REVIEW OF DISRUPTIVE DIGITAL SOLUTIONS IN THE FUNCTION OF MARITIME TRANSPORT AND SAFETY MATTERS

DOI
https://doi.org/10.18690/um.fov.4.2026.15

ISBN
978-961-299-152-4

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The development and improvement of a vast range of disruptive information technologies (IT), including revolutionary Artificial Intelligence (AI) applications, requires the continuous collection of data from ship navigation and transport, transforming it into meaningful information for end-users. Contemporary AI-driven applications in the maritime industry are significantly advanced for processing data directly at the source, ensuring resilience, minimizing latency and errors, and reducing overall costs. This paper aims to present and investigate the features of the latest disruptive IT and AI use case technologies with their real impact on maritime trade, transport, surveillance, and safety based on data sharing and exchange platforms. The innovative solutions review wrapped most recent AI tools and features, concluding with the analysis of the practical improvements in the maritime industry and operating systems. By embracing AI, the maritime industry makes remarkable success with regards to competitive edge, better user and customers' experiences, with an aim to achieve a higher operational efficiency.

Keywords:
maritime transport,
AI,
big data,
ADRIREP,
data sharing

University of Maribor Press

1 Introduction

Maritime transport undergoes revolutionary technological changes that involve a shift in various competencies, redefining how ships, ports, and logistics systems operate in the digital era (Kumar, 2025). Transportation, movement, and surveillance are transforming from purely technological considerations into digital services, thanks to Big Data, AI, and Internet of Things (IoT) sensor technologies serving to increase efficiency, accuracy, and reduce costs and errors (Schulz *et al.*, 2021). The digital transformation and optimization of core processes in shipping and logistics require the adoption of a wide range of modern technologies such as IoT, automation, cloud computing, and AI-supported intelligent decision-making (Raza *et al.*, 2023). Other disruptive technologies in the maritime navigation sector are digital twins, autonomous maritime vehicles, and metaverse integration, whose main purpose is to support maritime operational centres, in compliance with standards for data management and cybersecurity (Abu Hantesh, 2024; Tejwani, 2024).

The paper unfolds as follows: After methodology Chapter 2, the recent development in a ship mandatory reporting system, mostly used for dangerous cargoes in the Adriatic region (ADRIREP – ADRIatic traffic monitoring REPorting), and enhanced technological advancements in maritime and logistic physical internet, are summarized in Chapter 3, reviewing two outstanding projects, the EUREKA and the ePIcenter. Chapter 4 provides a study of advanced digital platforms for managing the cargo flows in maritime transport and logistics, and the most important recently developed AI solutions in the maritime industry, focusing on the maritime safety, surveillance, and security issues, while Chapter 5 gives discussion and analysis of the application of AI-supported modules in maritime safety and transport efficiency.

2 Methodology

The methodological approach of this paper is a qualitative structured research design, providing a comprehensive overview of contemporary maritime transport, safety, and logistics IT solutions involved in recent digital transformation within the maritime industry. This research has reviewed the most recent developments in the maritime sector, focusing on the analysis of technical features, including presentation of two innovative projects in maritime and transport digitalization. Several cases of implementation of AI in maritime transport systems were analyzed by criteria of data collection, sharing, and cost-effectiveness in operational and safety functions.

3 Presentation of recent Maritime Digitalisation Projects technologies

3.1 Achievements of the Project EUREKA regarding ADRIREP system

The EUREKA project represents a coordinated regional initiative (between Italy, Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, Albania, and Greece) focused on improving maritime safety, surveillance efficiency, and institutional cooperation among Adriatic-Ionian countries. Conducted within the INTERREG ADRION framework, the project addressed long-standing challenges in maritime monitoring systems, data exchange, and regulatory alignment by introducing integrated technical and organizational solutions. Its central objective is to increase navigational safety through systematic coordination among national maritime administrations, harmonized legal frameworks, standardized Vessel Traffic Service (VTS) structures, improved data exchange, and the development of unified training standards for operators (Šorović *et al.*, 2023).

A key achievement of the project is the modernization of the ADRIREP ship reporting system, originally adopted in 2003 under International Maritime Organization (IMO) regulations (Figure 1), as an obligatory reporting mechanism for vessels carrying dangerous cargo onboard or meeting specific tonnage thresholds. The EUREKA introduced an updated technical design to automate reporting processes, reduce administrative workload and enhance surveillance accuracy through digitalization and integration. These improvements allow ship data to be submitted, processed, and shared electronically, significantly reducing redundant reporting and manual communication (Šorović *et al.*, 2023).

Also, this project introduced a centralized reporting architecture based on an Integrated Report Distribution (IRD) platform, which serves as a shared repository for maritime data. Through this infrastructure, ship reports can be exchanged automatically or manually among competent coastal authorities, enabling faster information flow with improved situational awareness. The system supports interoperability with existing national and EU maritime databases and ensures that previously submitted information can be reused rather than repeatedly transmitted.

Such integration is particularly important for Vessel Traffic Monitoring and Information Systems (VTMIS), whose effectiveness depends on accurate, timely, and shared navigation data among multiple stakeholders (Komadina, 2013; Kuma, 2015). Thus, beyond technical modernization, the EUREKA project produced significant institutional outcomes. One of its main contributions is the establishment of a Maritime Safety Permanent Transnational Network, intended to maintain long-term cooperation among participating countries and ensure continuity of safety improvements after project completion. In addition, this project supports the harmonization of VTS organizational structures and develops standardized training programs and competence requirements for operators, promoting consistent professional qualifications across the region. These measures strengthen interoperability, facilitate joint operations, and support coordinated responses to maritime incidents.

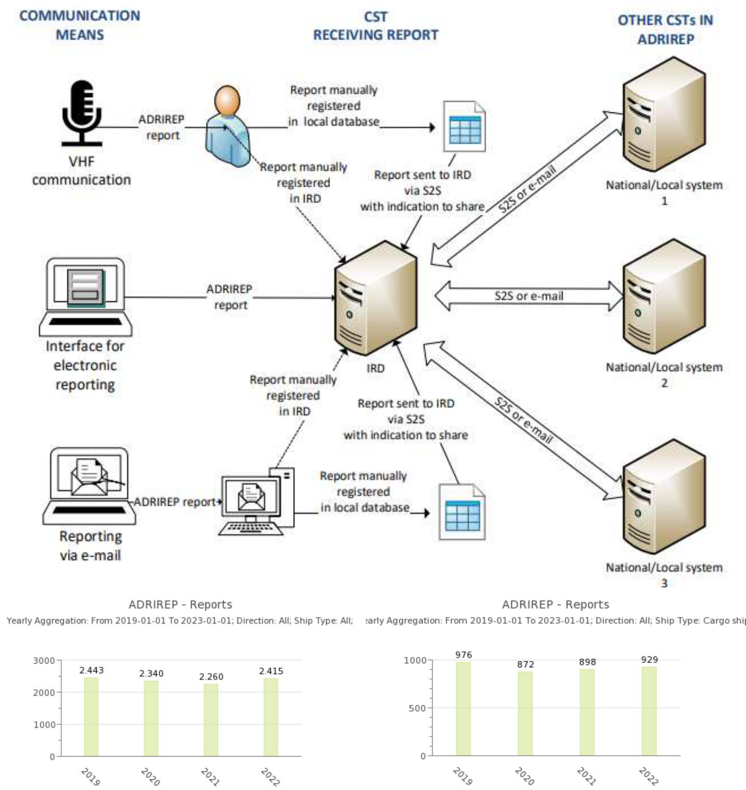

Figure 1: The ADRIREP system context diagram with output ship statistics in Port of Bar
Source: EMSA, 2022; Šorović *et al.*, 2023

Another important innovation is the planned testing and evaluation of Sea Traffic Management (STM) integration within national monitoring systems. This concept aims to optimize logistics, communication, and traffic management processes in ports and surveillance areas, contributing to more efficient vessel movement and safe navigation conditions (Šorović *et al.*, 2023). By combining modern technologies with coordinated governance mechanisms, the project demonstrates how regional cooperation can address complex maritime challenges more effectively than isolated national approaches. Overall, the results of the EUREKA project show that integrated digital platforms, harmonized procedures, and sustained institutional collaboration can significantly enhance maritime safety and operational efficiency. The modernization of ADRIREP, reduction of administration burdens, elimination of redundant data collection, and improvement of real-time monitoring collectively form a comprehensive framework for safer navigation in the Adriatic-Ionian region. As such, the project serves as a model for future multinational initiatives seeking to modernize maritime governance through technological innovation.

3.2 Achievements of the Project ePIcenter towards logistic optimization

Modern global logistics chains operate under conditions of high interdependence, dynamic flows, and increased uncertainty. In such an environment, disruptions in the supply chain (delays, transport disruptions, port congestion, unplanned schedule changes, and capacity constraints) have a ripple effect across multiple system links, which may lead to broader operational and economic consequences (Christopher & Peck, 2004). Additionally, the growing complexity of trade flows, reflected in multimodality, the large number of stakeholders, and the geographical dispersion of processes, further complicates the planning and coordination of transport activities. A particular challenge is the presence of information asymmetries among stakeholders, as different participants in the supply chain often have access to inconsistent, incomplete, or delayed information, which reduces decision-making quality and increases the risk of misalignment in logistics operations.

In this context, the ePIcenter project developed and tested IT solutions that enhance daily logistics activities, including planning, coordination, and monitoring of cargo flows along the supply chain. One of the project's key contributions is the improvement of connectivity and coordinated data exchange among different actors in the logistics system. Instead of a fragmented approach, where each participant uses isolated information systems, ePIcenter promotes collaboration through a shared ecosystem of tools and methods based on cloud infrastructure. This approach reduces information fragmentation and ensures more consistent data exchange, which is particularly important in multimodal logistics, where even minor delays or untimely updates can significantly affect planning decisions (ePIcenter GA, 2020).

In maritime logistics, the ePIcenter project's case study highlights the importance of advanced data-sharing platforms and harmonized digital processes as a foundation for more efficient coordination among stakeholders. Examples of structured information exchange in port and shipping environments include initiatives such as Maritime Single Window (MSW), Port Community Systems (PCS), smart containers, Transporeon multimodal visibility solution and others systems based on mandatory IMO and UN regulations on data sharing (Paladin *et al.*, 2024). Availability of information on schedule changes, shipment status, and port events enables early detection of deviations and timely adjustment of plans before delays accumulate and cause broader operational disruptions. This is particularly important in conditions of frequent disruptions in global supply chains, as improved visibility and data exchange enhance resilience and the ability to respond quickly. The application of the same principle of digital connectivity also has a significant impact on road and rail transport, as planning in land-based segments often directly depends on events synchronization in the maritime stage. In this regard, the approach developed within the ePIcenter project enables faster coordination and rescheduling of dispatch and land transport operations when changes occur. By relying on harmonized data exchange and shared decision-support workflows, updated information from ports and maritime arrivals can be integrated earlier into land transport planning. This reduces timing mismatches between maritime and land segments, mitigates the effects of information asymmetries among stakeholders, and lowers the risk of congestion at transfer points between sea and land transport (ePIcenter GA, 2020).

Viewed in a broader context, the contribution of the ePIcenter project is not limited to technical improvements of digital tools but also includes strengthening the coordination capacity of logistics chains under conditions of global complexity and disruption. Therefore, system connectivity, standardized data exchange, and shared decision-support mechanisms represent key prerequisites for greater resilience, flexibility, and efficiency of modern transport and logistics systems.

4 Synthesis of an advanced digital technologies framework to ensure Maritime Transport, Surveillance, and Cargo Safety

4.1 Advanced digital solutions in maritime transport and logistics

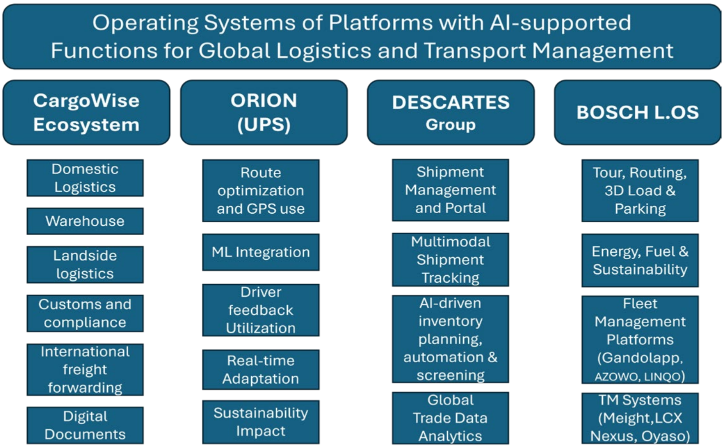

Figure 2: General overview of main operating ecosystem functions
Source: Own elaboration based on websites references

As an outstanding contemporary platform widely used in logistics and supply chain management, we elaborate on CargoWise software that brings together all key freight forwarding functions into a single platform used for global operations. Among the advanced capabilities of this tool, the end-to-end integration of functions such as bookings management, shipments, consolidations, customs clearance, and billing should be pointed out. What is especially important is the integrated AI-powered assistant CargoWise Ace that provides answers to any question about the platform, with clear, step-by-step guidance, making the use of CargoWise easier. As a software for intelligent logistics execution, Ace represents a step towards deeper AI integration in CargoWise, enabling the automation of routine tasks, uncovering real-time insights, flagging exceptions, and leading to a high level of productivity. Following the mentioned advanced solutions in logistics, the global delivery company United Parcel Service, Inc. (UPS), leverages AI to optimize its package delivery routes and operations and to reduce fuel consumption, by using an AI-driven optimization engine called ORION (On-Road Integrated Optimization and Navigation), which analyses factors such as delivery volume, requirements, and traffic patterns to generate efficient routes for drivers (Soumpenioti, 2023). Other relevant platforms in international logistics are DESCARTES and BOSCH L.OS. The general overview of their operating ecosystem functions is shown in Figure 2.

4.2 Maritime Safety Monitoring Technologies and Reporting

Of paramount importance to comprehensive maritime surveillance and continual management of vessel traffic is establishing a reliable monitoring system for accurate navigation and safety evaluation that will enable reaching a high level of situational awareness and preparedness at sea. This comprehends a determined position, speed, course, weather conditions, and other relevant technical factors that make the navigation safe and efficient, using the equipment and complex devices based on reliability, integrity, interference, and failure resilience. These devices leverage the advanced features of integrated sensors and monitoring systems for maritime navigation and situational awareness, including interference suppression, multisensor-processing, monitoring of integrity, back-up storage, data plausibility, and Automatic Identification System (AIS)/Radar fusion (Noack *et al.*, 2017). These technologies are widely based on operational Global Navigation Satellite Systems (GNSS), satellite navigation devices (GPS), functions known as PNT (Positioning, Navigation and Timing), and specifically used by the EU, the GALILEO, together with the EGNOS satellite-based augmentation system (SBAS) to enhance the accuracy of the global GNSS. The system's high-level architecture for multisensor ship data processing and outputs is illustrated in Figure 3.

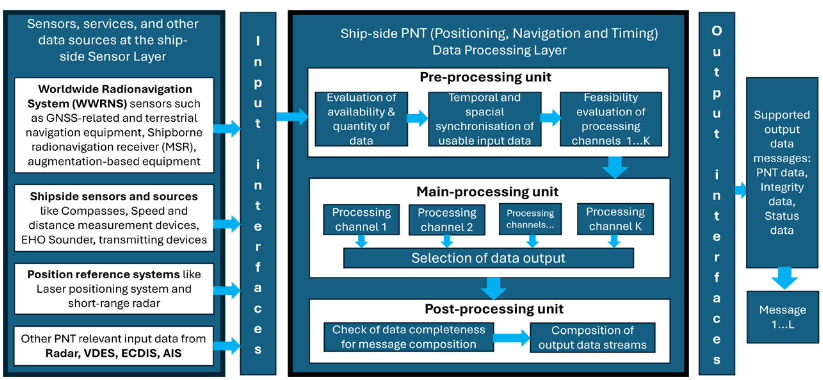

Figure 3: The high-level architecture of GNSS and PNT data processing framework
Source: Our elaboration from Noack *et al.* (2017)

Given that maritime safety relies on technological systems for vessel surveillance and rapid exchange of information through national maritime authority systems, EU countries established the concept of a Common Information Sharing Environment (CISE). The idea for this stems from EUCISE2020, a project standard network for sharing and exchanging relevant maritime data and information between cooperating agencies. Based on the European Maritime Safety Agency (EMSA) Guidelines for CISE, the entire information sharing/exchange/interpretation process is managed through the CISE Data & Services Model, which is structured in five main building blocks: the legacy system (LS) of the agency participating in the maritime data exchange, the EU/regional/national CISE node, the CISE adapter, the CISE node/gateway, and the CISE network (Paladin *et al.*, 2022; 2023).

Another important recently developed platform for sharing of data in the maritime sector is the Data Space large database, utilized as a new approach to decentralized and sovereign data sharing, consisting of several architectural components: The Connectors, the Identity Provider, the Data Broker, and Governance. Such a design of the Maritime Connectivity platform integrated within the VTS and Traffic Management System (TMS) offers advanced features in the sovereign and secure data provision, connection of heterogeneous data sources, integrity and certification, finding, and availability of maritime data (Höhn *et al.*, 2025). Concerning the VTS, AI enhances its functions by predicting ship arrival times, optimizing berthing schedules, and managing congestion, by using the Machine Learning (ML) models that analyze real-time AIS data and weather reports, to ensure safe and efficient vessel movement. The outstanding example for this in the EU is the Port of Rotterdam, which already employs AI-driven analytics to predict ETA and EDA (Estimated Time and Date of Arrival) with high accuracy, reducing idle times and port congestion (Kumar, 2025).

4.3 Advanced AI modules in maritime surveillance and logistics

In recent years, AI advancements at all segments of the maritime sector, especially in driving predictive maintenance, enhancing safety and security, and streamlining compliance with the needs of port and shipping operators, as well as both national and international regulations (Abu Hantesh *et al.*, 2024). AI is also widely applied in various aspects of logistics, such as shipping demand forecasting, route optimization, predictive models for congestion management in ports, ship collision risk assessment, automation of customs clearance processes, and maritime surveillance. One of the most important features of AI in maritime navigation is that, based on historical data and real-time conditions analysis from Big Data repositories, AI algorithms find the optimal route that minimizes cost function, respecting the constraints like fuel prices, traffic conditions, and weather patterns, which significantly reduces transportation costs and improves delivery times and reliability (Amadasu, 2024).

Table 1: Maritime and logistics AI projects/products examples by tasks performed

<table>
<tr><th>Sector</th><th colspan="2">Sensing</th><th colspan="2">Thinking</th><th colspan="2">Acting</th></tr>
<tr><th></th><th>Company</th><th>AI project / product</th><th>Company</th><th>AI project / product</th><th>Company</th><th>AI project / product</th></tr>
<tr><td rowspan="3">Intra-logistics</td><td rowspan="3">Fraunhofer (DE)</td><td rowspan="3">Identification based on natural features</td><td>VTT (FI)</td><td>KnowlEdge</td><td rowspan="3">Fraunhofer (DE)</td><td rowspan="3">Real autonomous robot navigation</td></tr>
<tr><td>Baobab (ES)</td><td>Production Planning</td></tr>
<tr><td>TU/e (NL)</td><td>AI Planner</td></tr>
<tr><td rowspan="5">Ports</td><td rowspan="2">Port de Barcelona (ES)</td><td rowspan="2">Goclever-Sensor, Cloud, and API Integration</td><td>UD (ES)</td><td>LOGISTAR</td><td rowspan="5">TUDelft & TNO (NL)</td><td rowspan="5">SWARM-PORT (Agent-based model simulation for decision support tool for the port nautical services, developed in PySeidon)</td></tr>
<tr><td>Port of Algeciras (ES)</td><td>PortXChange And IDOM & AWS</td></tr>
<tr><td rowspan="2">Captain AI (NL)</td><td rowspan="2">AI based radar tracker for inland shipping</td><td>Fundación Valenciaport (ES)</td><td>E2RM</td></tr>
<tr><td>Circle Group (IT)</td><td>Milos Intelligence</td></tr>
<tr><td>ICCS (EL)</td><td>5G-LOGINNOV</td><td>IMEC (BE)</td><td>COOCK Smart Port 2025</td></tr>
<tr><td rowspan="4">Transport Management</td><td rowspan="4">DB Schenker Enterprise Lab (DE/AT) and Fraunhofer IML (DE)</td><td rowspan="4">Video Analytics in Landtransport (automated yard access control, real-time allocation of (un)loading docks using MLCVZoo and OCR algorithms)</td><td>CIMNE (ES)</td><td>TOOL: Traffic fOrcasting fOr Logistics</td><td rowspan="2">ITAINN OVA (ES)</td><td rowspan="2">SmartDriving (Telemetry processing to update speeds based on fuel consumption)</td></tr>
<tr><td>FH Steyr (AT)</td><td>Demand prediction in retail</td></tr>
<tr><td>TU/e & UT (NL)</td><td>DYNAPLEX and Digital Twins for City Logistics</td><td rowspan="2">Utwente (NL)</td><td rowspan="2">ICCOS (using AI to reduce empty mileage, by Python and Google Colab)</td></tr>
<tr><td>Rulex (IT)</td><td>Data driven dashboard</td></tr>
</table>

Source: Adapted according to the Murrenhoff *et al.*, (2023) ALICE, with companies' seats countries codes

Utilizing the Big Data repositories, the analysis of a vast amount of maritime and ship data, reflects in main groups: supervised, semi-, and unsupervised algorithms (Vu *et al.*, 2024). Supervised analysis is based on linear and logistic regression, decision trees, and support vector machines, used for predictive purposes and requiring historical data, while unsupervised analysis is based on clustering, used for data structuring. Following these facts, there has already been an increasing trend for the implementation of ML methods as part of AI applications in the maritime industry, whose examples follow (Gomez-Ruiz *et al.*, 2023):

1. Prediction of ship motion, possible paths, and providing optimal trajectory.
2. Evaluation of navigation, oil spill event risk, and ship fuel consumption rates.
3. Development, application, and eco-design optimization of intelligent vessels.
4. Estimation of the berthing state of autonomous maritime surface ships.

An overview of the most relevant AI applications is given in Table 1.

An important field of transformative and developing AI platform applications is reflected in autonomous shipping and navigation tasks in the form of Maritime Autonomous Surface Ships (MASS). In this sense, the set of AI-driven systems for MASS integrate data from sensors, radars, Light Detection and Ranging (LIDAR), RGB and infrared cameras, Motion Reference and Inertial Measurement Units (IMU/MRU), AIS, weather and depth data sensors and satellite communication networks (GNSS) to support decision-making, situational awareness, ship and shore recognition, and predictive navigation (Kumar, 2025; Koch, 2022). A classic example of system integration of all the mentioned features is the Mayflower Autonomous Ship, produced in 2022. Therefore, a high level of intelligent assistance systems provides the ship autonomy and the new methods of ship handling to use existing infrastructure more efficiently. This will make expensive infrastructure projects unnecessary, such as dredging. It is important to mention that the highly automated ships already exist, e.g., "Yara Birkeland" of the Norwegian shipping company Kongsberg, and the highly automated ship "C-worker-7", managed by a British shipping company (Hesse *et al.*, 2019). A recent market analysis of the most disruptive AI tools utilized in maritime navigation, done by Stach *et al.* (2024), covered 26 products, among which the highly evaluated were Avikus NeuBoat and

HiNAS 2.0, Groke Pro, Kongsberg Maritime Intelligent Awareness, MTU NautIQ Copilot, Sea Machines SM300, Seasight and Wärtsilä Voyage Autonomy Solutions, which correspond to safety and quality requirements from the IMO, and ISO/IEC.

5 Discussion on the application of AI-supported modules in maritime safety and transport efficiency findings

Two essential conditions to enable the maritime transport flows proper are safety and risk mitigation. Safety in maritime transportation refers to the measures and practices implemented to prevent accidents and incidents that could endanger human life, damage property, or harm the marine environment, while the risk management in maritime transportation involves the systematic identification, assessment, and mitigation of risks associated with maritime operations. To manage these challenges, some global maritime multinational companies have introduced advanced AI modules such as Kongsberg's KognifAI Maritime Ecosystem for Predictive Maintenance, Maersk's AI-Powered Risk Management, DNV GL Veracity Platform for risk analysis, Wärtsilä's Fleet Operations Solution and ABB Ability™ Marine Pilot Vision for the safety of navigation systems. With the mentioned AI tools, Maersk increased the ability to ensure the safety of its vessels and crew while maintaining efficient and safe operations. On the other side, the Veracity platform enables continuous monitoring of critical systems, providing insights into their condition and performance. The Wärtsilä system's predictive capabilities enhance situational awareness and reduce the risk of accidents, contributing to safer and more efficient maritime operations (Durlik *et al.*, 2024).

As stated in Amadasu (2024), the combined use of AI-supported modules and blockchain in maritime applications contributed to higher safety and reduction the operational costs in port by 15%. Also, it is important to mention that sectors with the biggest opportunities for AI, based on the report of McKinsey (Chui *et al.*, 2018), are transport and logistics industries, having an annual value of US$ 400-500 billion, which is a great potential to capitalise on this business value. Therefore, AI potential in the freight logistics sector is based on various use cases, depending on the research project for the particular use or process, as follows (du Plessis *et al.*, 2025):

- Freight opportunity platform (matching the transport supply and demand);
- Production, regulation, or control of goods to prevent under-production;

- Resilience of logistical system (risk mitigation, adjustment of safety levels);
- Sustainability initiatives, energy or fuel consumption, and waste reduction;
- Ship and cargo safety (security hotspot identification, accident detection);
- Transport management system (booking/allocation system optimisation);
- Efficiency improvement (loading/unloading and routing of vehicles/ships).

Due to fierce international shipping competition, the industry is under cost pressure and must innovate, but highly automated systems promise relief. According to the study of Hesse *et al.* (2019), a highly automated freighter can save US$4.3 million over 25 years compared to a traditionally manned vessel.

An interesting approach for an integrated use of AI tools and digital twins (a digital projection of the ship) is provided by the Marine Digital GmbH company in the field of ship performance optimization. This combination offers modular digitization and the improvement of modern ships' equipment, navigational devices, and tools. The digital twin collects all data and streams it to a compliant and secure cloud, where fleet managers get live notifications such as: weather events, maintenance messages, ETA changes, and routes generated by AI algorithms, focusing on optimal fuel consumption and ETA restrictions. Fuel savings and the associated emissions optimization effect range from 5% to 12%, depending on the specific operating characteristics of the individual vessel (Schulz *et al.*, 2021).

This paper has confirmed a profound impact of AI technology on the maritime transportation sector, shaping its development, efficiency, and scalability to meet the high standards and requirements. Also, AI-driven software brings many positive aspects to the overall safety and security of the ship's digital and transport system in general, covering a wide range of functions and areas of vital significance to stakeholders, leading to greater productivity of companies and resilience of critical assets. However, careful attention must be given to data privacy and cybersecurity.

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