaining 6% included various professionals such as Environmental Officers, Safety Inspectors, and Financial Analysts, enriching the research with diverse perspectives on the ecological, safety, and economic dimensions of AI in maritime logistics. This calculated assortment of roles ensures a balanced overview of the expectations and real-world implications of AI in the domain of port operations.

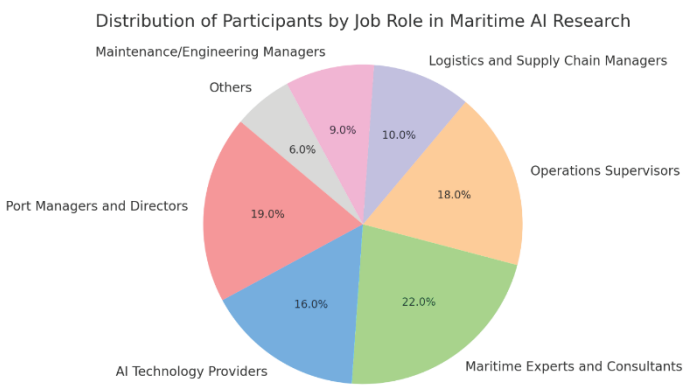

Fig. 2. Distribution of participants by job in maritime AI research
Source: Authors

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As shown in Figure 3 and in terms of the benefits of AI in port operations, 25% of the participants recognize increased automation of tasks as a significant advantage. This reveals that 25% of the respondents see the promise of AI in enhancing and refining a variety of processes within the port. Moreover, 37.5% of the respondents identify the enhancement in supply chain clarity as a notable benefit of incorporating AI. This points to the fact that almost 38% of the respondents grasp the significance of employing AI to boost clarity and accountability in the maritime supply chain's product flow.

Also, 18.75% of the respondents view AI's capability to refine ship scheduling and pathing favorably. This suggests that about one in five respondents appreciate AI's potential in streamlining maritime logistics, leading to a spike in overall operational prowess. Approximately 12.5% of the respondents consider the live tracking of port activities as a primary advantage of AI. This points out that around 12% of the respondents understand the importance of AI in offering instantaneous data and facilitating decisions based on this data, ensuring seamless port operations. In conclusion, 6.25% of the respondents see AI's potential in streamlining cargo processing and stock management. This indicates that a minority of the participants, approximately 6%, are aware of AI's ability to optimize these critical aspects of port operations, leading to improved productivity and cost-effectiveness.

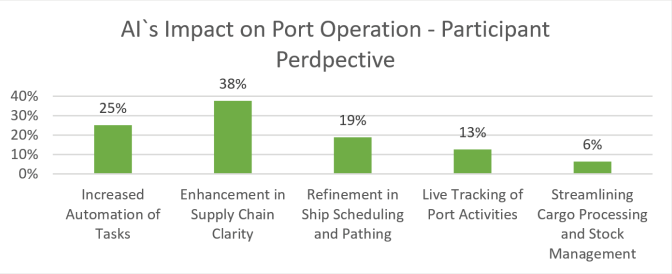

Fig. 3. AI's impact on port operations - participant perspectives
Source: Authors

DISCUSSION AND FINDINGS

Discussion

The continuous digital evolution has driven unprecedented transformations across industries worldwide, and the maritime sector is no exception (Fruth & Teuteberg, 2017). Among the various technologies being introduced, AI holds a particular promise in revolutionizing maritime port operations (Munim et al., 2020).

AI, being a potent technological advancement, has found applications in a broad spectrum of port operations, encompassing areas as vessel arrival schedule and better cargo handling (Lechtenberg et al., 2019), vessel traffic management, and port logistics (Shaheen, 2021). The deployment of AI in these areas has demonstrably enhanced operational efficiency and accuracy (Babica et al., 2020). Additionally, AI's predictive capabilities offer remarkable potential for predictive maintenance, possibly leading to a considerable extension in machinery lifecycle and a subsequent reduction in the operational costs (Zerbino et al., 2019).

However, the incorporation of AI in the maritime industry is not devoid of challenges. For instance, the digitalization of maritime transport operations comes with significant data privacy and security concerns (Kougias et al., 2021). The cost of implementing AI systems is another critical concern, especially for smaller ports with limited resources (Priadi, 2022). Furthermore, there is a significant workforce displacement fear associated with the automation of tasks through AI (Zhuo et al., 2023).

Addressing these challenges requires a balanced approach that factors in the potential benefits while also considering the adverse implications of AI deployment. The industry's need for digital skills calls for substantial investment in training and educational programs to bridge the skill gap. This backdrop sets the stage for a comprehensive understanding of AI's current capabilities, future implications, and how it is shaping the maritime industry.

For validation in the sense of a SWOT analysis, the results of the work were verified and found to be consistent with the literature. Table 1 shows the agreement with the literature.

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Table 1: Compatibility between SWOT Analysis and Sources of Literature

SWOT	Factor	Source	Author
Strengths	Increased Efficiency	Journal of Industrial Information Integration	De La Peña Zarzuelo et al., 2020
		Business Process Management Journal	Wamba-Taguimdje et al., 2020
		Port of Rotterdam Official Website	Port of Rotterdam, 2022
		Port of Los Angeles Official Website	Port Optimizer, 2022
	Increased Accuracy	Journal of Mega Infrastructure & Sustainable Development	Lehmacher et al., 2022
		Science-Open Preprints	Shaheen, 2021
		PTI Blog: Port Machine Learning, AI and IoT. Port Technology International.	Port Technology, 2017
	Enhanced Safety and Security	IntechOpen eBooks	Hirata et al., 2022
		EKOLOJI, 28(107)	Chang, 2019
Weaknesses	Data Management Challenges	Journal of Marine Science and Engineering	Munim et al., 2021
		Maritime Policy & Management	Munim et al., 2020
	High Costs	IOP Conference Series	Priadi, 2022
		Sustainable Cities and Society	Moustafa, 2021
	Ethical Issues	arXiv (Cornell University)	Zhuo et al., 2023
		Science-Open Preprints	Shaheen, 2021
Opportunities	Technological Advancements	Journal of Industrial Information Integration	De La Peña Zarzuelo et al., 2020
		Business Process Management Journal	Wamba-Taguimdje et al., 2020
		Port of Rotterdam Official Website	Port of Rotterdam, 2022
		Port of Los Angeles Official Website	Port Optimizer, 2022
	Greater Predictive Capabilities	International Journal of Mechanical Engineering	Rao & Jayasree, 2022
		Journal of Industrial Information Integration	De La Peña Zarzuelo et al., 2020
		Business Process Management Journal	Wamba-Taguimdje et al., 2020
Threats	Cybersecurity Risks	Transportation Research Part E-logistics and Transportation Review	Li et al., 2023
		Logistics	Song, 2021
	Regulatory Challenges	Science-Open Preprints	Shaheen, 2021
		Journal of Marine Science and Engineering	Munim et al., 2021
		Maritime Policy & Management	Munim et al., 2020

Source: Authors

For leveraging AI effectively in port operations, the outcome percentages indicate that a certain proportion of participants suggest investing in AI training and education for the workforce. This emphasizes the importance of upskilling and preparing employees for the integration of AI technologies in their work processes. Collaboration with AI technology providers to develop tailored solutions is also recognized by a specific percentage of participants, indicating the significance of engaging external expertise in optimizing AI applications within the maritime industry. Furthermore, the establishment of industry-wide standards and regulations for AI implementation is recommended by a certain percentage of participants, reflecting the need for a unified and ethical framework to guide AI adoption. The outcome also suggests that a certain proportion of participants prioritize data privacy and security measures, recognizing the

potential risks associated with handling sensitive data in AI-enabled port operations. Finally, fostering a culture of innovation and openness to AI adoption is recommended by a certain percentage of participants, underscoring the importance of embracing a forward-thinking mindset to fully harness the benefits of AI in port operations.

It is important to note that these findings are based on the percentages of the outcomes derived from the responses of the limited sample size of 32 participants. While these insights provide valuable initial indications, a larger and more diverse sample size would be needed to generalize the findings to a broader population.

Findings

As shown in Table 2, the implementation and future direction of AI in the maritime industry is viewed in terms of both positive and negative aspects, based on the results of the SWOT analysis, questionnaire, and previous research.

Table 2: Findings- Positive and Negative Aspects

Positive Aspects	Negative Aspects	Impacts
Operational Efficiency: AI improves efficiency by automating tasks and optimizing workflows (Zerbino et al., 2019).	**Workforce Displacement:** AI automation may reduce the need for certain port jobs (Zhuo et al., 2023).	Enhanced port operations yet potential job losses.
Safety: Reduction in human intervention in hazardous operations increases safety (Kougias et al., 2021).	**Data Privacy and Security:** Concerns over data misuse and security breaches (Kougias et al., 2021).	Safer working conditions yet risks of data breaches.
Predictive Maintenance: AI enables predictive maintenance, preventing costly downtimes (Priadi, 2022).	**High Initial Investment:** Significant initial costs can be a barrier, especially for smaller ports (Priadi, 2022).	Reduced downtime yet high setup costs.
Decision Making: AI assists in making timely and accurate decisions by analyzing large data volumes (Munim et al., 2020).	**Skill Gap:** The digital skill gap in the maritime industry necessitates training (Zerbino et al., 2019).	Improved decision-making yet a need for workforce upskilling.

Source: Authors

The positive aspects of AI are already applied by several port operators round the world under the smart port system. Table 3 provides a present example of five port operator applying smart port concept arranged according to number of terminals.

Table 3: Present Example of Five Port Operator Applying Smart Port Concept which Depends on Several AI Software

No	Port operator	Terminals and countries	Region
1	DP World	83 terminals across 22 nations	Asia, Europe, Africa, the Middle East, and the Americas and Australia
2	Terminal Investment Limited (TIL)	70 terminals in 31 countries	Europe, Africa, Asia, Americas
3	APM Terminals	65 Terminal in 58 countries	Europe, Africa, Middle East, Asia, Americas
4	Singapore's PSA International	60 terminals across 42 countries	Asia, the Middle East, and Europe
5	Hutchison Port Holdings (HPH)	54 terminals in 25 countries	Asia, Europe, Africa, the Middle East, and the Americas and Australia

Source: Authors; Data collected from the official websites of the operators

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CONCLUSION

Even though AI will increase the operation efficiency and safet, help reduce the equipment maintenance cost and better decision-making, and improve cargo handling and logistics, the management of AI applications requires an ethical framework to ensure that technology advancement does not compromise ethical boundaries or lead to unfair practices. The maritime industry should adapt strategies and legislation to overcome the challenges which likely to face, due to the potential transition of AI, such as the workforce that could be displaced due to automation, providing appropriate training and provide opportunities to the existing workforce to prepare them for a more technologically driven work environment.

Moreover, the industry needs to adopt a practical and balanced approach to steer these challenges, focusing on the entire policy that could incorporate risk justification, ethical considerations, and cost management. Stakeholder collaboration, policy development, and regulatory adjustments will play an integral role in this journey, ensuring the responsible and ethical application of AI. In addition to arranging for data privacy and security measures, recognizing the potential risks associated with handling sensitive data in AI-enabled port operations. Finally, a culture of innovation and openness upgrade to AI adoption is recommended, emphasizing the importance of accepting a forward-thinking mindset to fully harness the benefits of AI in port operations.

RECOMMENDATION

1. Digital Infrastructure Allocation: Very essential for the successful integration of AI into port operations and should include the development of data centers, advanced internet solutions, and state-of-the-art data processing tools.

2. Digitally Competent Workforce: Offer training to upskilling the present workforce and onboarding new members who have expertise in AI and data analytics.

3. Data Handling and Protection: Protocols should be in place. Alongside, strong cybersecurity measures should be adopted to ensure the protection of essential and sensitive data.

4. Unified Collaboration: Consistent communication and collaboration across various stakeholders, including port administrators, terminal operators, logistic bodies, and regulatory bodies.

5. Ethical Framework: Due to the rise of AI applications in ports, ethical considerations should be vital. This includes challenges related to job alterations, data integrity, and privacy. By establishing clear guidelines, which can ensure that AI is used sensibly and ethically.

6. Innovation and Advancement: There is a need for more progress and exploration in the field of AI. To enhance the operation efficiency, safety, and cost-effectiveness in port operations.

7. Legislative Evolution: It is seriously necessary to adopt rules and legislations to encourage innovation while ensuring adherence to safety standards and global best practices.

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