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Role Of Big Data Analytics In Ehnancing Maritime Supply Chain Resilience

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Abstract:
Globalization of trade has distinct maritime supply chain to make it more efficient, resilient and adaptive. In this scenario, Big Data Analytics (BDA) is one of the essential tools that has stepped into play a crucial role in revolutionizing maritime industries by providing more data driven decisions, optimizing operations and improving end to end supply chain processes. This results in better insights which leads to projects like increased predictive maintenance, route optimization and risk management. Real-time view of supply chain provides unprecedented visibility into the movement of goods and vessels for shipping companies, port authorities, and logistics providers. This ultimately allows for more precise forecasting and inventory management, reducing the probability of disruptions and delays. In predicting and mitigating risks within maritime supply chains, the article also ponders upon the role of advanced analytics techniques, such as machine learning and artificial[1] intelligence. These are able to predict problems like bad weather, or crowded port based on the historical data and patterns available; thereby proactively suggest alternative strategies before the disruptions take place. In wholesome, BDA is emerging as cutting-edge tool in global maritime supply chain to mitigate the evolving challenges by driving efficiency, resilience, and sustainability. The integration of BDA into maritime domain will not only foster the decision-making but will also harness the industry for future challenges. This research emphasizes the significance of leveraging BDA to unleash the full potential of global maritime supply chains in highly complex and interconnected world.

***Keywords**: Big Data Analytics, Maritime Supply Chain, Logistics, Global Trade, Data Integration, Predictive Analytics.*

1.1 Introduction

Maritime trade has become the main driver for economic development over the last few centuries (Lam et al., 2019), especially the very recent two centuries with regards to containerization has facilitated the growth of international trade enormously (Mangan, Lalwani & Calatayud, 2021). The maritime supply chain is essential for the global economy, with over 80% of the world's goods are transported by sea. The efficiency and reliability of supply chain essentially influence international trade, economic stability, and consumer access to goods (Prajogo and Olhager 2012). Recent years have seen maritime transport and logistics have significantly been impacted by the pandemic, geopolitical conflicts like the Ukraine war, Suez

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Canal blockage by Ever Given and climate change. These challenges have resulted in port congestion, reconfigured routes, delays, and soaring shipping costs. To address these and other challenges of near and foreseeable future like capacity, fleet renewal, connectivity enhancement, environment friendly operations etc would necessitate significant role of latest technologies like Big data Analytics (UNCTAD, 2022).

This paper aims to provide a rigorous examination of the concepts of BDA and supply chain analytics, offering a detailed framework that elucidates the interconnection between these two domains. Additionally, it will review extant literature, identify challenges, assess the current state of research, and propose future directions for the integration of big data within supply chain practices.

1.2 Literature Review

Big Data Analytics **(**BDA) refers to the systematic processing and analysis of large amounts and complex data sets, known as big data, to extract valuable insights. To simply define, the term risk involves "concepts of uncertainty and potential negative consequences". Risk can comprise real risk or subjective perception of risk. Managers' perceptions and attitudes to risk influence their crisis and disaster planning and strategies (Ritchie and Jiang 2019). BDA allows for the uncovering of trends, patterns and correlations in large amounts of raw data to help analysts make data-informed decisions. This environment and process will enable organizations to exploit vast, rapidly growing data from any number of sources including internet-of-things sensors, social media, financial transactions, smart devices combining both structured and unstructured information using advanced analytics techniques to achieve this (Mucci & Stryker, 2024).

Maritime sector which covers shipping companies, port authorities, logistics providers as well as regulatory bodies that can account for transporting about 80% of the world's goods. The efficient functioning of this complex supply chain involving multiple stakeholders is vital for the global (Wendler-Bosco & Nicholson, 2020). However, according to experts like Yoon et. al, 2020, Koilo, 2019, Balci & Surucu, 2021 the maritime industry faces substantial challenges including demand variations, operational inadequacies, regulatory compliances and environmental aspects.

In recent years, BDA is emerging as a disruptive tool to solve the problems and be more efficient in handling scourges of global maritime supply chain. It helps to collect, process and analyze large amounts of data to identify patterns, trends, and indicators that can help organizations in making more informed business decisions (Chatterjee, et.al, 2023). The integration of BDA in the maritime sector increases operational efficacy, cost effectiveness, improve safety and ensure sustainability for all stakeholders operating in this domain (Zhao, et. al. 2024).

In order to improve routes safety, reduce fuel consumption and delays / disruption shipping companies can get real-time data from various tentacles including ships, ports and logistics networks. This improved visibility enables more accurate tracking/monitoring of shipments, forecasting arrival time to a greater extent and better coordination among various stakeholders involved in the supply chain. Additionally, according to Parola, et.al, 2020, BDA can help to detect bottlenecks and inadequacies in the supply chain to further assist the stakeholders to effectively address these issues.

Another key application of BDA in the global maritime supply chain involves enhancing compliance with safety, environmental, labour, and regulatory standards. Farah et.al, 2024 are of the view that leveraging BDA enables efficient monitoring and enforcement of these critical protocols. Within the context of today's competitive business environment, supply chain professionals are actively pursuing innovative methodologies to gather, organize, and analyze data, thereby generating valuable insights applicable across diverse industries. Chen et. al, are of the view that application of BDA to expansive datasets facilitates strategic

decision-making, empowering organizations to anticipate crucial opportunities and potential threats within the supply chain.

1.2.1 The Evolution of Maritime Supply Chain

Over the ages, maritime shipping has played a significant and enduring role in the global supply chain. According to Casson, 2020, the seas have been a pivotal element in the worldwide distribution of products, spanning the era of ancient seafarers trading valuable commodities to the present-day environment dominated by container ships and international trade. Wang, 2006 is of the view that the maritime transportation has rich history, dating back to ancient societies that utilized ships for the trade of items such as spices, silks, and valuable metals. During the colonial era, European nations leveraged maritime routes to establish global trade networks, leading to the exchange of diverse commodities and the migration of populations to distant regions. Dacera, 2023 opine that the maritime commerce of past eras has laid the foundation for the intricate global supply chain we observe today. The introduction of the standardized shipping container is widely considered the most impactful development in the evolution of global supply chains, facilitated by concurrent advancements in supporting logistics and transportation infrastructure (Hamed, 2024).

As per Rodrigue, 2020, the key attribute of shipping containers is their intermodal functionality, enabling seamless transportation across diverse modes of conveyance. Bernhofen, et.al, 2016 are of the view that regardless of whether a container is transported by truck, rail, or international container vessel, the standardization of these containers enables rapid and efficient handling. This efficiency leads to significant cost savings and enhanced operational effectiveness across the supply chain. Each minute saved in transit contributes to faster product delivery, reduced waste and environmental impact, and improved profit margins. While full standardization of shipping containers was not achieved until the late 1960s, the initial container designs emerged in the mid-1950s, concurrent with the development of specialized transport vehicles. The advent of containerization has been a crucial factor in decreasing costs and enhancing the efficiency of global trade (Team, 2019).

1.2.2 Factors Causing Supply Chain Disruptions

Aspects posing barricades to global supply chain can be grouped under three main categories as discussed by Tang et. al, 2008 and Tulach & Foltin, 2020 during their research. These factors are discussed as under: -

- **Factor 1: Deviations in the Supply Chain.** This implies that the system suffers some variation amongst all or anyone of the major control parameters for the supply chain like costs, demand and the timelines for delivery without causing any significant change in the original structure of that logistics chain.
- **Factor 2: Disruption in the Chain.** This aspect refers to a natural or human induced phenomenon of such nature and scope having direct impact on the logistics nodes or edges, resulting into their unavailability for the supply chain operations.
- **Factor 3: Disruption Caused by Natural Disasters**. This refers to complete non-availability of the supply network due to unanticipated and unpredicted natural disasters like earthquake, hurricane etc due to non-functionality of the logistical nodes and transportation apparatus.

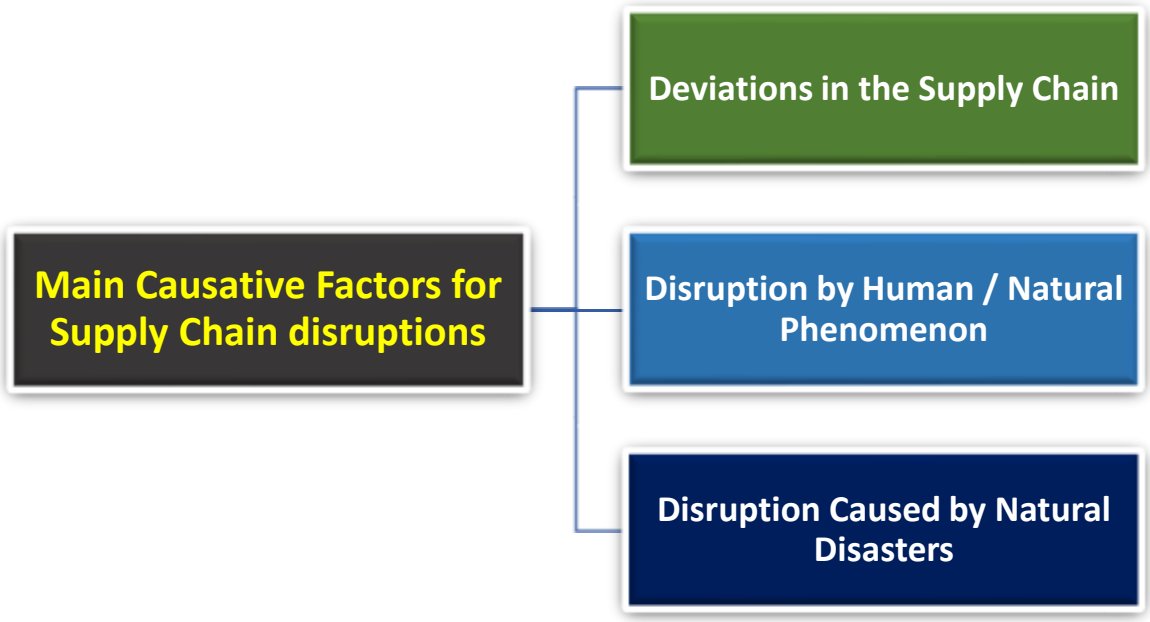

Figure 1: Factors - Supply Chain Disruptions, Source: Tang et. al, 2008 and Tulach & Foltin, 2020

Linkages Between Big Data Analytics and The Supply Chain.

Owing to the inherent intricacies of the supply chains, management of the information between stakeholders and quality of data related to material inflows assume paramount significance for value creation and long-term viability of the chain (Diop et. al, 2021). Wang et al, 2016 are of the opinion that the speed, volume and intricacy of the Big Data produced during the complex organizational processes like the one in supply chain operations is beyond processing capability of the traditional systems. Therefore, experts like Modgil et, al, 2021 are of the view that digitization can be an effective instrument in creating transparency and optimizing the complex interconnected processes like labour, manufacturing processes and establishing a digital communication within the supply chain systems.

Bridge Next Think Tank, 2023, is of the view that the overall technology used in logistics and supply chains is evolving with cutting edge solutions. The writers have divided the technologies having or likely to have profound impact on supply chains across the globe into three categories as under:-

- **Must Have Technologies.** These technologies include automation technologies like Process Mining, Robotic Process Automation (RPA), Data Analytics, Cloud Computing, Electronic Data Interchange (EDI) and Application Programming Interface (API). These are used for betterment of the fundamental supply chain processes by using enhanced knowledge form data, automating the often-repetitive processes while improving the overall accuracy, seamless exchange of information as well as data while minimizing dependence on physical infrastructure.
- **Great-to-Have Technologies**. Technologies like Edge Computing enabling rapid decision making through localized and fast data processing and hence reducing the process time as well as costs.

- **Aspirational Technologies – Good to Have.** Technologies like Artificial Intelligence (AI), Machine Learning (ML) and Natural Language Processing (NLP) can help a great deal in ease of complicated processes involved in supply chains, thereby expediting decision making based on real time data and reducing the overall costs.

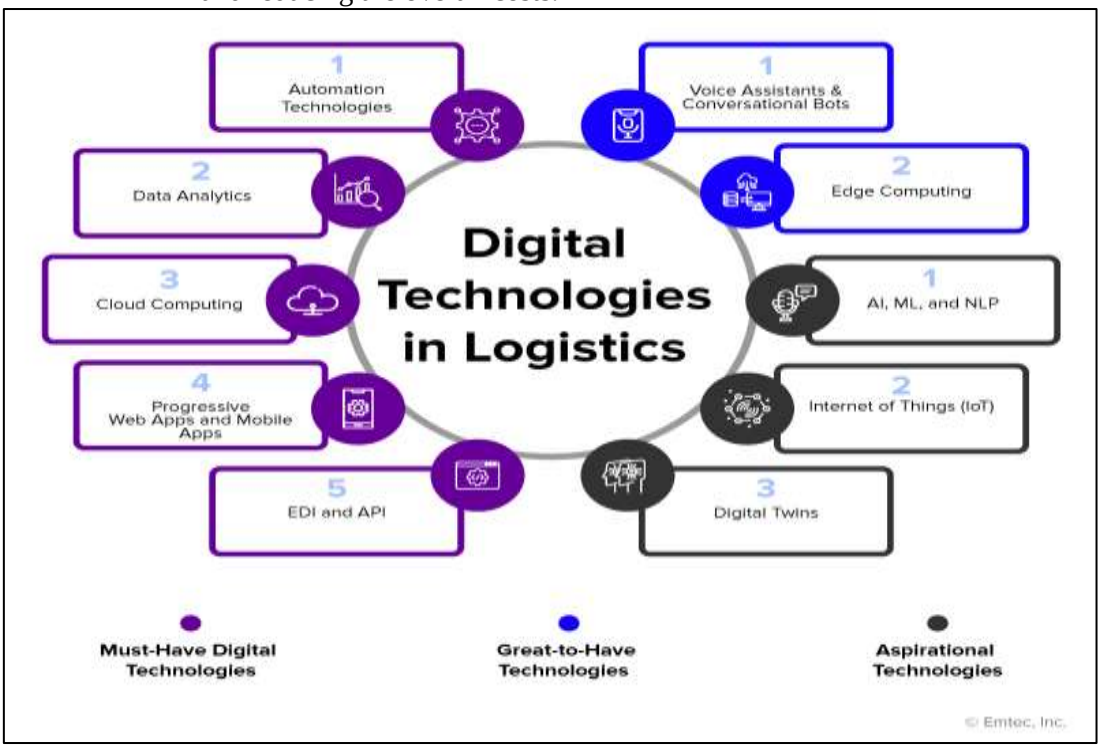

Figure 2 Digital Technologies in Supply Chains and Logistics, Source : BridgeNext Think Tank, 2023

From the discussion, it becomes obvious that incorporation of Big Data and related digital technologies can significantly enhance integration, improve the efficiency of the systems resulting into enhanced sustainability and managing the risks likely to be confronted by the supply chains (Tseng et al., 2021; Negri et al., 2021). Similarly, Chatterjee, et.al, 2023, are of the view that the rise of BDA offers a substantial opportunity to enhance decision-making across diverse industries. Recent research suggests that the adoption of BDA tools has a transformative effect on product innovation and supply chain optimization.

The advent of smart factories has introduced a greater degree of flexibility, driven by advanced automation and the seamless integration of digital supply chains (Soori et al., 2023). Given the extensive volume of information generated, the relationship between big data and supply chain management is particularly noteworthy, as the data collected throughout the supply chain from beginning to delivery has seen a remarkable increase (Wang et al., 2016).

In a comprehensive literature review based study published last year titled “Big data Optimization and Management in Supply Chain Management: A Systematic Literature Review”, Alsolbi et al., (2023) discusses various Big data instruments being utilized in the supply chain management field in the decade between 2010-21. The paper discusses conclusion by Chen & Zhao, 2012 that the executives or decision-making hierarchy of major supply chain platforms may have difficulties in understanding the application and potential uses of the big data during its various stages of data cycle i.e. from generation to destruction.

The same issue was further elaborated by Tan et al. (2015), wherein they produced a framework to structure and categorize Big data analytics to process requisite information into

a useful decision-making instrument for the decision makers at various levels. The framework is an endeavour in providing a fused picture from various data sets to enable managers making quick and correct decisions using this coherent picture (Figure 3).

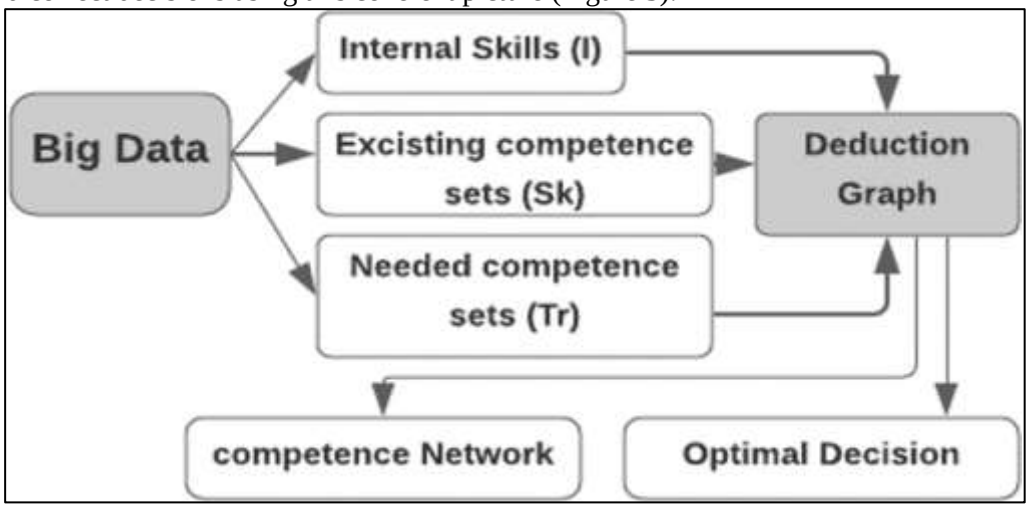

Figure 3 Framework for Analytics Infrastructure: Source Tan et al. (2015)

The study cites inference form Mohamed et al. 202, that establishment of open source libraries entailing machine learning and data mining have played a significant role in the overall progress made by various big data platforms like Spark, Hadoop and Flink, etc. However, the study opines that despite rapid advancements, many big data instruments that can play a game changing role in transforming the supply chain systems are still mere mystery for a large proportion of the users. This indicates a great opportunity that exists in awareness and subsequent employment of Big data instruments in the supply chain systems at global level.

1.3 Research Framework and Methodology

The design employed for this research adopts descriptive or exploratory approach, aimed at exploring the intricate yet very important enabling a nuanced understanding of complex relationship between BDA and supply chain risk dynamics. Undertaking a comprehensive and critical examination of the peer-reviewed articles, white papers, maritime industry reports and overarching academic discourse on the subject this paper tends to ascertain the existing and impending trends and significant opportunities proffered by BDA and its instruments towards massive improvements in the maritime supply chain risk mitigation. The paper also endeavours to shed light on the challenges and threats currently being faced by stakeholders in implementing the seamless integration of BDA into the maritime logistics system.

The methodology adopts a process of structured literature review to collect and evaluate qualitative data from various primary and secondary resources from the academically as well as geographically diverse backgrounds to study the discourse in a wholesome manner. Adoption of qualitative methodology enables the paper to endeavor for providing an an in-depth and contextually rich analysis of BDA's potential to completely transform the prevailing system of risk management in international supply chain management. The paper provides workable recommendations for all stakeholders from industry to academia to industrial stakeholders while simultaneously adding significantly towards the ongoing academic discourse related to the integration of big data into supply chain practices at global level.

Analysis & Results

2.0 Key Findings

2.1 Impact of Big Data Analytics on Maritime Supply Chain: The maritime industry, a key pillar of global trade, has mostly been dependable on manual procedures and instinctive-driven decision-making. However, with the genesis of BDA, the situation is rapidly evolving. Big Data encompasses the collection, analysis, and application of huge amounts of data from various sources, leading to valuable input in the efficiency, safety, and sustainability of maritime supply chains (Rao & Amritha, 2024). Few of key elements impacting BDA on Maritime Supply Chains typically are:

2.1.1 Optimization of Operation

According to Zaman et al. 2017, the integration of analytical tools fosters the operational efficiency and resilience of maritime operations including their processes, reduce idle time and assisting in quick and better decision-making throughout the supply chain. By critical examining both historical statistics and real-time information, maritime practitioners can decrease down time and improve collaboration among various stakeholders, including port authorities, shipping companies, and logistics providers. Predictive analysis can assist in foreplaning of maritime operations including avoiding port congestions, reducing delays and facilitating better scheduled and smooth operations. Moreover, the adoption of emerging disruptive technologies especially BDA can enable to foster the routine functioning in maritime operations thereby enabling all stake holders to adjust effectively to fluctuating market conditions and evolving customer needs (Hassan et al., 2024)

2.1.2 Predictive Maintenance of Vessels:

The predictive maintenance assist in in depth analysis of data received from multiple sensors and monitoring system and thereby mitigating likely failures well in time. Particularly within the maritime industry, the predictive maintenance is playing pivotal role in transforming the traditional maintenance techniques to continuous analysis of information from sensors and monitoring system installed onboard, thereby mitigating likely failures beforehand. This approach not only ensures safety of critical parts but also ensures the issues related to unplanned costly maintenance vis-à-vis helping the vessel to remain operational for longer span. It also supplements the safety by mitigating incidents pertaining to equipment malfunctions, thereby ensuring safety of both crew members and cargo (Lee et al., 2017)

2.1.3 Optimization of Fuel Consumption and Route Planning

According to Handayani et al (2023), BDA can assist in prediction analysis of uncontrollable factors like weather and ocean currents, thereby assisting in reduction of fuel consumption, which directly affects environmental sustainability and profitability. BDA can assist in efficient route planning for vessels in real time in response to changing circumstances; recommending most fuel-efficient routes and resultantly helping in reducing emissions and consumption of fuel (Man et al.,2020). For instance, if a bad weather is anticipated to disrupt the planned route, the system may suggest an alternative route that would avoid bad weather and save fuel. This ultimately reduces operating costs of shipping industries with reduction in marine industry's carbon impact (Sadiq, et al., 2021)

2.1.4 Real-time Monitoring and Visibility

In today’s global economic environment customers / stakeholders expect real time visibility of their cargo throughout the supply chain. BDA plays pivotal role in synthesizing data from various sources including RFID technology, GPS tracking systems and Internet of Things (IoT) devices, which together augment the transparency of cargo movements (Lindskog, 2023). The

real time tracking of cargo and to know its condition can be accessed with this capability, thereby assuring that cargos are delivered on time to their desired locations (Taj et al., 2023). The visibility of cargo facilitates all stakeholders to timely foresee and counter likely delays like customs challenges, delays at ports or incidents of theft (Mani et al., 2017). To ensure optimal condition of perishable goods the real time information including temperature and humidity plays vital role for the efficient and effective transport. These features of BDA provide more resilience, transparency and generate trust amongst various stakeholders in supply chain.

2.1.5 Improving Decision-Making Processes: In a multifaceted environment of maritime logistics, the BDA processes the huge volumes of data produced by the ships, ports and logistics networks including GPS signals, weather forecasts, and cargo sensors (Jović, et al., 2019) in real time and assist in making timely and accurate decisions, which ultimately helps shipping companies to avoid congested ports, selection of best routes and saving fuel consumption, while adhering to delivery schedules (Sadiq et.al, 2021).

2.1.6 Data-Driven Risk Assessment and Management. According to Amirell, 2016, maritime supply Chain is vulnerable to bad weather conditions, geopolitical conflicts/rifts, piracy, and disruption. Factually, in maritime domain risk management is significantly depended on historical data and the expertise of decision-makers. However, in contrast, Mohamed et al. are of the view that the advent of BDA provides a more anticipatory and predictive framework. Big data technologies can detect potential risks prior to their occurrence by synthesizing and examining data from diverse sources, such as meteorological information, geopolitical analyses, and real-time vessel tracking(Park & Signh, 2023). This proactive approach mitigates the chances of disruptions and increases the safety.

2.1.7 Strategic Planning and Market Forecasting: According to experts like Demirel, 2019 and Gao et al. 2022, smooth and effective maritime operations are basically augmented by strategic planning and market forecasting. Sagiroglu & Sinanc, 2013 are of the view that integration of BDA fosters these actions by providing detailed understanding into global trade trends, consumer behavior, and key economic indicators. This ultimately enables the stakeholders to plan and forecast variation in demand supply, updating inventory levels, and make well informed decisions. BDA assists in predicting market trends with great precision and ensures companies remain viable in a rapidly changing global market by assisting in formulation of effective pricing strategies (Mwatha, 2020).

2.1.8 Enhanced Collaboration Across Stakeholders: BDA plays a vital role in improving collaboration among various stakeholders, such as companies, port authorities, logistics providers, and customers, by creating a unified platform for data exchange and communication. According to Surucu-Balci, 2024, the capacity to share real-time information enables all involved parties to have access to the same data, which is essential for maintaining consistency. Additionally, the integration of blockchain technology with BDA adds an extra layer of security and. Blockchain technology offers a permanent record of transactions and movements, which fosters trust among stakeholders and decreases the chances of fraud or disputes (Tatineni, 2019).

2.1.9 Reducing Costs and Environmental Impact: The maritime industry plays a vital role in global trade within a diverse framework including logistics, regulatory concerns and environmental aspects (Lim, 2017). According to Ahmed et al. 2018, integration of BDA has remarkably transformed this industry by through state of art strategies to reduce operational expenses and environmental issue. BDA is improving cost efficiency and helping

environmental sustainability in maritime supply chains, with particular consideration to reduce idle times and transit delays, minimizing greenhouse gas emissions through efficient routing, and achieving cost reductions through optimal asset utilization.

2.1.10 Minimizing Idle Time and Reducing Transit Delays. As per Elmi, 2023 transit delays and Idle time are major factors in inefficiencies of maritime supply chains. Ships spending bulk of its time at ports in waiting to load or off load vis-à-vis disruptions /delays enroute not only causes higher operational costs but also augments in increased fuel consumption and carbon emissions. These all impediments can easily be addressed through skillful usage of BDA by planning more precise scheduling and real-time decision making (Ahmed et.al, 2022) By skillful use of past data and real time feedback from various components such as port congestion data, weather reports and vessel traffic flow; Big Data can easily predict foreseeable delays and recommend best suitable window for arrival and departure of vessels. For example, predictive models can assist in forecast of port congestion, thereby facilitating shipping companies to tailor their schedules accordingly and reduce idle time. Furthermore, BDA can recommend alternative routes or speed adjustments by continuously tracking vessel movements and external conditions to avoid delays.
Reducing the delay enables the shipping company to make a tighter schedule, improve on service reliability, and eliminate the requirement of additional portion of stock which ends up costing the business.

2.1.11 Lowering Greenhouse Gas Emissions through Optimal Routes.
Mao & Larsson, 2023 are of the view that due to excessive usage of fossil fuel the maritime industry is a major contributor to global greenhouse gas emissions. In present era, the maritime industry is facing increasing pressure, where environmental regulations are becoming tighter over reduce carbon footprint. Specially in this scenario, BDA can assist the maritime industry by determining the most fuel-efficient routes through analyzing the huge amounts of data including weather patterns, ocean currents, and vessel performance metrics. Moreover, big data can assist in optimization of vessel speed thereby complementing the tradeoff between fuel efficiency and delivery schedules. This will not only contribute to lower greenhouse gas emissions, but will also augment in substantial cost savings for shipping companies (Ahmed et. al, 2018)

2.1.12 Cost Savings from Improved Asset Utilization
Kache, & Seuring, 2017 opine that BDA is a critical enabler for shipping companies for optimal utilization of their assets by complementing data from numerous sources, including vessel capacities, cargo bookings and market demand, ultimately leading to cost reduction and enhanced profitability. For example, it can assist in matching cargo loads with the best suitable vessels, ensuring that vessels are neither underloaded nor over stuffed. This not only optimizes the use of available storage capacity but also reduces the need for additional trips, further cutting the costs.

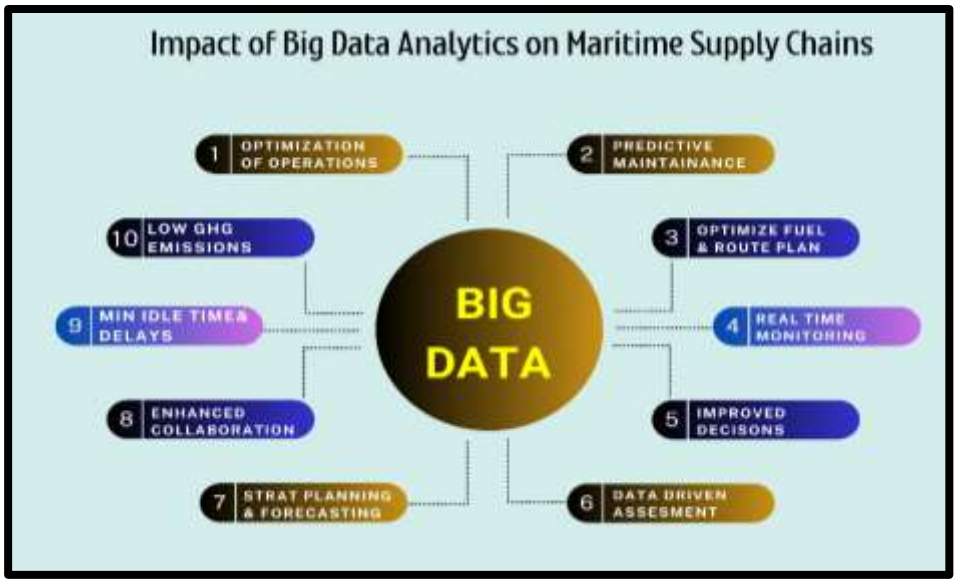

Figure 4, Impact of Big Data Analytics on MSC, Source: Researcher's Own Illustration

3.0 Major Challenges in Adoption of Big Data Analytics as Per the Study.

There are few challenges and hiccups in adoption of BDA in the global maritime industry. These impediments not only offshoot of complexities of the industry itself but also from wide issues related to data management, organizational culture, and regulatory frameworks. Below, I delve into the specific challenges within the following key areas: -

3.1 **Data Privacy and Security Concerns**.

With the advent of emerging disruptive technologies, the risk of various threats is also emerging consistently, which includes risks of cyberattacks and data breaches. On one hand though the technology in shape of Big Data has interconnected the various stakeholders i.e. ships, ports or terminals but on other hand these terminals have also become susceptible to various vulnerabilities including data breaches, disruption of operations and hacking of data or even taking control of critical maritime systems. Mostly the maritime vessels operate in far-off areas with limited connectivity thus making secure data transmission a colossal task. This issue is further expounded due to use of obsolete / outdated communication means/ channels. Moreover, many systems especially legacy systems used in the maritime supply chain, lack robust encryption or data protection measures, making them more vulnerable to cyber-attacks. The non availability of end-to-end encryption can endanger sensitive data related to cargo, shipping routes, and operational schedules (Melnyk et. al, 2022).

3.2 **Legal and Regulatory Compliance Issues**.

Due to lack of international maritime law many stakeholders / countries are working in silos and storing the data locally. This practice impedes the free passage of data / information and creates a bottle neck in in the adoption of BDA solutions that rely on centralized or cloud-based analytics platforms. Absence of central regulatory body to ensure safe handling of data and lack of clarity in how international maritime law applies to emerging technologies like BDA are major impediments.

3.3. **Integration and Interoperability**.

Maritime industry faces issues in form of lack of unified data ecosystem. The maritime industry is using diverse system and platforms with fragmented IT infrastructure, which is the biggest

hurdle in data integration across different system such as ships, ports, logistics companies, customs authorities etc and often resides in siloed databases.

3.4 **Standardization of Data Formats and Protocols**.

Lack of a homogenous data formats, is a biggest impediment in compatibility for various systems and stakeholders. Resultantly huge effort is required to translate the data into a useable information. Moreover, the accuracy of data sifted or gathered from numerous stakeholders has bearing on its authenticity.

3.5 **Skill Gaps and Organizational Resistance**.

The maritime industry faces the unique issue of professional competent who have the competency or expertise in both domains such as maritime operations and data analytics. Lack of such professionals has severe implications in implementation of BDA in this domain.

3.6 **Overcoming Resistance to Technological Change**.

BDA being an emerging disruptive technology may have some uncertainties for many companies, who are still sticking to their old long-established operations and resistant to adoption of new technologies. On other hand many workers considers the automation and analytics-driven decision-making a threat, which can act as their substitute particularly in operational roles such as ship navigation, logistics planning, or port management.

Figure 5 Major Challenges in Adoption of Big Data, Source : Author's Own Illustration

4.0 **The Future of Big Data Analytics in Maritime Supply Chains**

4.1 **Emerging Trends and Technologies**

4.1.1 **AI and Machine Learning in Predictive Analytics**.

Machine learning and Artificial Intelligence (AI) has transformed the maritime industry especially in predictive analytics. AI integrated system can forecast likely disruption with great accuracy by critically and carefully analyzing the huge data comprising previous shipping schedules, port congestion levels, and weather patterns. Resultantly shipping industry can

effectively mitigate the risk of disruption/ delays, forecast hike in seasonal demand and better fleet management.

4.1.2 **Blockchain for Secure and Transparent Transactions**.
Blockchain technology is crucial in maritime industry, which provides decentralized and secure record transactions amongst various stakeholders. This technology offers decentralized, transparent and secure transactions, which ultimately reduces the risk of fraud, errors or disputes and fosters the operation efficiency. For example, smart contracts which are self-executing agreements on blockchain can assist automatically in release of the shipment information to the recipient, as soon container reaches its destination, thereby saving lengthy delays in various formalities taken at port.

4.1.3. **The Role of 5G in Enabling Real-Time Data Processing**.
5G networks provides significant boost in data transmission with great speed and reliability in almost real time. It can help in ensuring fast and reliable communication between ships, ports and management. 5G with Internet of Things (IoT) devices onboard enhance the resilience in shipping industry by assisting in making real-time decision, such as rerouting ships to avoid port congestion or inclement weather conditions apart from real time monitoring of cargo conditions, equipment status, and vessel movements.

4.2 **Sustainability and Green Shipping Initiatives**

4.2.1 **Big Data's Role in Achieving Environmental Goals**.
Big data analytics by keeping record of fuel consumption, carbon emissions, and vessel performance plays an important role in supplementing the maritime sector to substantially reduce the greenhouse gas emissions. Predictive models facilitate in implementation of environmental regulations by sharing accurate, real-time reporting on emissions.

4.2.2 **Innovations in Eco-Friendly Shipping Practices**. Big data analytics is also complementing in bringing novelties in sustainable maritime practices. Various shipping companies are carrying out experiments to reduce the carbon footprint vis-à-vis achieve optimum operational efficiency by operating ships at slow speed to minimize fuel consumption and emissions by taking help of analytical tools. Which can help in reducing carbon foot print and at the same time gives optimal performance in terms of cost, fuel consumption and environmental impact. Similarly, predictive analytics can assist in evaluating the performance and feasibility of alternative fuel such as liquefied natural gas (LNG), biofuels, and hydrogen by analyzing their impact on operations.

Figure 6 Future of Big Data in SCM, Source: Author's Own Illustration

4.3 Recommendations for Stakeholders

4.3.1 Investing in Data Infrastructure and Talent Development

To gain optimum advantage of BDA the maritime stakeholders must invest in modern data infrastructure including cloud-based platforms, IoT devices and Integrating data across various systems, which will empower seamless analytics and facilitate wholesome visibility. In addition, companies must recruit data scientists, analysts, and IT specialists apart from having partnerships with academia and research institutions to foster innovation and knowledge exchange.

4.3.2 Collaborating Across Industry to Develop Standards and Best Practices

The various stakeholders in maritime industry must establish a common data standards and protocols for information sharing to unleash the optimum potential of big data analytics. This practice will augment interoperability, reduce data shattering, enable secure data sharing and better transparency and resilience.

4.3.3 Embracing Data-Driven Culture for Continuous Improvement.

In maritime industry digitization plays a pivotal role in the long-term goals. Maritime companies need to educate, train their staff to use analytics tools in their routine functioning and critical business processes starting from their fleet management to customer service. Decision makers must master in data-driven decision-making by laying clear objectives and tracking performance through key metrics. With each passing day, organizations must embrace data-driven culture to gain a competitive advantage by becoming more agile, efficient, and resilient.

5. Conclusion.

The adoption of BDA in maritime supply chain is transforming the industry by optimizing the operational efficiency, reduced fuel consumption vis-a vis reduced carbon emission, predictive maintenance of vessels and providing real-time cargo tracking and visibility.

This innovative disruptive technology has not only improved the profitability and sustainability of shipping operations but also augmented the resilience in global supply chain. As the maritime industry embarks upon the disruptive technology / digitalization, the role of

BDA will foster further innovation and efficiency in future. This adoption of BDA in the global maritime industry is also gelled with inherent challenges concerning data security, interoperability, integration, as well as bridging the technical skill gaps and organizational resistance. Which requires a wholistic approach amongst various stake holder of maritime industry including regulatory bodies, and technology providers in improving the efficiency and resilience of the maritime supply chain.

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