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Big Data in Maritime Industry

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ABSTRACT

Big data is a term used to describe large volumes of data, collected from a variety of sources and processed at high speed. Big data analytics is revolutionizing the maritime industry, enabling better decision-making, improved efficiency, and enhanced safety through the analysis of vast amounts of data generated by vessels and ports. Big data has become a game-changer in the maritime industry. The industry heavily relies on data analytics and has embraced big data to optimize operations, improve efficiency, and enhance safety. This paper explores big data as a tech trend that is shaping the maritime industry.

KEYWORDS: *big data, big data analytics, maritime industry*

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INTRODUCTION

Global trade has been the backbone of human civilizations since time immemorial. The maritime industry is one of the largest and most important industries in the world, responsible for keeping global trade alive. It is the backbone of international trade and transportation, connecting countries, economies, and people. It is one of the oldest and traditional industries to still rely more on intuition than on data. The industry is involved in three-quarters of all worldwide trade. In spite of this, studies on the synthesis of big data application in maritime are rare, which has created a gap in the academic literature due to the importance of big data and AI in maritime operations. The applications of big data in the maritime industry are considerable. Big data in the maritime industry is increasingly informing business operations and logistics.

Big data refers to large datasets analyzed computationally to reveal patterns, trends, and associations. In the the maritime sector, this implies a vast and deep sea of facts, figures, and statistics from weather conditions to logistics, all crucial for operational performance and informed decision-making. Imagine harnessing large amounts of data to steer ships more efficiently, predict maintenance, and optimize routes. That is what the transformative power of big data analytics in maritime industry is all about. Big data analytics is transforming the maritime industry, enabling fuel optimization, vessel performance monitoring, regulatory compliance, and predictive maintenance. Big data in the maritime sector is derived from key sources such as [1]:

- Ship sensors provide real-time information on vessel performance and condition.
- Weather reports give updates on conditions that could impact sailing routes.
- Port information includes data about cargo, berthing schedules, and more.

This data optimizes shipping routes when harnessed effectively, resulting in significant fuel savings and timely deliveries.

WHAT IS BIG DATA?

Big data applies to data sets of extreme size (e.g. exabytes, zettabytes) which are beyond the capability of the commonly used software tools. It involves situation where very large data sets are big in volume,

velocity, veracity, and variability [2]. The data is too big, too fast, or does not fit the regular database architecture. It may require different strategies and tools for profiling, measurement, assessment, and processing. Different components of big data are shown in Figure 1 [3]. The cloud word for big data is shown in Figure 2 [4].

Big Data is essentially classified into three types [5]:

- *Structured Data:* This is highly organized and is the easiest to work with. Any data that can be stored, accessed, and processed in the form of fixed format is known as a structured data. It may be stored in tabular format. Due to their nature, it is easy for programs to sort through and collect data. Structured data has quantitative data such as age, contact, address, billing, expenses, credit card numbers, etc. Data that is stored in a relational database management system is an example of structured data.
- *Unstructured Data:* This refers to unorganized data such as video files, log files, audio files, and image files. Any data with unknown form or the structure is classified as unstructured data. Almost everything generated by a computer is unstructured data. It takes a lot of time and effort required to make unstructured data readable. Examples of unstructured data include Metadata, Twitter tweets, and other social media posts.
- *Semi-structured Data:* This falls somewhere between structured data and unstructured data, i.e., both forms of data are present. Semi-structured data can be inherited such as location, time, email address, or device ID stamp.

The different types of big data are depicted in Figure 3 [6].

The process of examining big data is often referred to big data analytics. It is an emerging field since massive computing capabilities have been made available by e-infrastructures [7]. Big data analytics is the application of advanced analytic techniques to large, heterogeneous data sets that comprise structured, semi-structured, and unstructured data from many sources with sizes ranging from terabytes to zettabytes.

Analytics include statistical models and other methods that are aimed at creating empirical predictions. Data-driven organizations use analytics to guide decisions at all levels. Several techniques have been proposed for analyzing big data. These include the HACE theorem, cloud computing, Hadoop, and MapReduce [8].

CHARACTERISTICS OF BIG DATA

Big data is growing rapidly and expanding in all science and engineering, including physical, biological, and medical services. Different companies use different means to maintain their big data. As shown in Figure 4 [9], big data is characterized by 42 Vs. The first five Vs are volume, velocity, variety, veracity, and value .

- *Volume*: This refers to the size of the data being generated both inside and outside organizations and is increasing annually. Some regard big data as data over one petabyte in volume.
- *Velocity*: This depicts the unprecedented speed at which data are generated by Internet users, mobile users, social media, etc. Data are generated and processed in a fast way to extract useful, relevant information. Big data could be analyzed in real time, and it has movement and velocity.
- *Variety*: This refers to the data types since big data may originate from heterogeneous sources and is in different formats (e.g., videos, images, audio, text, logs). BD comprises of structured, semi-structured or unstructured data.
- *Veracity*: By this, we mean the truthfulness of data, i.e. weather the data comes from a reputable, trustworthy, authentic, and accountable source. It suggests the inconsistency in the quality of different sources of big data. The data may not be 100% correct.
- *Value*: This is the most important aspect of the big data. It is the desired outcome of big data processing. It refers to the process of discovering hidden values from large datasets. It denotes the value derived from the analysis of the existing data. If one cannot extract some business value from the data, there is no use managing and storing it.

On this basis, small data can be regarded as having low volume, low velocity, low variety, low veracity, and low value. Additional five Vs has been added [9]:

- *Validity:* This refers to the accuracy and correctness of data. It also indicates how up to date it is.
- *Viability:* This identifies the relevancy of data for each use case. Relevancy of data is required to maintain the desired and accurate outcome through analytical and predictive measures.
- *Volatility:* Since data are generated and change at a rapid rate, volatility determines how quickly data change.

- *Vulnerability:* The vulnerability of data is essential because privacy and security are of utmost importance for personal data.
- *Visualization:* Data needs to be presented unambiguously and attractively to the user. Proper visualization of large and complex clinical reports helps in finding valuable insights.

Instead of the 10V's above, some suggest the following 5V's: Venue, Variability, Vocabulary, Vagueness, and Validity) [10].

Industries that benefit from big data include the healthcare, financial, airline, travel, restaurants, automobile, sports, agriculture, and hospitality industries. Big data technologies are playing an essential role in farming: machines are equipped with sensors that measure data in their environment. The analysis of both structured and unstructured data is crucial in the shipping industry to gain insights into customer behavior, improve operational efficiency, and make informed business decisions.

MARITIME BIG DATA

Maritime big data encompasses the extensive information collected from sources such as satellites, aerial remote sensing, observation stations, ships, and buoys, which are employed across a range of marine-related applications. The principal types of maritime big data employed in this field encompass ship navigation data, meteorological data, marine environment data, channel and port data, accident and emergency data, and ship inspection and management data. These datasets provide crucial support for comprehensive maritime safety assessments [11]. Figure 5 shows a symbol for maritime big data [12].

Big data analytics has become a powerful tool for extracting valuable insights from large and complex data sets. With the help of advanced analytics techniques and big data tools, companies can now analyze vast amounts of data to uncover hidden patterns, trends, and correlations. Big data in the maritime industry is not just about the volume of data but the valuable insights and actionable intelligence you derive from it. Big data in shipping refers to the vast amount of information generated within the maritime sector and the use of data systems to process and analyze this information. By harnessing shipping data, companies can gain valuable insights that help improve operational efficiency. With the vast amount of data generated by vessels, ports, and logistics systems, maritime companies can now analyze and interpret this information to make informed decisions and drive innovation. In the maritime industry, leveraging big data has led to better route planning, improved cargo tracking, and enhanced supply chain management. Figure 6 shows data transmission between ships [13].

EXAMPLES OF MARITIME BIG DATA

Marine big data can be described as a large amount of data collected through remote aerial sensing, ships, stations, buoys, and satellites. Big data is a large set of data that is structured and unstructured to enable the industry to make accurate, informed decisions. By analyzing vast amounts of data, companies like Transmetrics, CoVadem, LogComex, and HiLo are revolutionizing the shipping and logistics industry, with their innovative use of big data. These companies are at the forefront of leveraging big data to drive innovation and efficiency in the shipping industry. We briefly discuss these examples of companies leveraging maritime big data [14]:

- *Transmetrics* uses predictive analytics to optimize freight capacity utilization and reduce inefficiencies in the supply chain. By analyzing historical data and using machine learning algorithms, they can accurately forecast demand and suggest optimal cargo allocation.
- *CoVadem* leverages big data to provide real-time water depth information, enabling ships to navigate more efficiently and safely.
- *LogComex* utilizes big data to streamline customs processes and improve trade compliance. Their platform integrates multiple data sources to provide customs brokers with accurate and up-to-date information.
- *HiLo* analyses data from many different sources by using advanced algorithms and machine learning. It analyzes big data to identify and mitigate safety risks in the shipping industry, helping to prevent accidents and improve overall safety standards. HiLo's risk management platform provides data and insights that help shipping companies to proactively prevent incidents, protecting crew, ships, and cargo.

APPLICATIONS OF MARITIME BIG DATA

Key uses of big data in maritime sector include analytics for shipowners, data engineering, vessel performance, and fleet situational management. Big data is used to manage ship sensors and for predictive analysis, which is needed to prevent delays and improve the overall operational efficiency of the industry. Common areas of application of maritime big data include the following [1,14-17]:

- *Shipbuilding:* The shipbuilding industry will be one of the prime beneficiaries of the advent of big data. Big data can play an important role in

shipbuilding. Basically, this will be possible by analyzing the results obtained from the sensors of previously used vessels. Data collected and analyzed over the life of the vessel will be useful for future improvements in ship design. Previous datasets could help in testing the proposed ship design without physically developing it. That is a big win-win situation for the shipping industry.

- *Route Optimization:* Shipping companies harness vast amounts of data to determine the most efficient paths for their vessels. By analyzing historical and real-time information, such as weather patterns, ocean currents, and vessel speeds, big data algorithms predict the optimal route for a ship. This involves a complex calculation considering fuel consumption, time efficiency, and safety.
- *Predictive Analytics:* Predictive analytics is a key component of big data. It allows companies to forecast demand and optimize storage and transportation. This helps reduce costs and minimize delays in the supply chain. Predictive analytics and artificial intelligence in the maritime industry employ advanced techniques to monitor and analyze information from sources such as sensors on ship equipment, maintenance logs, and environmental conditions. By aggregating and analyzing data, predictive models identify patterns and anomalies that signal potential equipment failures. Big data analytics can also help identify potential risks and predict disruptions in the shipping process. Predictive analytics, powered by maritime analytics and shipping data, provide valuable insights into direction of asset prices and demand patterns over time. Figure 7 shows predictive analytics in shipping [18].
- *Chartering:* Vessel owners and operators try to ensure that their fleets are acceptable for use by charterers. A key function of charterers is to find the right ship for cargo at the most economical price. The task is highly dependent on information provided to them by known brokers and ship owners. Big data analytics can provide charters with readily available, accurate, and actionable information to improve decision-making. Charters can find all available alternatives as well as the freight forecast. This can give charterers and ship owners access to more options thus improving transparency and competitiveness.
- *Fleet Management:* Big data analytics in the shipping industry can also support fleet management through predictive analytics and maintenance. By predicting equipment anomalies and failures, shipping carriers can schedule preventative maintenance initiatives to reduce downtime, increase productivity and extend the working life of equipment. Analysis of container shipping data and marine statistics can be performed by shipping companies to assess the performance of individual vessels, identify areas for improvement, and make informed decisions about fleet composition and deployment. For example, shipping companies can use big data to analyze fuel consumption patterns, monitor equipment performance, and track maintenance history.

BENEFITS

The benefits of big data analytics in the maritime industry range from operational efficiency and cost savings to enhanced safety measures and environmental sustainability. Big data analysis helps identify optimal routes, speeds, and engine settings to minimize fuel consumption, a significant cost in shipping. Big data for the shipping industry can be used to make decisions in the future to predict and avoid costly problems, and to create more reliable cargo delivery options. Other benefits of maritime big data include [1]:

- *Improved Safety:* The most important benefit of big data analytics in maritime industry is improved safety. Shipping is a high-risk industry, and accidents can have serious consequences. By analyzing data on vessel performance, maintenance records, and crew behavior, shipping companies can identify and address potential safety risks before they lead to accidents. By analyzing the data points collected every day by shipping companies, it is possible to identify the red flags pointing to future incidents, reducing the risk of human injury and damage to ships and cargo. The knowledge gained from marine accidents serves as the cornerstone for the development of modern marine safety management practices. The automatic identification system (AIS) is a system for enhancing the safety and efficiency of navigation. It is designed to automatically provide information about a ship to other ships and to coastal authorities.
- *Enhancing Security:* Maritime companies detect and mitigate potential security threats by collecting and analyzing data from ship sensors, navigation systems, and communication networks. For example, anomaly detection systems powered by big data analytics identify unusual patterns in ship-to-

shore communications, indicating a cyberattack or system vulnerability.

- *Time-saving:* The implementation of big data analytics in the maritime industry significantly streamlines communication and email management. This way, critical information is easily accessible, reducing the time staff spends sifting through their inboxes. This is particularly beneficial in managing the high volume of emails typical in shipping operations. Data analytics can be used to identify areas where processes can be streamlined, reducing costs and increasing productivity.
- *Maintenance:* Decisions regarding vessel maintenance, including hull cleaning and propeller polishing, are taken based on intuition or a schedule rather than on actual vessel performance. Fuel consumption data can also be used for cost-benefit analysis of vessel maintenance. Data analytics can make it easier for operators to decide the timing and the benefits of performing maintenance.
- *Marine Engineering:* In the maritime business, big data is transforming the field of marine engineering. By analyzing vast amounts of data, engineers can optimize the design and performance of container ships, making them more efficient and environmentally friendly.
- *Maritime Efficiency:* In an industry where conditions change rapidly, real-time data processing is critical. Scholars have used big data and AI to achieve better energy efficiency in maritime transport from different perspectives. For better energy efficiency of vessels, liner companies usually consider slow steaming as the best practice.

CHALLENGES

While big data offers unparalleled insights for optimizing operations, its implementation is not without challenges. The shipping industry has been facing numerous disturbances and challenges such as market fluctuations, over supply, margin pressures, and labor shortages. Players are uncertain about implementing big data as it is a relatively new technology in the industry. These challenges are expected to impact the industry's profitability. There is a lack of cross-enterprise processes. Companies are concentrating on automating processes within functional silos instead of taking a holistic view of the enterprise. This prevents the true potential of big data from being realized. Other challenges of maritime big data include the following [1,15]:

- *Cost of Infrastructure:* Implementing big data systems and analytics can be costly, and shipping companies may be hesitant to invest in these technologies if they are not convinced of the potential benefits. Setting up a robust big data system entails significant investment, primarily in high-powered computing resources, sophisticated software for data analysis, and secure data storage solutions to handle the vast quantities generated daily. This setup includes data collection, processing hardware, advanced analytics, and visualization software. Maritime companies, especially smaller ones, frequently face budget constraints, making it crucial to find cost-effective solutions.
- *Complexity:* The maritime industry has always been complex, involving numerous stakeholders such as charterers, shipowners, and operators. It is a complex network of people, countries, agencies and authorities. This complexity makes operational efficiency critical. Due to the complexity and large size of ships, implementing autonomous control has proven to be a very challenging undertaking. Dealing with data volume and complexity in the maritime industry involves the enormous amount of information generated from various operations, such as vessel tracking, cargo handling, and crew management. There are numerous formats and types of data sources, like ship sensor data, port transaction records, and weather tracking systems. Navigating the complexities of communication flow, particularly while integrating big data in the maritime industry, requires the right technology solution. The complexity of the maritime industry is typically shown in Figure 8 [19].
- *Real-time Processing:* Making timely decisions based on current maritime data is crucial in scenarios like navigating treacherous weather or managing fleet logistics. The difficulty lies in rapidly processing and analyzing all the data continuously generated by sources such as GPS systems, weather stations, and onboard sensors. The shipping company needs to process this data in real-time to optimize routes and ensure safety.
- *Integration with Legacy Systems:* Another significant challenge is the integration of big data technologies with existing systems. Many shipping companies operate with legacy systems that are not readily compatible with modern big data solutions. Many maritime operations rely on older technology not designed to integrate today's advanced data processing tools. This mismatch

leads to significant hurdles in data utilization and operational continuity. Merging these disparate systems requires custom solutions, like developing middleware for effective data processing.

- *Data Quality:* Ensuring the quality and accuracy of the data being analyzed is critical for reliable insights and decision-making. In the maritime industry, data may be generated from a variety of sources, including vessel sensors, cargo tracking systems, and manual record-keeping. Ensuring the consistency and integrity of this data can be a huge challenge.
- *Data Security:* Ensuring data security and privacy is a twofold challenge: protecting sensitive information from external breaches and managing internal privacy concerns. The maritime industry handles sensitive information, such as vessel and cargo tracking data, and ensuring the security of this data is essential. Implementing big data systems and analytics can introduce new security risks, and shipping companies must have robust security measures in place to protect against these threats. Marine IT and telecommunication infrastructures are at high risk of penetration from cyber criminals, terrorists or other malevolent interests. A breach leads to severe financial and reputational damage for companies and, in some cases, even poses national security risks. Maritime companies address security issues by implementing advanced encryption methods to protect data in transit and at rest. Cybersecurity is becoming a greater concern as the level of digitalization increases, and obsolete methods of obtaining and storing data will need to be updated to guard against potential dangers.
- *Regulatory Compliance*: In the dynamic realm of the shipping industry, adherence to international regulations and standards is not just a legal obligation but a cornerstone of operational integrity. The complexity of maritime regulations, such as the International Maritime Organization (IMO) standards, SOLAS (Safety of Life at Sea), and MARPOL (Marine Pollution) conventions, demands meticulous monitoring and reporting. Big data analytics plays a crucial role here, enabling companies to efficiently track and manage compliance-related data. Stricter environmental regulations, like the IMO 2023 targets, require accurate tracking and reporting of emissions, which big data analytics facilitates. Moreover, big data facilitates streamlined reporting and documentation processes, a critical aspect of regulatory compliance.
- *Safety Compliance:* This is another area where big data proves indispensable. Advanced analytics can predict potential safety hazards by assessing historical incident data and real-time inputs from onboard sensors. This proactive approach to safety management not only aligns with regulatory standards but significantly enhances the safety of crew and cargo.
- *Labor Shortage:* Ensuring enough quantity and quality of human resources is essential for developing the use of big data solutions for maritime. There is a shortage of highly trained data scientists. Despite the massive amount of data generated by shipping companies, extracting meaningful insights becomes challenging when you lack the necessary skilled personnel and analytical expertise. Maritime education plays a vital role in equipping industry professionals with the necessary skills and knowledge to navigate the ever-changing landscape.

CONCLUSION

Big data has already taken the maritime industry by storm globally. As the maritime industry continues to embrace big data, the evolution of data analysis and the rise of big data tools have become instrumental in optimizing operations and improving decision-making processes. With the advent of advanced data processing techniques and the utilization of artificial intelligence, the maritime industry is now able to analyze massive amounts of data in real-time. By leveraging big data, the industry can improve route optimization, enhance supply chain management, increase overall efficiency, and improve operations and better decision-making processes. Moreover, big data enables maritime companies to personalize their services, offer more targeted advertising and marketing campaigns, and improve customer satisfaction.

Big data analytics can provide valuable insights into various aspects of maritime trade, including vessel performance, route optimization, cargo tracking, and port operations. The future of big data in maritime trade holds immense potential for enhancing operational efficiency and reducing risks. More information about big data in the maritime industry can be found in the books in [20-23] and the following related journals:

- Journal of Big Data
- Maritime Policy & Management
- Marine Policy
- Ocean Engineering
- Journal of Marine Science and Engineering
- Journal of Navigation

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Figure 1 Different components of big data [3].

Figure 2 The cloud word for big data [4].

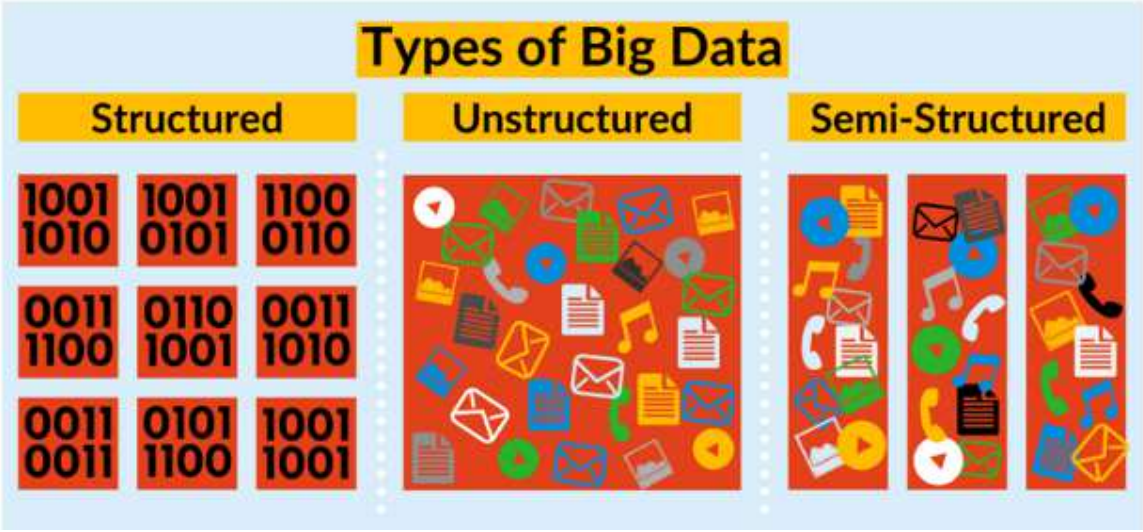

Figure 3 Types of big data [6].

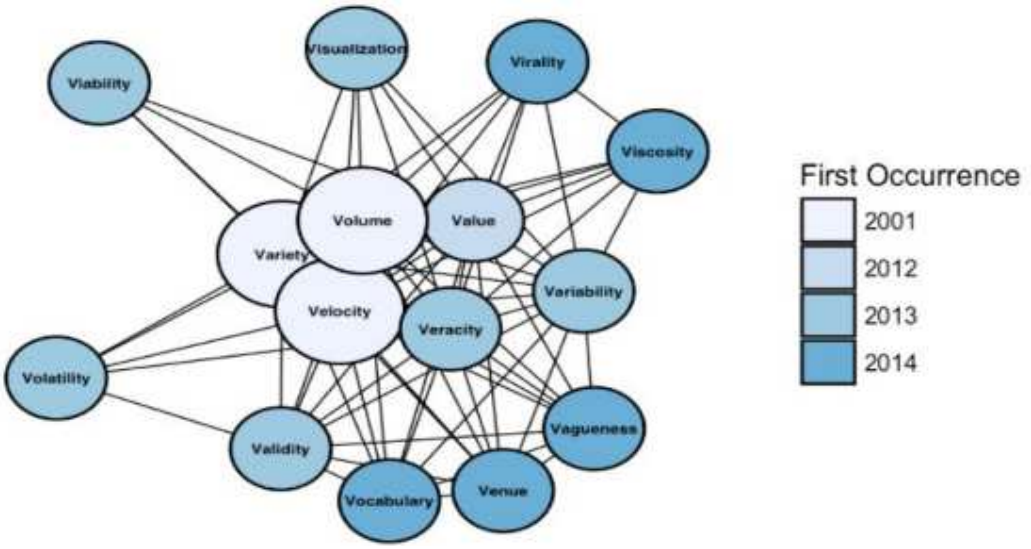

Figure 4 The 42 V's of big data [9].

Figure 5 A symbol for maritime big data [12].

Figure 6 Data transmission between ships [13].

Figure 7 Predictive analytics in shipping [18].

Figure 8 The complexity of the maritime industry [19].