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Navigating the Sea of Data: A Comprehensive Review on Data Analysis in Maritime IoT Applications

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Abstract: The Internet of Things (IoT) is significantly transforming the maritime industry, enabling the generation of vast amounts of data that can drive operational efficiency, safety, and sustainability. This review explores the role and potential of data analysis in maritime IoT applications. Through a series of case studies, it demonstrates the real-world impact of data analysis, from predictive maintenance to efficient port operations, improved navigation safety, and environmental compliance. The review also discusses the benefits and limitations of data analysis and highlights emerging trends and future directions in the field, including the growing application of AI and Machine Learning techniques. Despite the promising opportunities, several challenges, including data quality, complexity, security, cost, and interoperability, need to be addressed to fully harness the potential of data analysis in maritime IoT. As the industry continues to embrace IoT and data analysis, it becomes critical to focus on overcoming these challenges and capitalizing on the opportunities to improve maritime operations.

Keywords: maritime industry; Internet of Things (IoT); data analysis; machine learning; predictive maintenance

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1. Introduction

The maritime industry, integral to global commerce, has evolved as a pivotal force, driving economies for centuries. From shipping and logistics to diverse sectors, such as naval operations, fishing, offshore drilling, and marine tourism, its expansive reach has shaped globalization and fostered cultural connections. This introduction sets the stage for the subsequent subsections. We delve deeper into the historical and current significance of the maritime industry, shedding light on its dominant role in international trade, especially with the increased integration of technology and IoT applications (Figure 1).

1.1. Background to the Maritime Industry

Historically, the maritime domain has been the linchpin of global commerce. Today, it continues its legacy with over 90% of global trade transported by sea. Renowned for its cost-effectiveness and efficiency, maritime transport boasts the unparalleled capability to handle vast cargo loads across expansive distances. This efficiency makes it indispensable in connecting global economies and anchoring international trade [1].

The maritime industry is multi-faceted, encompassing shipping lines, port operations, naval defense, offshore exploration, fishing, and maritime tourism, each with its unique characteristics and challenges. In recent years, the industry has seen remarkable changes brought about by technological advancements, evolving regulations, environmental concerns, and the pressing need for operational efficiencies [2,3].

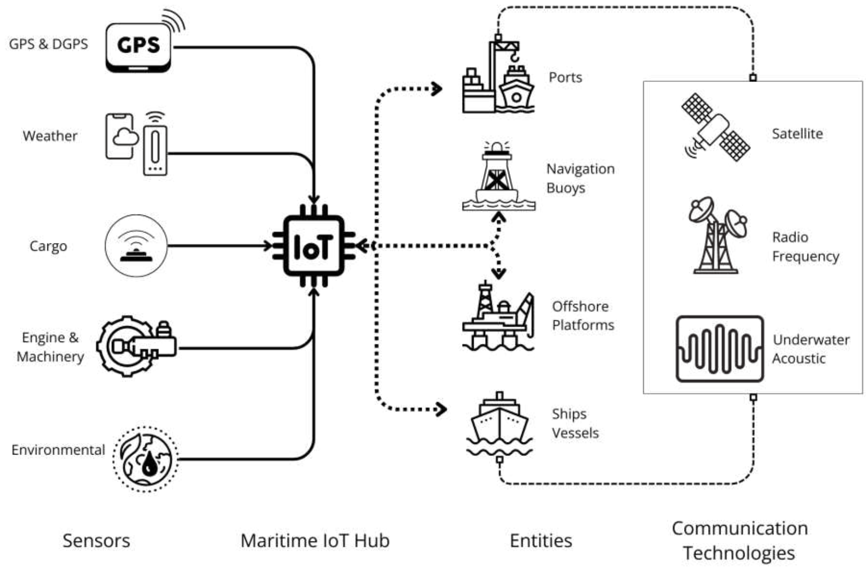

Figure 1. Comprehensive Overview of Maritime IoT Applications and Interconnections.

Shipping, the most prominent component of the industry, has evolved significantly from the days of sail ships to the era of fully automated vessels. Ports, once considered mere points of transfer, have morphed into complex logistics hubs offering a range of services. Furthermore, emerging sectors such as offshore wind energy and marine biotechnology are paving the way for a more sustainable and diversified maritime industry [4].

However, these advances also bring about new challenges and complexities. The industry grapples with issues such as environmental pollution, maritime security, overcapacity, infrastructure constraints, and supply chain inefficiencies. These challenges underline the need for technological solutions that can optimize operations, increase efficiency, enhance safety, and reduce environmental impact [5,6].

As the maritime industry sails into the digital era, Internet of Things (IoT) technologies have emerged as potential game-changers. IoT's ability to interconnect devices, systems, and services to gather, store, and analyze data could significantly transform the industry's operations and business models, marking the onset of a new era of 'smart shipping' and 'smart ports' [2,7].

The wave of digital transformation has swept across numerous industries over the past few decades, reshaping operational dynamics and opening up avenues for innovation and efficiency. Industries ranging from finance and healthcare to agriculture have embraced the digital tide, harnessing the power of emerging technologies to redefine their landscapes. However, the maritime industry, with its deep-seated traditions and vast operational complexities, has been somewhat gradual in this adaptation. It is only in recent years that we have begun to see a significant digital shift in maritime operations. This relatively slow-paced adoption stresses the immediacy and pertinence of understanding the role of technologies such as IoT and data analysis in the maritime domain. As the maritime industry navigates this digital era, there is a compelling need to understand its trajectory, ensuring it aligns with global digital trends while preserving the industry's unique identity [1–7].

1.2. Emphasis on Challenges and Technological Solutions

As the maritime industry remains the backbone of global trade, it inevitably grapples with a plethora of challenges that amplify in magnitude and complexity with each passing year. Among the most pressing issues is environmental pollution, a consequence of decades-long practices and processes. Emissions from ships, oil spills, ballast water discharge, and waste disposal have taken a toll on our marine ecosystems, threatening marine life and, subsequently, human health. The carbon footprint of ships alone accounts for a significant portion of global greenhouse gas emissions, propelling the urgency for sustainable interventions [8].

Another formidable challenge is maritime security. In an age where piracy has evolved from rogue seafarers to organized crime syndicates with advanced tools, ensuring the safety of both cargo and crew has never been more critical. Threats of terrorism, smuggling, and illegal fishing add further layers to this intricate challenge [9,10].

Yet, in the midst of these challenges lies the potential for innovation. Technological solutions, particularly IoT, emerge as beacons of hope. For environmental concerns, IoT-enabled sensors can monitor emissions in real-time, ensuring compliance with international standards and pinpointing areas for improvement. Intelligent systems can predict and prevent potential oil spills, while also monitoring the discharge of ballast water, ensuring it aligns with environmental standards [11].

In terms of security, IoT has the potential to revolutionize maritime safety protocols. Advanced tracking systems can keep vessels safe from piracy by identifying and alerting ships about potential threats. Additionally, integrated communication tools ensure timely responses during emergencies, while surveillance systems using interconnected cameras and sensors can monitor every nook and cranny of a ship, deterring illicit activities [12].

As we sail further into this article, we will explore how these technological innovations, anchored by IoT, have the potential not just to address but to redefine the very challenges that have beset the maritime industry.

1.3. Significance of IoT in the Maritime Industry

The Internet of Things (IoT), with its capacity to connect a multitude of devices and systems over networks to gather, exchange, and analyze data, has significant implications for the maritime industry. By leveraging IoT, maritime operations can realize unprecedented levels of efficiency, safety, and environmental sustainability.

IoT technologies are transforming traditional maritime operations into a connected ecosystem. Ship-to-ship and ship-to-shore communication, real-time tracking of vessels and cargo, condition monitoring of critical equipment, and predictive maintenance are just some examples of IoT maritime applications. These technologies provide operators with a wealth of real-time information, enabling them to make data-driven decisions and take proactive measures [1,13–15].

For instance, IoT-enabled smart shipping involves embedding sensors and devices throughout the ship to monitor various parameters, such as location, speed, fuel consumption, engine performance, and weather conditions. This data can be used to optimize routes, improve fuel efficiency, and prevent equipment failure, significantly enhancing operational efficiency and cost-effectiveness [16–20].

Similarly, 'smart ports' leverage IoT technologies to streamline and automate operations. IoT devices monitor and control cargo handling, manage logistics, track vehicles and equipment, and automate processes, reducing waiting times, improving cargo turnover, and minimizing human errors [19,20].

Furthermore, IoT plays a crucial role in enhancing maritime safety and security. It aids in piracy control, collision avoidance, emergency response, and environmental protection. On the sustainability front, IoT-driven data can help reduce greenhouse gas emissions and mitigate the environmental impact of maritime operations [21].

1.4. Role and Importance of Data Analysis in Maritime IoT Applications

As the maritime industry embraces IoT, the volume of data generated from various operations is skyrocketing. This data, while a valuable resource, is of little use without the ability to effectively analyze and interpret it. That is where data analysis comes into play [22].

Data analysis in maritime IoT applications involves the extraction, processing, and interpretation of data to transform raw data into actionable insights. These insights can inform strategies, optimize operations, drive innovation, and provide a competitive edge [22,23].

For instance, predictive analytics can analyze maintenance data to predict equipment failures before they occur, allowing for timely intervention and reducing downtime. Similarly, analyzing vessel and cargo data can help optimize shipping routes and schedules, leading to fuel savings and improved service delivery. Data analysis can also enhance safety and security by detecting anomalies and potential threats [24,25].

In the context of smart ports, data analysis can help manage and coordinate complex logistical operations, enhancing efficiency, and reducing delays. In terms of sustainability, analyzing emissions data can guide strategies for reducing the environmental footprint of maritime operations [26] (Figure 2).

Figure 2. Application Areas of Data Analysis in Maritime Industry (self-created).

However, harnessing the potential of IoT data in the maritime industry is not without its challenges. Issues such as data quality, data security, data privacy, and the lack of skilled personnel can hamper data analysis efforts. Furthermore, the maritime industry, being traditionally conservative, may be slow to adopt new technologies.

While the initial allure of data analytics in the maritime sector seems heavily skewed towards bolstering operational efficiency, its applications are far more profound and expansive. Beyond the realm of operations, data analytics emerges as an indispensable tool, transforming the way the maritime industry approaches market dynamics, customer feedback, and service refinement [27].

1. Market Analysis: In a rapidly evolving global trade landscape, staying ahead of market trends is paramount. Data analytics offers the maritime industry an eagle's-eye view of market fluctuations, trade route profitability, and emerging market demands. By analyzing trade volumes, route popularity, and cargo types, businesses can forecast demand, adjust capacities, and even anticipate shifts in global trade dynamics. This level of market insight ensures that maritime businesses remain agile and adaptable in the face of market volatilities [28].

2. Customer Feedback Processing: The maritime industry, like any service-driven sector, thrives on customer satisfaction. Leveraging data analytics to process and interpret feedback can reveal underlying patterns, preferences, and pain points of the customers. Whether concerning the efficiency of cargo handling, the punctuality of shipments, or the quality of onboard amenities, data-driven insights can help businesses prioritize areas that matter most to their clientele [29].
3. Refining Service Offerings: In the age of customization, a one-size-fits-all approach falls short of customer expectations. Through data analytics, maritime operators can fine-tune their services to cater to niche markets. For instance, analyzing data on the popularity of specific cargo types can prompt shipping companies to offer specialized services, such as temperature-controlled containers for perishables or enhanced security measures for high-value goods [30].

In essence, data analytics in the maritime realm is not just about optimizing what's on the inside, but about looking outward, understanding the ever-changing dynamics of markets and customer expectations, and recalibrating services to fit these evolving narratives. As the maritime industry continues its voyage into the digital age, embracing the full spectrum of data analytics applications will be key to navigating the choppy waters of global trade.

In the face of rising complexities and multifaceted challenges confronting the maritime industry, there is a pressing urgency to delve deeper into the transformative capabilities of IoT and data analysis as potential harbors of solutions. These technological tools, which have revolutionized other sectors, beckon with promises of innovation and efficiency for maritime operations. Recognizing this imperative, our article sails forth with a dedicated purpose: to harness and consolidate the myriad insights scattered across case studies, research findings, and expert opinions on this topic [31].

Our endeavor goes beyond mere narration. We aim to stitch together a comprehensive tapestry, elucidating how IoT and data analysis can reshape the contours of the maritime industry. By bridging the gap between theory and practice, our contributions lie in the convergence of research and its practical implications, providing both a compass and map for stakeholders navigating the digital transformation of maritime operations.

This review aims to shed light on these aspects, delving into the role, benefits, challenges, and future prospects of data analysis in maritime IoT applications. By doing so, it hopes to provide a comprehensive understanding of this emerging field and its potential to transform the maritime industry [26,32,33].

As we navigate the vast waters of maritime IoT and data analytics, it is paramount to understand the existing body of knowledge and the landmarks set by prior research. The forthcoming sections will embark on an extensive literature review, providing a comprehensive survey of the state-of-the-art in maritime IoT and data analytics. This exploration will not only detail the milestones achieved but will also illuminate the existing gaps and areas that remain uncharted. By laying out this landscape, we set the stage for the unique contributions of this article, positioning it within the broader discourse and emphasizing its significance in furthering the understanding of the maritime industry's digital transformation.

2. IoT in the Maritime Industry

The Internet of Things (IoT) in the maritime industry represents a new paradigm that enhances various operations such as navigation, freight tracking, fleet management, and maintenance. It involves the use of sensors, devices, and software to collect, process, and analyze data, leading to improved decision-making and efficiency. With an increasing need for digitization and automation, the adoption of IoT in the maritime industry has been gaining momentum [34,35] (Table 1).

Table 1. Key Applications of IoT in the Maritime Industry.

Application	Description	Impact on the Industry
Navigation	Utilizes IoT devices for real-time tracking of ships, efficient route planning, collision avoidance, and improving navigation safety [36].	Improved route optimization leading to fuel efficiency, reduced travel time, and enhanced safety [34].
Monitoring	IoT devices are used for monitoring various parameters such as engine performance, fuel consumption, temperature, humidity, etc. in real-time [37].	Enhanced vessel performance through timely interventions, reduced downtime, predictive maintenance [38].
Safety	Incorporates IoT for continuous surveillance, identifying potential hazards, and immediate response to emergency situations [24].	Reduction in the number of accidents, improved safety measures, enhanced protection of cargo and crew [2].
Efficiency	IoT is applied in optimizing operations such as cargo handling, berth scheduling, loading and unloading, etc. [39].	Increased operational efficiency, reduction in waiting times, and cost savings [40].
Environmental Sustainability	IoT sensors monitor emissions and waste to ensure compliance with environmental regulations [41].	Improved environmental performance, compliance with regulations, and reputation management [42].

2.1. Evolution and Growth of IoT in the Maritime Industry

The use of IoT in the maritime sector has been a gradual yet transformative process, evolving in tandem with technological advancements and the industry's growing need for optimization [43].

In the early stages, IoT was employed primarily for simple tracking and monitoring purposes. The use of Automatic Identification Systems (AIS) and Radio Frequency Identification (RFID) systems, for example, improved the tracking of ships and cargo, providing real-time updates about location, speed, and direction.

The advent of more advanced technologies saw the role of IoT expand significantly. Today, IoT is integral to 'smart shipping'—a concept where vessels are equipped with myriad sensors and devices that monitor various parameters, from engine performance and fuel consumption to weather conditions and crew health. This data is processed and analyzed to optimize operations, enhance safety, improve efficiency, and reduce environmental impact [23,25,44–46].

On the other hand, 'smart ports' use IoT technologies to streamline operations, automate processes, and improve logistics. IoT devices installed at ports can monitor and control cargo handling, track vehicles and equipment, and automate gate operations and container movement, among other factors. These improvements have resulted in decreased waiting times, enhanced cargo turnover, and minimized human errors [47–49].

Furthermore, IoT has found applications in maritime safety and security, environmental protection, and energy efficiency. For instance, IoT devices can detect illegal activities such as piracy or smuggling, monitor emissions to ensure compliance with environmental regulations, and optimize energy use in various operations [49–51].

The growth of IoT in the maritime industry is expected to continue, driven by the industry's need for digital transformation, the rise of autonomous shipping, increasing environmental concerns, and advancements in technology. The global maritime IoT market, valued at $4.15 billion in 2020, is projected to reach $21.36 billion by 2027, reflecting the burgeoning importance of IoT in this sector [52,53].

Despite this growth, the adoption of IoT in the maritime industry is not without its challenges. Issues such as data security, privacy, interoperability, and the high cost of implementation need to be addressed to fully realize IoT's potential in the maritime industry. The following sections delve deeper into these aspects, providing a comprehensive overview of the state of IoT in the maritime sector [54].

2.2. Key Applications of IoT: Navigation, Monitoring, Safety, and Efficiency

IoT has emerged as a transformative force in the maritime industry, having a significant impact across various domains. Below are some of the key applications of IoT in this sphere (Figure 3):

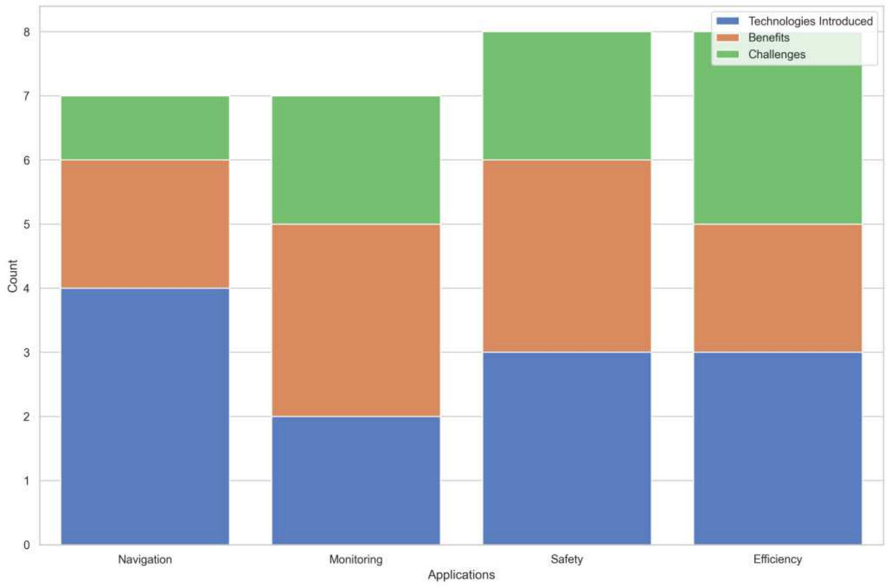

Figure 3. Key Applications of Maritime IoT (self-created).

- Navigation: With the advent of technological advancements, maritime navigation has benefited from a variety of systems beyond the traditional Global Positioning System (GPS). While GPS remains a foundational tool, there are several other complementary and supplementary technologies that offer enhanced precision and capabilities [55,56]:
- Differential GPS (DGPS): This augments the standard GPS system by correcting signals to eliminate potential errors, providing improved location accuracy. Fixed, ground-based reference stations transmit the difference between the known position and the GPS position to DGPS-equipped receivers, ensuring a higher degree of accuracy.
- Real-Time Kinematic (RTK) Navigation: RTK is a satellite navigation technique that enhances the precision of position data derived from satellite-based positioning systems. By using data from at least one reference station, RTK can provide centimeter-level accuracy, making it crucial for specific maritime operations that demand high precision.
- Laser Systems: In some maritime contexts, especially in close-quarter maneuvering or docking, laser systems are employed. These systems provide precise distance measurements between the vessel and a fixed point, such as the quay, assisting in safe and efficient berthing.

These technologies, in tandem with traditional GPS, form the backbone of modern maritime navigation, each with its specific applications and advantages in different maritime contexts.

- Monitoring: IoT devices are extensively used for monitoring various aspects of maritime operations. Onboard sensors can continuously track the performance and condition of essential machinery, alerting the crew to potential issues before they lead to failures. In cargo shipping, IoT-enabled smart containers can monitor the condition of goods, tracking parameters, such as temperature and humidity to ensure cargo quality [37,38].
- Safety: Enhancing maritime safety is a critical application of IoT. Advanced sensor networks can detect abnormalities or malfunctions early, mitigating risks. For instance, structural health monitoring systems can identify potential damage in a ship's structure. IoT devices also contribute to maritime security, enabling real-time tracking of ships and cargo to prevent piracy and smuggling [2,34].
- Efficiency: IoT significantly contributes to operational efficiency in the maritime industry. In 'smart shipping,' data from various sensors is analyzed to optimize fuel consumption, reduce idle time, and enhance overall operational efficiency. Similarly,

‘smart ports’ leverage IoT for automation of various operations, reducing waiting times and improving cargo turnover [39,40].

2.3. Current State of IoT Integration in the Maritime Sector

The integration of IoT in the maritime sector is steadily progressing, driven by the need for digital transformation and the desire to improve efficiency, safety, and sustainability. Various stakeholders, including ship owners, operators, port authorities, and tech firms, are investing in IoT solutions to modernize their operations.

‘Smart shipping’ is becoming increasingly prevalent, with modern vessels equipped with numerous sensors and devices to monitor their performance and condition. Real-time data from these sensors is utilized to enhance operational efficiency and safety. For instance, major shipping companies have started implementing IoT-based predictive maintenance systems to reduce downtime and operational costs [2,7].

Ports are also embracing IoT to transform into ‘smart ports.’ Automated cranes, self-driving trucks, and IoT-based cargo handling systems are becoming common, improving efficiency and reducing the time ships spend in port.

Additionally, IoT is being used to improve maritime safety and security. Vessel traffic management systems, piracy detection systems, and emergency response systems leveraging IoT technologies are being deployed to enhance maritime security [57,58].

However, while the benefits of IoT in the maritime sector are undeniable, several challenges need to be addressed for wider adoption. Data security and privacy concerns, high implementation costs, lack of interoperability, and the need for skilled personnel are among the significant hurdles. Despite these challenges, the trend towards digitization and the numerous benefits offered by IoT ensure its continued growth and integration in the maritime sector [50,59].

3. Understanding Data Analysis for IoT

In the context of IoT, data analysis serves as the bridge that transforms the raw data collected from various IoT devices into meaningful and actionable information. By employing various techniques, data analysis can discover patterns, extract insights, and make predictions that can significantly impact decision-making processes and operational efficiency in various industries, including the maritime sector [60,61].

3.1. Overview of Data Analysis Techniques Relevant to IoT

The unprecedented volume, velocity, and variety of data generated by IoT devices necessitate the application of diverse data analysis techniques to extract meaningful information. Here are some key techniques relevant to IoT (Figure 4):

- Descriptive Analysis: This technique is used to understand and summarize the data in a meaningful way, providing insights into past occurrences. It includes simple data aggregations, such as mean, median, mode, and more complex ones, such as correlation and standard deviation [62].
- Diagnostic Analysis: This form of analysis aims to identify the cause of a particular outcome. It often involves more in-depth data exploration techniques, including data mining and correlations.
- Predictive Analysis: By utilizing statistical techniques and machine learning models, predictive analysis can forecast future events based on historical data. Techniques such as regression, time series analysis, and various machine learning algorithms fall under this category [63].
- Prescriptive Analysis: This advanced form of analysis recommends actions to take for optimal outcomes. It utilizes a combination of techniques, including simulation, optimization, and decision-tree algorithms, to provide actionable insights [64].
- Real-time Analysis: This type of analysis is crucial in IoT setups where immediate processing of data is required. It enables the system to respond instantaneously to

changing circumstances, which is critical in applications such as collision avoidance in maritime navigation [65].
- Machine Learning and AI: Machine learning and AI algorithms play a significant role in analyzing IoT data. From supervised learning techniques for predictive analysis to unsupervised learning for pattern discovery and anomaly detection, these techniques provide valuable insights and predictions [66].
- Big Data Analytics: Given the volume of data generated by IoT devices, big data analytics techniques are often employed. These techniques can handle large data sets, ensuring efficient storage, processing, and analysis of data [67].

Each of these techniques plays a unique role in the data analysis process and can be employed individually or in combination depending on the specific needs and objectives of the IoT application in question.

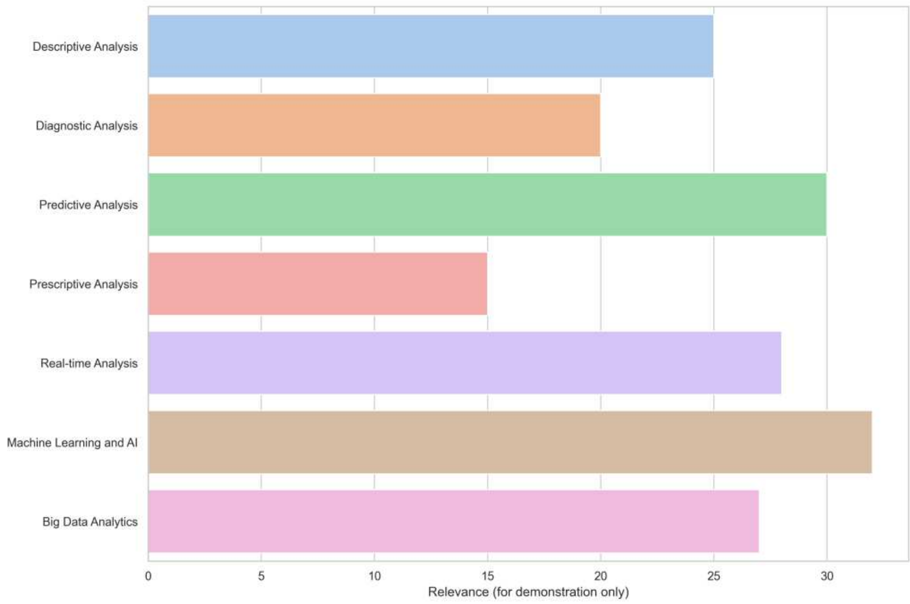

Figure 4. Overview of Data Analysis Techniques Relevant to IoT.

3.2. Importance of Data Analysis in IoT Systems

The unprecedented volume, velocity, and variety of data generated by IoT devices necessitate the application of diverse data analysis techniques to extract meaningful information. Here are some key techniques relevant to IoT:

Data analysis plays a pivotal role in IoT systems due to the massive volumes of data generated. However, it is not the data itself that is valuable, but the actionable insights derived from it. Herein lies the significance of data analysis:

- Inform Decision Making: By transforming raw data into meaningful information, data analysis supports informed decision-making. Whether it is optimizing shipping routes, scheduling preventative maintenance, or managing port logistics, decisions backed by data analysis can significantly enhance efficiency and outcomes [68].
- Predictive Capabilities: Predictive analytics, a subset of data analysis, uses historical data to predict future events. In the context of maritime IoT, this could mean forecasting machinery failures or predicting fuel consumption, allowing for proactive measures and strategic planning [69].
- Efficiency Gains: Data analysis can identify inefficiencies and bottlenecks in processes. In the maritime industry, this could translate into better fuel management, efficient cargo handling, and reduced port dwell time, leading to cost savings and improved operations [70].
- Enhanced Safety and Security: By detecting anomalies and potential threats, data analysis can improve maritime safety and security. For instance, analyzing ship

movement data could identify potential collisions, while analyzing communication data could detect security threats [71].

3.3. Challenges in IoT Data Analysis

The unprecedented volume, velocity, and variety of data generated by IoT devices necessitate the application of diverse data analysis techniques to extract meaningful information. Here are some key techniques relevant to IoT:

While data analysis offers immense benefits, it is not without its challenges, particularly in the context of IoT [72–74].

- Volume and Variety of Data: The sheer volume and diversity of data generated by IoT devices can be overwhelming, posing challenges in data management, storage, and processing.
- Data Quality: The accuracy and reliability of insights depend on the quality of the underlying data. However, IoT data can be prone to errors, missing values, and inconsistencies, affecting the quality of the analysis.
- Data Security and Privacy: With increasing concerns around data breaches and privacy violations, ensuring the security and privacy of IoT data is a significant challenge.
- Lack of Skilled Personnel: Data analysis, especially advanced techniques involving AI and machine learning, requires specialized skills. The scarcity of such skilled personnel can hinder effective data analysis.
- Integration and Interoperability Issues: IoT devices from different manufacturers might use different standards and protocols, posing challenges in data integration and interoperability.

These challenges need to be effectively addressed to unlock the full potential of data analysis in IoT applications. The upcoming sections delve deeper into these aspects in the context of the maritime industry.

4. Data Analysis in Maritime IoT Applications

As the maritime industry increasingly adopts IoT solutions, the importance of data analysis in this sector is being recognized. By applying data analysis to the information collected from IoT devices, maritime stakeholders can gain meaningful insights to enhance operational efficiency, improve safety, and make strategic decisions [75].

4.1. Case Studies of Successful Data Analysis in Maritime IoT

Several successful implementations highlight the power of data analysis in maritime IoT applications (Table 2).

Table 2. Case Studies of Successful Data Analysis in Maritime IoT.

Case	Application	Results/Benefits
Maersk	Predictive Maintenance	Reduced downtime and operational costs [76]
Port of Rotterdam	Efficient Port Operations	Improved efficiency and reduced waiting times for vessels [77]
Rolls-Royce Marine	Navigation and Safety	Enhanced safety through informed navigation decisions [78]
Carnival Corporation	Environmental Compliance	Ensured compliance with environmental regulations, optimized fuel consumption [79]
Mohammad Danil Arifin's research	Ship Allocation Model	Balanced supply and demand, identified effective vessel specifications, gauged impact of vessel efficiency on demand [80]
Dimitrios Dalaklis et al.	Optimization in Shipping and Port Industries Through Big Data Analytics	Improved maritime transport activities and port operations through effective Big Data management [81]

4.1.1. Case Study 1

Predictive Maintenance in Shipping: One of the leading global shipping companies, Maersk, has integrated IoT sensors with their vessels to monitor engine performance, fuel consumption, and various other parameters. The collected data is analyzed in real-time to predict potential machinery failures and schedule maintenance accordingly. This predictive maintenance approach has significantly reduced downtime and operational costs [66].

One of the largest shipping companies in the world, Maersk, has taken proactive steps towards digitalization by harnessing the power of IoT and data analysis. The primary application has been the deployment of a predictive maintenance strategy aimed at improving the reliability and efficiency of their vast fleet.

Integration of IoT Sensors

To achieve this, Maersk has integrated a broad range of IoT sensors into their vessels, covering vital components such as engines, generators, fuel systems, and various other mechanical and electrical systems. These sensors continuously collect data related to temperature, vibration, pressure, and fuel consumption, among other parameters.

Real-Time Data Analysis

The collected data is transmitted in real-time to a central monitoring system, employing advanced data analysis techniques. Statistical models, machine learning algorithms, and AI-based systems are utilized to understand normal operation patterns and detect deviations that could signify potential equipment failure.

This real-time monitoring and analysis allow the system to identify the initial signs of potential malfunctions or degradation. For example, an increase in engine vibration or a change in fuel consumption patterns might indicate an issue that needs attention.

Predictive Maintenance and its Benefits

The key benefit of this system is its predictive maintenance capability. Maintenance can be scheduled based on the condition of the equipment, rather than following a set time-based schedule. If the system detects an anomaly suggesting a potential failure, maintenance can be scheduled to address the issue before it leads to a breakdown. Conversely, if the system is operating normally, routine maintenance can be postponed, avoiding unnecessary downtime.

This predictive maintenance approach has multiple benefits:

- Reduced Downtime: By addressing potential issues before they lead to failures, the downtime of vessels can be significantly reduced. This can have a direct impact on the bottom line, as downtime can be extremely costly in the shipping industry.
- Lower Maintenance Costs: Condition-based maintenance can often be less expensive than routine maintenance. By avoiding unnecessary maintenance and focusing on potential issues, costs can be significantly reduced.
- Increased Operational Efficiency: With vessels spending less time undergoing maintenance, they can spend more time in operation. This can enhance operational efficiency and profitability.
- Extended Equipment Life: By maintaining equipment in optimal condition and avoiding over-maintenance, the lifespan of machinery and equipment can be extended.

Maersk's use of IoT and data analysis for predictive maintenance exemplifies the transformative potential of these technologies in the maritime industry. By turning vast volumes of data into actionable insights, they have managed to reduce costs, enhance efficiency, and ensure the reliable operation of their fleet.

4.1.2. Case Study 2

Efficient Port Operations: The Port of Rotterdam, one of the world's busiest ports, has employed a comprehensive IoT solution to enhance its operations. Sensors installed throughout the port generate data about ship movements, berthing availability, weather conditions, and more. This data is analyzed to optimize various operations—from ship berthing to cargo handling—leading to improved efficiency and reduced waiting times for vessels [77].

Case Study 2—Efficient Port Operations

The Port of Rotterdam, one of the world's busiest and most technologically advanced ports, provides an excellent case study on how IoT and data analysis can streamline operations and increase efficiency.

IoT Infrastructure and Data Collection

The Port of Rotterdam has embarked on a mission to become the "smartest" port in the world. To achieve this, it has implemented a comprehensive IoT infrastructure, with numerous sensors installed throughout the port. These sensors generate data on various parameters, including ship movements, berthing availability, tide levels, wind speed, and weather conditions.

High-resolution cameras and radar systems are used for tracking ship movements and identifying any navigational challenges. Sensors on quaysides and berths provide information on berthing availability. Environmental sensors measure weather conditions, while flow sensors at container terminals measure cargo handling rates.

Data Analysis and Decision Making

The vast amount of data generated by these sensors are analyzed in real-time using advanced analytics and machine learning algorithms. The system can predict the most efficient sequence of ship movements, determine the optimal time for cargo loading or unloading, and forecast the availability of berths.

Moreover, real-time weather data is analyzed to inform decision-making in ship movements and cargo operations. For instance, if wind speeds are predicted to exceed safe operational limits, cargo handling can be rescheduled to ensure safety and avoid potential damage.

Operational Efficiency and Reduced Waiting Times

The insights derived from data analysis have significantly improved the port's operational efficiency. By predicting the most efficient sequence of ship movements, the port can minimize the time ships spend waiting for a berth. This not only reduces operational costs for shipping companies but also decreases emissions from idling ships, contributing to environmental sustainability.

Similarly, by optimizing cargo handling operations based on real-time data, the port ensures maximum productivity of cranes and other equipment, leading to faster turnaround times.

The implementation of IoT and data analysis by the Port of Rotterdam has transformed its operations, showcasing the immense potential of these technologies in managing complex port operations. The port's commitment to becoming the 'smartest' port has resulted in improved efficiency, reduced waiting times, and better resource utilization. This case serves as an inspiration for other ports worldwide aiming to leverage technology for operational excellence.

4.1.3. Case Study 3

Navigation and Safety: Rolls-Royce Marine has developed an Intelligent Awareness System that uses a combination of IoT and data analysis for safer navigation. The system employs a network of sensors to collect data regarding the vessel's surroundings. This data is analyzed and presented in an augmented reality format to the ship's crew, helping them make informed navigation decisions and enhancing safety.

Rolls-Royce Marine's development of an Intelligent Awareness System (IAS) showcases how IoT and data analysis can significantly enhance maritime navigation and safety. The system represents a significant step towards the realization of autonomous vessels.

Intelligent Awareness System—IoT Integration

The IAS is a comprehensive solution designed to augment the situational awareness of a vessel's crew. It employs an extensive network of IoT sensors, including LiDAR (Light Detection and Ranging), radar, thermal imaging, HD cameras, and satellite data to continuously collect data about the vessel's surroundings. This data encompasses everything, from weather conditions, nearby ships, and possible obstacles to the depth and condition of the water.

Data Analysis and Augmented Reality

The raw sensor data collected is analyzed using machine learning algorithms and artificial intelligence. The system can identify and classify objects, predict their future positions and movements, and assess potential collision risks.

Moreover, the processed data is presented in an augmented reality format on the bridge, giving the crew a comprehensive and intuitive view of the vessel's surroundings. The system can highlight potential hazards and propose optimal navigation paths, allowing the crew to make informed decisions and take appropriate actions promptly.

Enhanced Safety and Navigation

The implementation of the IAS has significantly improved maritime safety. By providing the crew with a complete understanding of the vessel's environment, it helps prevent collisions and other navigational accidents. The system also allows for safer operations in challenging weather conditions or congested waterways, where traditional navigation systems might fall short.

Additionally, the system enhances navigation efficiency. By suggesting the best paths based on real-time conditions and predictive analytics, it helps optimize fuel consumption, reduce travel time, and improve overall voyage efficiency.

Future Implications

The IAS has implications far beyond improving navigation and safety. It is a key step towards fully autonomous vessels, as it addresses one of the primary challenges in autonomous navigation—understanding and responding to the maritime environment.

Rolls-Royce Marine's Intelligent Awareness System illustrates the profound impact IoT and data analysis can have on maritime safety and navigation. It paves the way for safer, more efficient voyages, and potentially autonomous shipping in the future. It serves as a testament to the transformative potential of these technologies in the maritime industry.

4.1.4. Case Study 4

Environmental Compliance: Shipping companies are under increasing pressure to reduce their environmental impact. Carnival Corporation has leveraged IoT and data analysis to ensure their fleet's compliance with environmental regulations. The ships are equipped with sensors that monitor emissions in real-time, and the data is analyzed to ensure they are within the permissible limits. The system also provides insights for optimizing fuel consumption, contributing to environmental sustainability.

With increasing concerns about environmental sustainability and tighter regulations, the maritime industry is under significant pressure to reduce its environmental impact. Carnival Corporation, the world's largest cruise ship operator, provides an instructive case study of how IoT and data analysis can aid in environmental compliance and sustainability efforts.

IoT for Environmental Monitoring

In an industry-first initiative, Carnival Corporation has equipped its entire fleet with IoT sensors to monitor emissions in real-time. These sensors are installed in key areas such as exhaust stacks and engine rooms, continuously monitoring the emissions of harmful pollutants, such as sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter.

The data collected by these sensors is sent to a central system for real-time monitoring and analysis. This allows Carnival to ensure that its ships are in compliance with international maritime environmental regulations, such as those imposed by the International Maritime Organization (IMO).

Data Analysis for Compliance and Efficiency

The data analysis does not stop at compliance checking. Advanced algorithms and analytics are used to analyze the emissions data in conjunction with other operational data, such as engine performance, fuel consumption, and voyage details.

This data analysis provides valuable insights that Carnival uses for optimizing operations. For instance, it can identify operational conditions or practices that lead to higher emissions and suggest adjustments to reduce the environmental impact.

One key area of focus is fuel efficiency. By analyzing the correlation between operational parameters and fuel consumption, the system can suggest optimal cruising speeds, engine settings, and even route planning to minimize fuel consumption. This not only helps in reducing emissions but also contributes to significant cost savings.

Environmental Sustainability and Beyond

Carnival Corporation's application of IoT and data analysis goes beyond compliance with environmental regulations. It demonstrates a proactive approach to sustainability by minimizing emissions and optimizing fuel use.

Moreover, by enabling real-time monitoring and continuous data analysis, the system offers a level of transparency and accountability that can boost stakeholder confidence and improve the company's reputation in terms of environmental stewardship.

Carnival Corporation's initiative showcases how maritime companies can leverage IoT and data analysis for environmental compliance and sustainability. It represents a significant shift towards data-driven environmental management in the maritime industry, emphasizing the potential of these technologies in aiding the sector's transition towards a more sustainable future.

4.1.5. Case Study 5

Application of Internet of Things (IoT) and Big Data in the Maritime Industries: Ship Allocation Model is a research paper by Mohammad Danil Arifin that investigates the usage of IoT and Big Data in maritime industries, with a specific focus on a ship allocation model.

IoT, as a gateway to digital transformation, alongside Big Data, AI, and blockchain, relies heavily on digitized data. The study posits that the transformation of physical framework information into digital data opens up possibilities to improve vessel operations. Moreover, several stakeholders, including consignees, shipyards, shippers, manufacturers, and classification societies, are interested in maritime Big Data due to its potential to uncover hidden information useful for operations.

The research illustrates the significant changes in the world's ship logistics industry due to global cargo movement, which in turn has led to an exponential growth in available Big Data. The effective utilization of this Big Data and IoT could lead to major innovations in the shipping industry.

The paper presents a ship allocation model developed using maritime Big Data and data extracted from IoT. The model uses a Machine Learning Database (MLDB) with multiple types of data, such as AIS data, ship operational data, ship data, port data, and route data. Three distinct models were utilized to develop the ship allocation model, namely the shipper, shipowner, and operator models.

The paper highlights the development of a system for ship allocation using maritime Big Data and IoT data. The allocation model effectively balances supply and demand, identifies effective vessel specifications, and gauges the impact of vessel efficiency on demand. A 210,000 DWT vessel was found to be the most competitive for iron ore transport from Australia to Japan. The study suggests that future research should focus on simulating the automatic ship allocation model based on global ship allocations for different cargoes, ship sizes, and types [70].

4.1.6. Case Study 6

Optimization in Shipping and Port Industries Through Big Data Analytics: A study by Dalaklis et al. explores the role of Industry 4.0 technologies, such as AI, BDA, Cloud Computing, and IoT in revolutionizing operations within the shipping and port industries. The research focuses on the management of vast amounts of data generated by on-board ship computer systems and IT applications related to ship and port management. The authors propose the use of software tools to extract and process relevant information and advanced algorithms to perform statistical analyses. Through a SWOC (Strengths, Weaknesses, Opportunities, and Challenges) analysis matrix, the study identifies and discusses the tools and techniques associated with BDA, highlighting the potential of effective Big Data management in improving or optimizing maritime transport activities and port operations [71].

4.2. Role of Data Analysis in Enhancing Maritime Operations

Data analysis plays a critical role in augmenting maritime operations by enabling the extraction of actionable insights from vast amounts of data generated by IoT devices. It serves to (Figure 5).

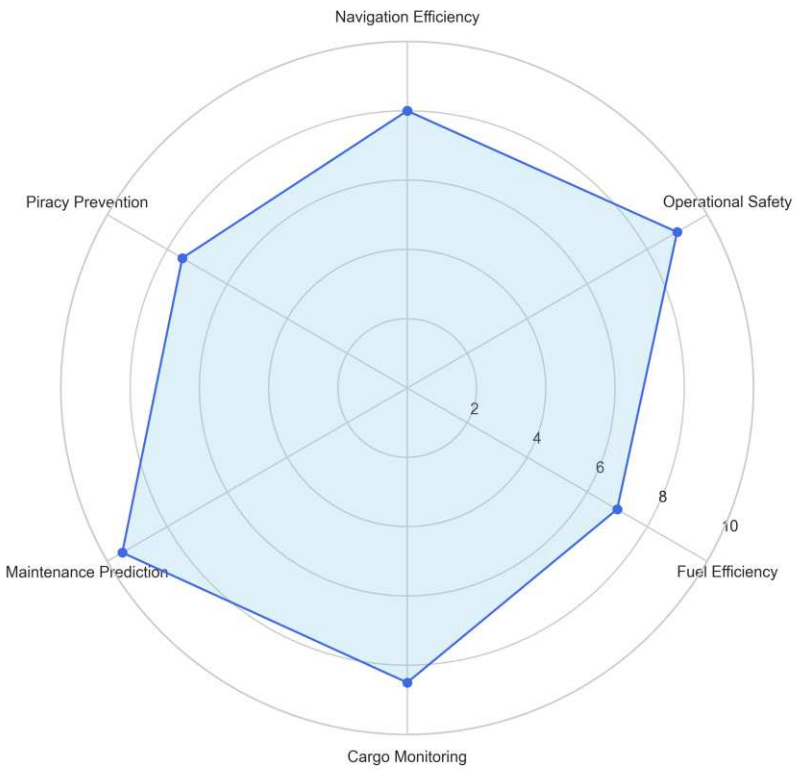

Figure 5. Enhancement in Maritime Operations due to Data Analysis.

4.2.1. Boost Operational Efficiency

Data analysis is a powerful tool for optimizing maritime operations. It enables the discovery of patterns and trends from the vast amounts of data generated by IoT devices in maritime environments. For example, by analyzing data related to vessel speed, fuel consumption, weather conditions, and sea currents, optimal routes can be determined to save fuel and time.

Moreover, data analysis can streamline various processes, such as cargo loading and unloading, by identifying bottlenecks and suggesting improvements. By correlating data from different sources, inefficiencies in operations can be pinpointed and resolved, thereby improving the overall operational efficiency of maritime organizations. [80].

4.2.2. Improve Safety

Safety is paramount in the maritime industry. Data analysis plays a crucial role in identifying potential safety hazards and risks. By analyzing data from various sensors and systems aboard a vessel, such as navigation systems, engine control systems, and safety equipment, anomalies and potential hazards can be detected early.

This early detection enables proactive measures, such as adjusting the vessel's course or performing emergency maintenance, preventing accidents and enhancing the safety of the crew, cargo, and vessel. In the long run, this could lead to the development of safer maritime practices and protocols, reducing the occurrence of maritime incidents [81].

4.2.3. Enhance Decision-Making

Data-driven decision-making is critical in today's complex and dynamic maritime environment. By transforming raw data into actionable insights, data analysis aids decision-makers in making more informed and strategic decisions.

From route planning and weather forecasting to maintenance scheduling and resource allocation, every aspect of maritime operations can benefit from data-driven insights. This not only leads to improved outcomes and reduced costs but also contributes to the resilience and adaptability of maritime organizations [81].

4.2.4. Enable Predictive Maintenance

One of the most significant benefits of data analysis in the maritime industry is the enablement of predictive maintenance. By analyzing real-time data from machinery and equipment, such as engine performance data, potential issues can be predicted before they result in major failures or downtime.

For instance, by identifying patterns in engine vibration or temperature data, it may be possible to detect an impending engine failure. This allows for timely maintenance, leading to significant cost savings by avoiding unplanned downtime and expensive emergency repairs [82].

4.2.5. Ensure Regulatory Compliance

In the face of stringent environmental regulations and standards, monitoring and analyzing data related to emissions and waste is crucial. Data analysis can provide accurate and real-time insights into a vessel's environmental impact, ensuring compliance with international and national regulations.

Avoiding non-compliance penalties is not the only benefit; preserving the reputation of the company in an increasingly environmentally conscious market can have long-term advantages. It also drives companies to adopt cleaner technologies and fuels, contributing to the global efforts to mitigate climate change [83].

4.2.6. Foster Innovation

Lastly, data analysis fosters innovation in the maritime industry. The insights derived from data analysis can reveal new opportunities for improving operations, optimizing performance, and creating value.

From developing advanced navigation systems that leverage real-time data to designing energy-efficient vessels based on fuel consumption data, the potential for innovation is immense. This not only drives the continuous improvement and evolution of maritime operations but also positions maritime companies to stay competitive in the digital age [78].

4.3. Benefits and Limitations

4.3.1. Increased Efficiency

Data analysis allows maritime organizations to use their resources more effectively. By understanding the patterns in data, organizations can streamline their operations, from vessel navigation to port logistics. As a result, shipping routes can be optimized, vessel speeds can be accurately determined to conserve fuel, and cargo can be loaded and unloaded more efficiently. These enhancements lead to substantial time savings and cost reductions, making maritime operations more efficient [84–86] (Table 3).

Table 3. Benefits and Limitations of Data Analysis in Maritime IoT.

Benefits of Data Analysis	Limitations of Data Analysis
Increased Efficiency	Data Quality
Improved Safety	Complexity
Enhanced Decision-Making	Security and Privacy
Predictive Capabilities	Cost
Regulatory Compliance	Interoperability
Innovation and Continuous Improvement	

4.3.2. Improved Safety

The maritime industry often faces diverse and extreme safety challenges, from unpredictable weather conditions to potential equipment failures. Data analysis provides an opportunity to mitigate these risks. By analyzing data from various sensors and IoT devices on a vessel, potential safety hazards can be identified and addressed promptly. This contributes to the enhancement of safety measures, reducing the risk of maritime accidents and ensuring the well-being of the crew and the integrity of the cargo [75].

4.3.3. Enhanced Decision-Making

Data-driven decision-making has revolutionized how maritime operations are managed. By analyzing vast amounts of data generated by IoT devices, maritime organizations can make decisions that are more accurate, strategic, and effective. This could range from selecting the best shipping route based on real-time weather and sea traffic data, to deciding the optimal time for equipment maintenance based on predictive analysis. As a result, these data-driven decisions lead to improved operational outcomes and increased profitability [87].

4.3.4. Predictive Capabilities

One of the most significant benefits of data analysis in maritime IoT is predictive capabilities. Through the analysis of real-time and historical data from IoT devices, potential issues such as machinery failures, route obstructions, or dangerous weather conditions can be predicted before they occur. This foresight allows for preemptive actions, which can prevent costly downtime and improve the reliability of maritime operations [88].

4.3.5. Regulatory Compliance

In an industry that is heavily regulated, ensuring compliance with environmental, safety and other regulations is crucial. Data analysis plays a key role in this, helping organizations monitor and analyze data related to emissions, waste disposal, safety protocols, and more. This enables them to ensure they are compliant, preserving their reputation and avoiding hefty penalties [89].

4.3.6. Innovation and Continuous Improvement

Data analysis can lead to profound insights, revealing new opportunities for improvement and innovation. These insights can drive the development of innovative solutions for challenges in the maritime industry, from energy conservation to automation. Additionally, continuous analysis of data allows for the constant refinement of processes, contributing to the ongoing improvement of maritime operations. It enables organizations to adapt and evolve with changing industry trends, market demands, and technological advancements, ensuring they remain competitive in the long term [90].

4.3.7. Limitations of Data Analysis in Maritime IoT

Data Quality

The effectiveness and accuracy of data analysis significantly depend on the quality of the data being analyzed. Poor quality data, which might be incomplete, inaccurate, outdated, or irrelevant, can lead to erroneous insights and faulty decision-making. For instance, inaccurate data from a weather sensor can lead to wrong predictions about sea conditions, potentially resulting in hazardous navigation decisions. Therefore, it is crucial to ensure the collection of high-quality, accurate, and relevant data for analysis in maritime IoT applications [91].

Complexity

Data generated from various IoT devices in the maritime industry can be immense in volume, high in velocity, and diverse in variety. Analyzing such big data requires sophisticated analytics capabilities, which can handle the complexity of different data types and structures, and the speed at which data is generated and processed. This adds a layer of complexity and requires a high level of expertise in data science and analytics, which might not be readily available in many maritime organizations [92].

Security and Privacy

As with any technology dealing with data, data security and privacy are significant concerns in maritime IoT. Sensitive data, including operational, financial, and personal data, needs to be protected from potential breaches. Any compromise on data security can have serious consequences, including financial losses, reputational damage, and even legal implications. Moreover, maritime organizations must ensure compliance with international and regional data protection regulations, adding another layer of complexity to data analysis in maritime IoT [93].

Cost

Implementing advanced data analytics can be costly. The investment needed for the necessary hardware, software, and infrastructure can be substantial. Additionally, there is the cost of hiring or training staff with expertise in data analysis. While these investments can lead to significant benefits in the long run, they might be prohibitive for smaller maritime organizations or for those with tight budgets [94].

Interoperability

In the maritime industry, data can come from various sources and in different formats, each with its own standards. The lack of standardization and interoperability between these systems can pose significant challenges in integrating and analyzing this data. Without effective integration, the full potential of data analysis cannot be realized, as valuable insights might be hidden in the unconnected, siloed data. This necessitates the adoption of common standards and protocols to ensure seamless data integration and maximize the benefits of data analysis in maritime IoT [95].

5. Emerging Trends and Future Directions

5.1. Current Research Trends in Data Analysis for Maritime IoT

The field of data analysis for maritime IoT is rapidly evolving, fueled by advancements in technology and increasing demands for efficiency, safety, and environmental sustainability in the maritime industry. The current researc75h trends indicate a progressive shift towards more advanced and sophisticated data analytics techniques and tools [8] (Figure 6).

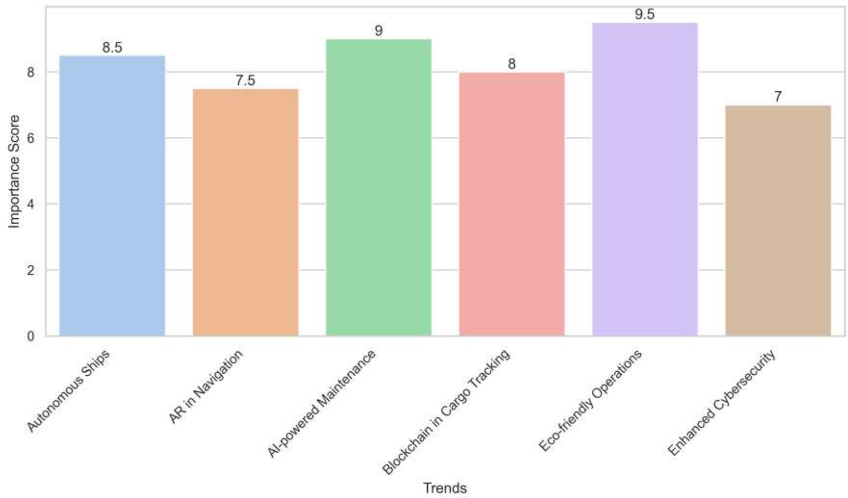

Figure 6. Emerging Trends in Maritime Operations.

- Edge and Fog Computing: To address the challenges of big data processing in maritime IoT, edge and fog computing are emerging as promising solutions. By processing data at the network edge or in a fog node, close to where it is generated, these techniques can reduce the latency, bandwidth usage, and load on the central servers, enhancing the efficiency and responsiveness of data analysis [95].
- Advanced Machine Learning and AI Techniques: Machine learning (ML) and artificial intelligence (AI) techniques are being increasingly applied to analyze maritime IoT data. These techniques can automate the analysis process and extract complex patterns and insights from large datasets that might be missed by traditional analysis methods. Current research is exploring various ML and AI techniques, including deep learning, reinforcement learning, and predictive analytics, for different maritime IoT applications [96].
- Real-time Analytics: As maritime operations become more dynamic and time-critical, the need for real-time data analysis is growing. Real-time analytics can provide instant insights from IoT data, enabling quick decision-making and responses to changing conditions. This is especially important for applications such as navigation, safety monitoring, and incident response, where delays in data analysis can have serious consequences [97].
- Cybersecurity Analytics: With the increasing reliance on IoT and data analysis, cybersecurity has become a critical concern in the maritime industry. Cybersecurity analytics is an emerging field that uses data analysis to detect and prevent cyber threats. This includes analyzing network traffic, system logs, and user behavior to identify suspicious activities and potential security breaches [98].
- Data Fusion and Multi-Source Analysis: Maritime IoT systems often involve multiple sensors and data sources. Data fusion techniques, which combine data from different sources to achieve more accurate and comprehensive insights, are being actively researched. This includes sensor fusion for improved navigation and monitoring, and fusion of operational, environmental, and financial data for strategic decision-making [99].

- Privacy-Preserving Data Analysis: With the increasing concerns about data privacy, research is focusing on developing techniques for privacy-preserving data analysis. These techniques aim to analyze data without compromising the privacy of individuals or revealing sensitive information. This is especially relevant for personal data collected by IoT devices on crew members and passengers, and confidential operational data [100].

5.2. The Role of AI and Machine Learning in Advancing Data Analysis for IoT

Artificial Intelligence (AI) and Machine Learning (ML) are playing a pivotal role in advancing data analysis, particularly in the context of IoT. In the maritime industry, they offer significant potential for automating and enhancing the analysis of data generated by IoT devices [83].

- Automating Data Analysis: ML algorithms can automate the process of data analysis, reducing the need for human intervention. This is particularly valuable for handling the large volumes of data generated by maritime IoT systems. ML can quickly analyze this data, identifying patterns and trends that can inform decision-making [101].
- Predictive Analysis: AI and ML excel at predictive analysis, which involves using historical data to predict future events or trends. In the maritime context, this can be used for predictive maintenance, forecasting weather and sea conditions, predicting port congestion, and more. These predictive capabilities can enhance efficiency, safety, and strategic planning in maritime operations [25].
- Real-time Data Analysis: AI and ML algorithms can process and analyze data in real time, enabling immediate responses to changing conditions. This can be vital for applications such as navigation, safety monitoring, and incident response, where delays in decision-making can have serious consequences [102].
- Complex Pattern Recognition: AI and ML can identify complex patterns and relationships in data that might be missed by traditional analysis methods. This can provide deeper insights into maritime operations and facilitate more informed and strategic decision-making [103–105].

5.3. Future Opportunities and Challenges in the Field

Artificial Intelligence (AI) and Machine Learning (ML) are playing a pivotal role in advancing data analysis, particularly in the context of IoT. In the maritime industry, they offer significant potential for automating and enhancing the analysis of data generated by IoT devices [93].

As the integration of IoT in the maritime industry continues to grow, so too does the potential for data analysis. However, with these opportunities come a set of challenges that must be addressed.

- Opportunities: The future of data analysis in maritime IoT holds immense opportunities. Advanced analytics can lead to more efficient operations, improved safety, enhanced decision-making, predictive capabilities, and compliance with regulations. Moreover, as data analysis techniques continue to evolve, they can uncover new insights, fostering innovation and continuous improvement in maritime operations.
- Challenges: Despite the potential, several challenges need to be tackled. Ensuring data quality, dealing with the complexity of big data analysis, protecting data security and privacy, managing the cost of implementing advanced analytics, and addressing interoperability issues are all significant hurdles. Furthermore, as the field continues to advance, keeping up with the latest techniques and technologies will be a constant challenge.

It is essential for the maritime industry to recognize and address these challenges to fully harness the potential of data analysis in IoT. Collaboration between industry, academia, and regulators will be key to developing effective solutions and moving the field forward.

6. Recommendations and Future Directions in Maritime IoT Data Analysis

The advent of the Fourth Industrial Revolution, characterized by IoT, AI, Big Data Analytics, and Cloud Computing, has significantly reshaped the maritime industry. As our comprehensive review demonstrates, the implications of data analysis in maritime IoT applications are vast. Here, we outline key recommendations and future directions, largely stemming from the insights of expert reviewers and emerging trends:

1. Ensuring Data Quality:
    - Embrace routine sensor calibration and periodic maintenance.
    - Harness data validation and filtering algorithms to tackle anomalies.
    - Champion industry-wide data standardization initiatives.
    - Advocate for collaborative data sharing platforms for cross-verification.
2. Strengthening Data Security:
    - Prioritize data encryption, both during transit and when stored.
    - Mandate regular security audits and penetration testing.
    - Establish robust access controls and rigorous authentication protocols.
3. Empowering Small-scale Maritime Operations:
    - Endorse open-source data analysis platforms.
    - Integrate cloud-based solutions, sidestepping the need for costly infrastructure.
    - Promote collaborations and consortiums for cost-sharing and resource pooling.
4. Fostering Interoperability:
    - Lead the charge for universal maritime data standards.
    - Integrate versatile middleware solutions for system harmonization.
    - Catalyze joint development initiatives, uniting stakeholders.
5. Harnessing AI and Machine Learning:
    - Capitalize on AI for dynamic functions, such as predictive maintenance and cargo tracking.
    - Recognize the boundless potential in realms such as autonomous shipping and advanced threat models.
6. Upholding Ethics and Data Privacy:
    - Establish transparent data policies.
    - Instill a culture of data ethics through consistent training.
    - Stay abreast of and compliant with evolving data privacy laws.
7. Expanding Case Studies:
    - Highlight success stories such as the Port of Singapore's traffic management analytics.
    - Showcase pioneering predictive analytics models, such as those adopted by Maersk Line.
8. Anticipating Maritime Tech Evolution:
    - Prepare for cutting-edge trends, such as edge computing and digital twins in maritime.
    - Encourage tech partnerships to stay ahead in the rapidly evolving landscape.
9. Prioritizing Environmental Conservation:
    - Leverage analytics for fuel-efficient routes and reduced emissions.
    - Develop systems to manage ballast water discharge, ensuring environmental sustainability.
10. Bridging the Research Gap:
    - Venture into developing resilient AI models tailored for maritime nuances.
    - Explore quantum computing's potential in maritime logistics.
    - Delve into the socio-economic implications of IoT in maritime contexts.

By addressing these areas and implementing these recommendations, the maritime industry can fully leverage the benefits of IoT and data analysis, propelling it towards a technologically advanced and sustainable future.

7. Conclusions

The advent of the Internet of Things (IoT) has had a transformative impact on the maritime industry, providing unprecedented opportunities for enhancing efficiency, safety, and environmental sustainability. The ability to generate vast amounts of data through IoT devices has ushered in a new era of data-driven operations, in which data analysis plays a pivotal role.

This review has explored the current state and potential of data analysis in maritime IoT applications. The case studies presented illustrate the real-world benefits of data analysis, from predictive maintenance and efficient port operations to improved navigation safety and environmental compliance. The discussion on the benefits and limitations of data analysis further highlights its potential and the challenges that need to be addressed.

Emerging trends and future directions in the field were also discussed, pointing to exciting developments such as the growing application of AI and ML techniques, real-time analytics, cybersecurity analytics, data fusion, and privacy-preserving data analysis. However, several challenges need to be tackled to fully harness these advancements, including data quality, complexity, security and privacy, cost, and interoperability issues.

As the maritime industry continues to embrace IoT and data analysis, it will be crucial to continue research and development in these areas, with a focus on overcoming the challenges and maximizing the opportunities. The future of maritime operations are likely to be defined by the industry's ability to effectively analyze and leverage the vast amount of data generated by IoT devices. This future promises exciting possibilities for improving maritime operations and contributing to a more efficient, safe, and sustainable industry.

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References

1. Katranas, G.; Riel, A.; Corchado-Rodríguez, J.M.; Plaza-Hernández, M. The SMARTSEA Education Approach to Lever-aging the Internet of Things in the Maritime Industry. In Systems, Software and Services Process Improvement. Proceedings of the 27th European Conference, EuroSPI 2020, Proceedings 27, Düsseldorf, Germany, 9–11 September 2020; Springer International Publishing: Berlin/Heidelberg, Germany, 2020; pp. 247–258.
2. Ashraf, I.; Park, Y.; Hur, S.; Kim, S.W.; Alroobaea, R.; Bin Zikria, Y.; Nosheen, S. A Survey on Cyber Security Threats in IoT-Enabled Maritime Industry. *IEEE Trans. Intell. Transp. Syst.* **2022**, *24*, 2677–2690. [CrossRef]
3. Dewan, M.H.; Godina, R. Effective Training of Seafarers on Energy Efficient Operations of Ships in the Maritime Industry. *Procedia Comput. Sci.* **2023**, *217*, 1688–1698. [CrossRef]
4. Mallam, S.C.; Ernstsen, J.; Nazir, S. Safety in Shipping: Investigating Safety Climate in Norwegian Maritime Workers. *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* **2019**, *63*, 1844–1848. [CrossRef]
5. Chang, C.H.; Wenming, S.; Wei, Z.; Changki, P.; Kontovas, C.A. Evaluating Cybersecurity Risks in the Maritime Industry: A Literature Review. In Proceedings of the International Association of Maritime Universities (IAMU) Conference, Tokyo, Japan, 29 October–1 November 2019.
6. Mallouppas, G.; Ioannou, C.; Yfantis, E.A. A Review of the Latest Trends in the Use of Green Ammonia as an Energy Carrier in Maritime Industry. *Energies* **2022**, *15*, 1453. [CrossRef]

7. Plaza-Hernández, M.; Gil-González, A.B.; Rodríguez-González, S.; Prieto-Tejedor, J.; Corchado-Rodríguez, J.M. Integration of IoT Technologies in the Maritime Industry. In *Distributed Computing and Artificial Intelligence, Special Sessions, 17th International Conference*; Springer International Publishing: Berlin/Heidelberg, Germany, 2021; pp. 107–115.
8. Ray, G.C.; McCormick-Ray, J. *Coastal-Marine Conservation: Science and Policy*; John Wiley & Sons: Hoboken, NJ, USA, 2009.
9. Prabhakar, L.W.; Ho, J.; Bateman, W.S.G. *The Evolving Maritime Balance of Power in the Asia-Pacific: Maritime Doctrines and Nuclear Weapons at Sea*; World Scientific: Singapore, 2006.
10. Kalley, T.E. *Importance of United States Naval Forward Presence in Mediterranean Affairs. Diss. Monterey, California*; Naval Postgraduate School: Monterey, CA, USA, 2001.
11. Tam, K.; Jones, K.D. Maritime cybersecurity policy: The scope and impact of evolving technology on international shipping. *J. Cyber Policy* **2018**, *3*, 147–164. [CrossRef]
12. Tac, B.O.; Akyuz, E.; Celik, M. Analysis of performance influence factors on shipboard drills to improve ship emergency preparedness at sea. *Int. J. Shipp. Transp. Logist.* **2020**, *12*, 92. [CrossRef]
13. Ben Farah, M.A.; Ukwandu, E.; Hindy, H.; Brosset, D.; Bures, M.; Andonovic, I.; Bellekens, X. Cyber Security in the Maritime Industry: A Systematic Survey of Recent Advances and Future Trends. *Information* **2022**, *13*, 22. [CrossRef]
14. Hiekata, K.; Wanaka, S.; Mitsuyuki, T.; Ueno, R.; Wada, R.; Moser, B. Systems analysis for deployment of internet of things (IoT) in the maritime industry. *J. Mar. Sci. Technol.* **2020**, *26*, 459–469. [CrossRef]
15. Razmjooei, D.; Alimohammadlou, M.; Kordshouli, H.-A.R.; Askarifar, K. Industry 4.0 research in the maritime industry: A bibliometric analysis. *WMU J. Marit. Aff.* **2023**. [CrossRef]
16. Salah, K.; Alfalasi, A.; Alfalasi, M.; Alharmoudi, M.; Alzaabi, M.; Alzyeodi, A.; Ahmad, R.W. IoT-Enabled Shipping Container with Environmental Monitoring and Location Tracking. In Proceedings of the IEEE 17th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 10 January 2020; pp. 1–6.
17. Mahmood, K.; Ferzund, J.; Saleem, M.A.; Shamshad, S.; Das, A.K.; Park, Y. A Provably Secure Mobile User Authentication Scheme for Big Data Collection in IoT-Enabled Maritime Intelligent Transportation System. *IEEE Trans. Intell. Transp. Syst.* **2022**, *24*, 2411–2421. [CrossRef]
18. Hasan, H.; AlHadhrami, E.; AlDhaheri, A.; Salah, K.; Jayaraman, R. Smart contract-based approach for efficient shipment management. *Comput. Ind. Eng.* **2019**, *136*, 149–159. [CrossRef]
19. Bracke, V.; Sebrechts, M.; Moons, B.; Hoebeke, J.; De Turck, F.; Volckaert, B. Design and evaluation of a scalable Internet of Things backend for smart ports. *Software Pract. Exp.* **2021**, *51*, 1557–1579. [CrossRef]
20. Leclerc, Y.; Ircha, M. Canada's Rapidly Evolving Smart Ports. In *Smart Ports and Robotic Systems: Navigating the Waves of Techno-Regulation and Governance*; Springer International Publishing: Cham, Switzerland, 2023; pp. 167–187.
21. Wang, X.; Yuen, K.F.; Wong, Y.D.; Li, K.X. How can the maritime industry meet Sustainable Development Goals? An analysis of sustainability reports from the social entrepreneurship perspective. *Transp. Res. D Transp. Environ.* **2020**, *78*, 102173. [CrossRef]
22. Liu, R.W.; Nie, J.; Garg, S.; Xiong, Z.; Zhang, Y.; Hossain, M.S. Data-Driven Trajectory Quality Improvement for Promoting Intelligent Vessel Traffic Services in 6G-Enabled Maritime IoT Systems. *IEEE Internet Things J.* **2020**, *8*, 5374–5385. [CrossRef]
23. Yang, C.-S. Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use. *Transp. Res. E Logist. Transp. Rev.* **2019**, *131*, 108–117. [CrossRef]
24. Aiello, G.; Giallanza, A.; Mascarella, G. Towards Shipping 4.0. A preliminary gap analysis. *Procedia Manuf.* **2020**, *42*, 24–29. [CrossRef]
25. Munim, Z.H.; Dushenko, M.; Jimenez, V.J.; Shakil, M.H.; Imset, M. Big data and artificial intelligence in the maritime industry: A bibliometric review and future research directions. *Marit. Policy Manag.* **2020**, *47*, 577–597. [CrossRef]
26. Feng, W.; Chen, Y.; Wang, C.-X.; Ge, N.; Lu, J. Hybrid Satellite-Terrestrial Communication Networks for the Maritime Internet of Things: Key Technologies, Opportunities, and Challenges. *IEEE Internet Things J.* **2021**, *8*, 8910–8934. [CrossRef]
27. Cowhey, P.F.; Aronson, J.D. *Digital DNA: Disruption and the Challenges for Global Governance*; Oxford University Press: Oxford, UK, 2017.
28. Okumus, D.; Gunbeyaz, S.A.; Kurt, R.E.; Turan, O. Towards a circular maritime industry: Identifying strategy and technology solutions. *J. Clean. Prod.* **2023**, *382*, 134935. [CrossRef]
29. Irani, Z.; Ezingeard, J.-N.; Grieve, R. Integrating the costs of a manufacturing IT/IS infrastructure into the investment decision-making process. *Technovation* **1997**, *17*, 695–706. [CrossRef]
30. Tan, C.C. *An Advanced Strategic Management Text: A Research-Oriented Approach*; IMRF Publication House: Vijayawada, India, 2018.
31. Kotabe, M.M.; Helsen, K. *Global Marketing Management*; John Wiley & Sons: Hoboken, NJ, USA, 2022.
32. Wright, R.G. *Unmanned and Autonomous Ships: An Overview of Mass*; Routledge: Abington, UK, 2020.
33. Mallam, S.C.; Nazir, S.; Sharma, A. The human element in future Maritime Operations—Perceived impact of autonomous shipping. *Ergonomics* **2020**, *63*, 334–345. [CrossRef]
34. Yang, D.; Wu, L.; Wang, S.; Jia, H.; Li, K.X. How big data enriches maritime research—A critical review of Automatic Identification System (AIS) data applications. *Transp. Rev.* **2019**, *39*, 755–773. [CrossRef]
35. Aslam, S.; Michaelides, M.P.; Herodotou, H. Internet of Ships: A Survey on Architectures, Emerging Applications, and Challenges. *IEEE Internet Things J.* **2020**, *7*, 9714–9727. [CrossRef]
36. Huo, Y.; Dong, X.; Beatty, S. Cellular Communications in Ocean Waves for Maritime Internet of Things. *IEEE Internet Things J.* **2020**, *7*, 9965–9979. [CrossRef]

37. Androjna, A.; Brcko, T.; Pavic, I.; Greidanus, H. Assessing Cyber Challenges of Maritime Navigation. *J. Mar. Sci. Eng.* **2020**, *8*, 776. [CrossRef]
38. Xu, G.; Shi, Y.; Sun, X.; Shen, W. Internet of Things in Marine Environment Monitoring: A Review. *Sensors* **2019**, *19*, 1711. [CrossRef]
39. Bakdi, A.; Kristensen, N.B.; Stakkeland, M. Multiple Instance Learning with Random Forest for Event Logs Analysis and Predictive Maintenance in Ship Electric Propulsion System. *IEEE Trans. Ind. Inform.* **2022**, *18*, 7718–7728. [CrossRef]
40. Roy, M.; Roy, A. Nexus of Internet of Things (IoT) and Big Data: Roadmap for Smart Management Systems (SMgS). *IEEE Eng. Manag. Rev.* **2019**, *47*, 53–65. [CrossRef]
41. Radouan Ait Mouha, R.A. Internet of Things (IoT). *J. Data Anal. Inf. Process.* **2021**, *09*, 77–101. [CrossRef]
42. Salam, A. Internet of Things for Sustainable Community Development: Introduction and Overview. In *Internet of Things for Sustainable Community Development*; Springer: Cham, Switzerland, 2020; pp. 1–31.
43. Široka, M.; Piličić, S.; Milošević, T.; Lacalle, I.; Traven, L. A novel approach for assessing the ports' environmental impacts in real time—The IoT based port environmental index. *Ecol. Indic.* **2021**, *120*, 106949. [CrossRef]
44. de la Peña Zarzuelo, I.; Freire Soeane, M.J.; López Bermúdez, B. Industry 4.0 in the port and maritime industry: A literature review. *J. Ind. Inf. Integr.* **2020**, *20*, 100173. [CrossRef]
45. Fraga-Lamas, P.; Varela-Barbeito, J.; Fernandez-Carames, T.M. Next Generation Auto-Identification and Traceability Technologies for Industry 5.0: A Methodology and Practical Use Case for the Shipbuilding Industry. *IEEE Access* **2021**, *9*, 140700–140730. [CrossRef]
46. Mudra, G.; Cui, H.; Johnstone, M.N. Survey: An Overview of Lightweight RFID Authentication Protocols Suitable for the Maritime Internet of Things. *Electronics* **2023**, *12*, 2990. [CrossRef]
47. Tan, W.C.; Sidhu, M.S. Review of RFID and IoT integration in supply chain management. *Oper. Res. Perspect.* **2022**, *9*, 100229. [CrossRef]
48. Jovic, M.; Kavran, N.; Aksentijevic, S.; Tijan, E. The Transition of Croatian Seaports into Smart Ports. In Proceedings of the 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia, 20–24 May 2019; pp. 1386–1390.
49. Wang, K.; Hu, Q.; Zhou, M.; Zun, Z.; Qian, X. Multi-aspect applications and development challenges of digital twin-driven management in global smart ports. *Case Stud. Transp. Policy* **2021**, *9*, 1298–1312. [CrossRef]
50. Yau, K.-L.A.; Peng, S.; Qadir, J.; Low, Y.-C.; Ling, M.H. Towards Smart Port Infrastructures: Enhancing Port Activities Using Information and Communications Technology. *IEEE Access* **2020**, *8*, 83387–83404. [CrossRef]
51. Babica, V.; Sceulovs, D.; Rustenova, E. Digitalization in Maritime Industry: Prospects and Pitfalls. In *ICTE in Transportation and Logistics 2019*; Springer International Publishing: Berlin/Heidelberg, Germany, 2020; pp. 20–27.
52. Kim, M.; Joung, T.-H.; Jeong, B.; Park, H.-S. Autonomous shipping and its impact on regulations, technologies, and industries. *J. Int. Marit. Saf. Environ. Aff. Shipp.* **2020**, *4*, 17–25. [CrossRef]
53. Clott, C.; Hartman, B. Do maritime innovation centers produce results? *WMU J. Marit. Aff.* **2022**, *21*, 283–326. [CrossRef]
54. Mikhaylov, K.; Alves, H.; Höyhtyä, M. Drivers, Use-Cases, Key Indicators, and Requirements for Satellite-Based Ma-chine-Type Connectivity and IoT. In Proceedings of the 39th International Communications Satellite Systems Conference (ICSSC 2022), Stresa, Italy, 18–21 October 2022; pp. 221–227.
55. Halff, A.; Younes, L.; Boersma, T. The likely implications of the new IMO standards on the shipping industry. *Energy Policy* **2019**, *126*, 277–286. [CrossRef]
56. Xia, T.; Wang, M.M.; Zhang, J.; Wang, L. Maritime Internet of Things: Challenges and Solutions. *IEEE Wirel. Commun.* **2020**, *27*, 188–196. [CrossRef]
57. Freire, W.P.; Melo, W.S.; do Nascimento, V.D.; Nascimento, P.R.M.; de Sá, A.O. Towards a Secure and Scalable Maritime Monitoring System Using Blockchain and Low-Cost IoT Technology. *Sensors* **2022**, *22*, 4895. [CrossRef] [PubMed]
58. Duran, C.A.; Fernandez-Campusano, C.; Carrasco, R.; Vargas, M.; Navarrete, A. Boosting the Decision-Making in Smart Ports by Using Blockchain. *IEEE Access* **2021**, *9*, 128055–128068. [CrossRef]
59. Yang, Y.; Zhong, M.; Yao, H.; Yu, F.; Fu, X.; Postolache, O. Internet of things for smart ports: Technologies and challenges. *IEEE Instrum. Meas. Mag.* **2018**, *21*, 34–43. [CrossRef]
60. Pu, S.; Lam, J.S.L. Blockchain adoptions in the maritime industry: A conceptual framework. *Marit. Policy Manag.* **2020**, *48*, 777–794. [CrossRef]
61. Adi, E.; Anwar, A.; Baig, Z.; Zeadally, S. Machine learning and data analytics for the IoT. *Neural Comput. Appl.* **2020**, *32*, 16205–16233. [CrossRef]
62. Siow, E.; Tiropanis, T.; Hall, W. Analytics for the Internet of Things. *ACM Comput. Surv.* **2019**, *51*, 1–36. [CrossRef]
63. Imran; Iqbal, N.; Kim, D.H. IoT Task Management Mechanism Based on Predictive Optimization for Efficient Energy Consumption in Smart Residential Buildings. *Energy Build.* **2022**, *257*, 111762. [CrossRef]
64. Lu, S.; Lu, J.; An, K.; Wang, X.; He, Q. Edge Computing on IoT for Machine Signal Processing and Fault Diagnosis: A Review. *IEEE Internet Things J.* **2023**, *10*, 11093–11116. [CrossRef]
65. Roy, T.L.D.; Rao, K.S.; Rachapudi, V.; Rani, B.U. An AI enabled IoT model to automate Shrimp culture. *AIP Conf. Proc.* **2023**, *2477*, 030030. [CrossRef]

66. Megalingam, R.K.; Manoharan, S.K.; Mohandas, S.M.; Reddy, C.P.K.; Vijay, E.; Naveen, P.N.V.K.; Chandrika, D. Wearable Hand Orthotic Device for Rehabilitation: Hand Therapy with Multi-Mode Control and Real-Time Feedback. *Appl. Sci.* **2023**, *13*, 3976. [CrossRef]
67. Miller, M.; Kisiel, A.; Cembrowska-Lech, D.; Durlik, I.; Miller, T. IoT in Water Quality Monitoring—Are We Really Here? *Sensors* **2023**, *23*, 960. [CrossRef]
68. Bi, Z.; Jin, Y.; Maropoulos, P.; Zhang, W.-J.; Wang, L. Internet of things (IoT) and big data analytics (BDA) for digital manufacturing (DM). *Int. J. Prod. Res.* **2023**, *61*, 4004–4021. [CrossRef]
69. Rajagopal, S.M.; Supriya, M.; Buyya, R. FedSDM: Federated learning based smart decision making module for ECG data in IoT integrated Edge–Fog–Cloud computing environments. *Internet Things* **2023**, *22*, 100784. [CrossRef]
70. Liu, Y.; Yu, W.; Rahayu, W.; Dillon, T. An Evaluative Study on IoT Ecosystem for Smart Predictive Maintenance (IoT-SPM) in Manufacturing: Multiview Requirements and Data Quality. *IEEE Internet Things J.* **2023**, *10*, 11160–11184. [CrossRef]
71. Ansere, J.A.; Kamal, M.; Khan, I.A.; Aman, M.N. Dynamic Resource Optimization for Energy-Efficient 6G-IoT Ecosystems. *Sensors* **2023**, *23*, 4711. [CrossRef]
72. El-Kady, A.H.; Halim, S.; El-Halwagi, M.M.; Khan, F. Analysis of safety and security challenges and opportunities related to cyber-physical systems. *Process. Saf. Environ. Prot.* **2023**, *173*, 384–413. [CrossRef]
73. Mazhar, T.; Irfan, H.M.; Haq, I.; Ullah, I.; Ashraf, M.; Al Shloul, T.; Ghadi, Y.Y.; Imran; Elkamchouchi, D.H. Analysis of Challenges and Solutions of IoT in Smart Grids Using AI and Machine Learning Techniques: A Review. *Electronics* **2023**, *12*, 242. [CrossRef]
74. Kumar, M.; Kumar, A.; Verma, S.; Bhattacharya, P.; Ghimire, D.; Kim, S.; Hosen, A.S.M.S. Healthcare Internet of Things (H-IoT): Current Trends, Future Prospects, Applications, Challenges, and Security Issues. *Electronics* **2023**, *12*, 2050. [CrossRef]
75. Kiobia, D.O.; Mwitta, C.J.; Fue, K.G.; Schmidt, J.M.; Riley, D.G.; Rains, G.C. A Review of Successes and Impeding Challenges of IoT-Based Insect Pest Detection Systems for Estimating Agroecosystem Health and Productivity of Cotton. *Sensors* **2023**, *23*, 4127. [CrossRef] [PubMed]
76. Zhang, H.; Gui, F. The Application and Research of New Digital Technology in Marine Aquaculture. *J. Mar. Sci. Eng.* **2023**, *11*, 401. [CrossRef]
77. Das, S. Digital Twins: The Key to Unlocking Industry 4.0 and Beyond. *SSRN Electron. J.* **2023**. [CrossRef]
78. Nikghadam, S.; Vanga, R.; Rezaei, J.; Tavasszy, L. Cooperation between vessel service providers in ports: An impact analysis using simulation for the Port of Rotterdam. *Marit. Transp. Res.* **2023**, *4*, 100083. [CrossRef]
79. Sam, T.H.; Zhang, H.; Jing, Y.; Yan, W.; Jie, W.; Jihu, L.; Vasudevan, A. An Empirical Analysis of the Factors Influencing Innovative Performance in the Sea Rice Market Industry in China. *GRADIVA* **2023**, *62*, 66–87.
80. Sarbanha, A.-A.; Larachi, F.; Taghavi, S.-M.; Thiboutot-Rioux, M.; Boudreau, A.; Dugas, G. Mitigation of Ship Emissions: Overview of Recent Trends. *Ind. Eng. Chem. Res.* **2023**, *62*, 1707–1724. [CrossRef]
81. El Mekkaoui, S.; Benabbou, L.; Caron, S.; Berrado, A. Deep Learning-Based Ship Speed Prediction for Intelligent Maritime Traffic Management. *J. Mar. Sci. Eng.* **2023**, *11*, 191. [CrossRef]
82. Fan, S.; Blanco-Davis, E.; Fairclough, S.; Zhang, J.; Yan, X.; Wang, J.; Yang, Z. Incorporation of seafarer psychological factors into maritime safety assessment. *Ocean Coast. Manag.* **2023**, *237*, 106515. [CrossRef]
83. Silionis, N.E.; Anyfantis, K.N. From preventive to predictive maintenance of ship hulls: The role of SHM. In Proceedings of the SNAME 8th International Symposium on Ship Operations, Management and Economics, Athens, Greece, 7–8 March 2023.
84. Chuah, L.F.; Mohd Rof'ie, N.R.; Mohd Salleh, N.H.; Abu Bakar, A.; Oloruntobi, O.; Othman, M.R.; Mohamed Fazlee, U.S.; Mubashir, M.; Asif, S. Analyzing the influencing factors of Port State Control for a cleaner environment via Bayesian network model. *Clean. Eng. Technol.* **2023**, *14*, 100636. [CrossRef]
85. Dalaklis, D.; Nikitakos, N.; Papachristos, D.; Dalaklis, A. Opportunities and Challenges in Relation to Big Data Analytics for the Shipping and Port Industries. In *Smart Ports and Robotic Systems*; Springer: Berlin/Heidelberg, Germany, 2023; pp. 267–290.
86. Rawson, A.; Brito, M. A survey of the opportunities and challenges of supervised machine learning in maritime risk analysis. *Transp. Rev.* **2023**, *43*, 108–130. [CrossRef]
87. Theotokatos, G.; Dantas, J.L.D.; Polychronidi, G.; Rentifi, G.; Colella, M.M. Autonomous shipping—An analysis of the maritime stakeholder perspectives. *WMU J. Marit. Aff.* **2022**, *22*, 5–35. [CrossRef]
88. Brous, P.; Janssen, M.; Herder, P. Internet of Things adoption for reconfiguring decision-making processes in asset management. *Bus. Process. Manag. J.* **2019**, *25*, 495–511. [CrossRef]
89. Khayyam, H.; Javadi, B.; Jalili, M.; Jazar, R.N. Artificial intelligence and internet of things for autonomous vehicles. In *Nonlinear Approaches in Engineering Applications: Automotive Applications of Engineering Problems*; Springer: Cham, Switzerland, 2020; pp. 38–69. [CrossRef]
90. Yakhou, M.; Dorweiler, V.P. Environmental accounting: An essential component of business strategy. *Bus. Strat. Environ.* **2004**, *13*, 65–77. [CrossRef]
91. Munirathinam, S. Industry 4.0: Industrial internet of things (IIOT). In *Advances in Computers*; Elsevier: Amsterdam, The Netherlands, 2020; Volume 117, pp. 129–164.
92. Fisher, C.W.; Kingma, B.R. Criticality of data quality as exemplified in two disasters. *Inf. Manag.* **2001**, *39*, 109–116. [CrossRef]
93. Iroju, O.; Oluwaseun, O. Big data in healthcare: Prospects, challenges and resolutions. In Proceedings of the Future Technologies Conference (FTC), San Francisco, CA, USA, 6–7 December 2016. [CrossRef]

94. Elgendy, N.; Elragal, A. Big data analytics: A literature review paper. Advances in Data Mining. Applications and Theoretical Aspects. In Proceedings of the 14th Industrial Conference, ICDM 2014, St. Petersburg, Russia, 16–20 July 2014. [CrossRef]
95. Vermesan, O.; Friess, P. (Eds.) . *Internet of Things: Converging Technologies for Smart Environments and Integrated Eco-Systems*; River Publishers: Aalborg, Denmark, 2013.
96. Badidi, E.; Mahrez, Z.; Sabir, E. Fog Computing for Smart Cities' Big Data Management and Analytics: A Review. *Futur. Internet* **2020**, *12*, 190. [CrossRef]
97. Soori, M.; Arezoo, B.; Dastres, R. Artificial intelligence, machine learning and deep learning in advanced robotics, a review. *Cogn. Robot.* **2023**, *3*, 54–70. [CrossRef]
98. Garg, S.; Singh, A.; Batra, S.; Kumar, N.; Yang, L.T. UAV-Empowered Edge Computing Environment for Cyber-Threat Detection in Smart Vehicles. *IEEE Netw.* **2018**, *32*, 42–51. [CrossRef]
99. Afenyo, M.; Caesar, L.D. Maritime cybersecurity threats: Gaps and directions for future research. *Ocean Coast. Manag.* **2023**, *236*, 106493. [CrossRef]
100. Adriano, B.; Xia, J.; Baier, G.; Yokoya, N.; Koshimura, S. Multi-Source Data Fusion Based on Ensemble Learning for Rapid Building Damage Mapping during the 2018 Sulawesi Earthquake and Tsunami in Palu, Indonesia. *Remote. Sens.* **2019**, *11*, 886. [CrossRef]
101. Gai, K.; Tang, H.; Li, G.; Xie, T.; Wang, S.; Zhu, L.; Choo, K.-K.R. Blockchain-Based Privacy-Preserving Positioning Data Sharing for IoT-Enabled Maritime Transportation Systems. *IEEE Trans. Intell. Transp. Syst.* **2022**, *24*, 2344–2358. [CrossRef]
102. Dornemann, J.; Rückert, N.; Fischer, K.; Taraz, A. Artificial Intelligence and Operations Research in Maritime Logistics. In *Data Science in Maritime and City Logistics: Data-Driven Solutions for Logistics and Sustainability, Proceedings of the Hamburg International Conference of Logistics (HICL)*; epubli GmbH: Berlin, Germany, 2020; Volume 30, pp. 337–381.
103. Milo, T.; Somech, A. Automating Exploratory Data Analysis via Machine Learning: An Overview. In Proceedings of the ACM SIGMOD International Conference on Management of Data, ACM, New York, NY, USA, 11 June 2020; pp. 2617–2622.
104. Challita, U.; Ferdowsi, A.; Chen, M.; Saad, W. Machine Learning for Wireless Connectivity and Security of Cellular-Connected UAVs. *IEEE Wirel. Commun.* **2019**, *26*, 28–35. [CrossRef]
105. Dimiduk, D.M.; Holm, E.A.; Niezgoda, S.R. Perspectives on the Impact of Machine Learning, Deep Learning, and Artificial Intelligence on Materials, Processes, and Structures Engineering. *Integrating Mater. Manuf. Innov.* **2018**, *7*, 157–172. [CrossRef]