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THE IMPACT OF DIGITALIZATION ON MARITIME SERVICES FROM A SHIPPING PERFORMANCE PERSPECTIVE

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ABSTRACT

This paper investigates the impact of digitalization on maritime services by utilizing high-frequency sensor data and monitoring shipping performance through modern digital platforms. This data collected from the fleet of Laskaridis Shipping Co. LTD operating 51 bulk carriers over a six-year period. The aim is to identify and analyze key characteristics of the organization's digitalization strategy through telemetry. This study focused on fuel oil consumption, a critical parameter for effectively monitoring fleet performance. The results suggest that the adoption of digital applications for performance monitoring by shipping companies can improve the fleet overall condition, streamlining all associating maritime services.

Keywords: Digitalization, Shipping Performance, Maritime Services, Fuel Oil Consumption

1. INTRODUCTION

Maritime transport plays a crucial role in international trade and the logistics supply chain (*Zhang et al., 2024*). More than 80% of global merchandise trade by volume and over 70% by value is transported via sea, with these figures being even higher for many developing countries (*Yang et al., 2023*). Although shipping is considered relatively safe and environmentally efficient in comparison with other modes of transportation, in line with the goals set by the Paris Agreement, decarbonization remains a priority. In 2018, the International Maritime Organization (IMO) reported that the shipping industry was responsible for 2.89% of global anthropogenic emissions (*Zhang et al., 2024*).

The increasing volume of maritime transport demands significant fuel oil consumption, and as fuel oil prices continue to rise, shipping companies are experiencing considerable freight pressure (*Hu et al., 2021*). Most ocean-going vessels rely on heavy fuel oil as it is a conventional energy choice (*Xue et al., 2024*). Nevertheless, the extensive use of fuel oil releases harmful pollutants, resulting in environmental pollution. For instance, container ships, emit sulphur oxides (SOx) during cargo transportation as they consume fuel oil, leading to serious environmental issues and posing health risks, particularly in densely populated coastal areas. Enforcing sulphur emission limits can help mitigate acid rain, tackle ocean acidification, protect marine ecosystems, and decrease the incidence of respiratory diseases (*Gu et al., 2025*).

Moreover, fuel expenses account for over 50% of a vessel's operational costs (*Nguyen et al., 2025*), making fuel oil consumption a critical parameter in navigation (Wang et al., 2023). Therefore, to enhance operational efficiency, monitoring fuel oil consumption is essential, as it is closely linked to fleet performance. More accurate fuel oil consumption predictions could lead to more precise bunker calculations, lower emissions, improved planning, and reduced operational costs (*Papandreou and Ziakopoulos, 2022*; *Bassam et al., 2022*).

The diffusion of digital technologies is anticipated to have profound impacts on the economy and society. However, there is still no agreement on whether digitalization is merely an incremental shift in existing technological trends or rather a complete transformation that could spark a new long-term cycle of economic growth and deep structural change (*Cirillo et al., 2021*). Ship operational performance monitoring through data analysis is mainly centred around modelling, predicting, and optimizing fuel oil consumption for both economic and environmental reasons (*Bassam et al., 2022*).

The contemporary maritime industry confronts urgent needs for digital transformation and technological innovation, while initial trials already have been conducted using Artificial Intelligence technology (*Yan et al., 2021*). Digital technologies, including Artificial Intelligence (AI), Robotics, Big Data Analytics (BDA), Augmented/Virtual Reality, Advanced Simulation, Machine Learning, Digital Twin Models, Digital Security, Cloud Computing, Additive Manufacturing, and the Internet of Things (IoT), are widely recognized for their potential to revolutionize business operations and significantly address current challenges. These digital tools

not only enable the transformation of existing company processes but also play an important role in the storage, sharing, and acquisition of knowledge (*Cheng et al. 2023*). Shipping and port services stand to benefit substantially from digital transformation, with these technologies forming the core of the change (*Yan et al. 2021*).

Shipping companies have started installing high-frequency data collection systems that enable them to collect large amounts of data from onboard sensors. Combined with sea and weather conditions, as well as port conditions, this data is used to calculate the estimated time of arrival (ETA) and estimated time of departure (ETD), optimize routing, and finally reduce fuel oil consumption (*Yan et al. 2021*).

Numerous studies emphasize the positive impact of digitalization across different fields (*Xu et al. 2023, Dabbous et al. 2023, Ichimura et al. 2022, Cirillo et al. 2021, Zheng et al. 2023*). *Zhang et al. (2024)* claim that according to China Classification Society, intelligent technologies used on "smart/intelligent" ships can be categorized into six categories, Intelligent hull, Intelligent energy efficiency management, intelligent cargo management, intelligent navigation, intelligent cabin and intelligent integration platform technologies, ie telemetry.

Liang et. al. (2024) highlighted the value of sensors and monitoring systems, which are installed in many vessels, enabling real-time data collection and analysis. This technology aids in making informed maintenance decisions, thereby minimizing the risk of any equipment failure and preventing potential maritime casualties. These practices enhance vessel safety and reliability while reducing maintenance costs and downtime.

To gain a comprehensive view and evaluation of the ship performance under real operational conditions, *Zhang et al. (2024)* in his research, collected high-frequency data with a 60-second resolution during extensive sea trials using a digitalization system. A typical example of a digitalization/telemetry system installed onboard a vessel is illustrated in Figure 1.

Figure 1: Digitalization/telemetry system typical structure onboard a bulk carrier vessel
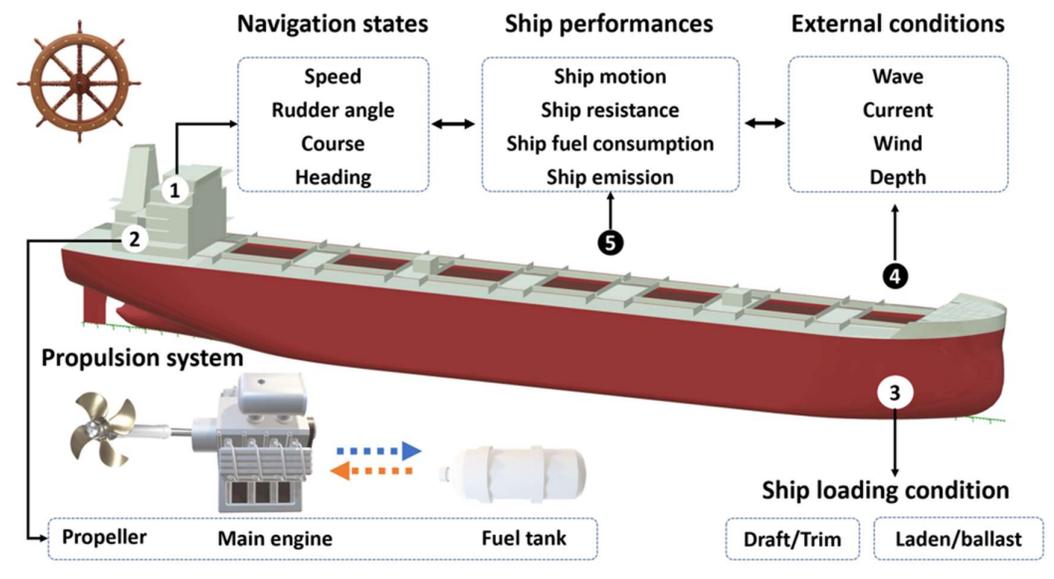
This highlights the imperative need to investigate comprehensively the particular mechanisms by which and to what degree digital technologies may facilitate the monitoring of fuel oil consumption. In this respect, the study aims to shed light on the following research question:

RQ1: Does fuel oil consumption across a shipping company's fleet show statistically significant differences before and after the implementation of telemetry?

The remainder of this paper is structured as follows: Section 2 provides a review of the existing literature in order to establish the frame of reference. Section 3 describes the methodology utilized while the findings of the study are presented in Section 4, followed by an analysis of their contribution to addressing the research questions in Section 5. Lastly, Section 6 provides an overview of the key conclusions, addresses any limitations, and suggests potential approaches for future research.
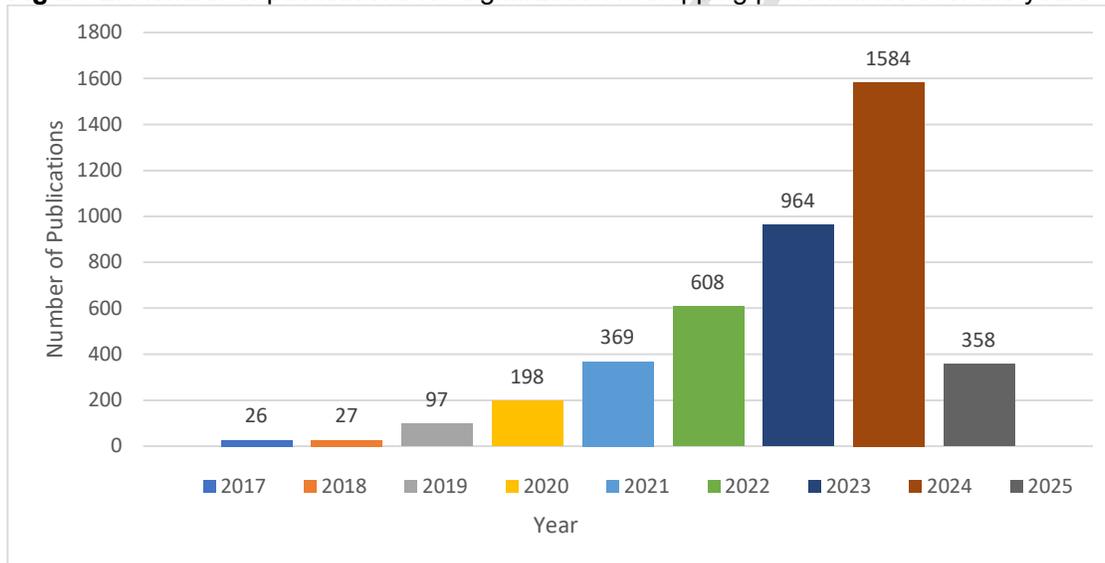
2. LITERATURE

2.1 Digitalization definition

To clarify the concept of digitalization, it is important to examine the affix "ization". The use of this suffix in forming a modern concept may introduce notable ambiguities. In English, when turning a verb into a noun by adding "ization," it can convey two meanings. The term refers both to the process described by the original verb and the resulting state that follows. In this context, digitalization would encompass both the state of being digitalized and the act of transitioning to a digital state (*Gong and Riviere 2021*).

Sustaining a clear distinction between the process and the final state of a phenomenon characterized by the suffix "ization" presents significant challenges, as it frequently leads to ambiguous interpretations. Therefore, it is recommended to focus on digitalization as the outcomes derived from the adoption and integration of digital technologies, emphasizing its impact on services, products, and relationships (*Gong and Riviere 2021*).

In their paper *Ichimura et al. (2022)* defined digitalization in shipping as transformation of the conventional business model through the successful implementation of novel technologies associated with Industry 4.0.

In recent years, there has been a remarkable increase in research examining and discussing the role and impact of digitalization on shipping (see Figure 2). In alignment with several previous studies (*Ametepey et al. 2024*, *Garg et al. 2024*), this research also utilizes the Scopus database to ensure a comprehensive and reliable analysis, employing the following algorithm to retrieve relevant results "digitalization OR digitalisation AND shipping OR maritime AND performance AND PUBYEAR>2015 AND PUBYEAR<2026" AND (LIMIT-TO (LANGUAGE , "English")). Among the totally 4,231 documents found from 2017 until March 2025, it is evident that, except for 2025 which is not a full year, there has been a steady increase in studies on digitalization. This trend indicates a growing interest in exploring this topic further.

Figure 2: Number of publications for digitalization in shipping performance over the years

2.2 Network visualization

Delving more into the literature on shipping digitalization and performance, Figure 3 shows a network map visualization of the co-occurrence of authors' keyword by performing a full counting analysis on the digitalization and performance dataset using VOSviewer software. In the network visualization, each item is represented by its label and is by default enclosed within a circle. The size of an item's label and circle is proportional to its weight meaning that the greater the weight, the larger the label and circle. The colour of the item is determined by the cluster it belongs to. Regarding the full counting method, the link between two keywords has a strength of 2. This indicates that both keywords have co-occurred in 2 documents. This visualization tool is used to extract and visualize the co-occurrence networks of authors' keywords from studies included in the review. The VOS method relies on mapping and clustering, utilizing a weighted and parameterized version of the modularity function (*Bukar et al. 2025*). The goal is to identify key subjects and relationships within the relevant literature, providing insights into the frequency and interrelationships of keywords. The distance between the key terms indicates the strength of their relationship. The size of the

keywords reflects their frequency of occurrence (*Gursel et al. 2025*). Specifically in this analysis, 'ships', 'digitalization', 'shipping', 'digital transformation, 'decision making' and 'performance' are among the most frequent keywords.

The following algorithm was used to retrieve results among 2,481 relevant documents for Figure 3: digitalization OR digitalisation AND shipping AND performance AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE, "English"))

Figure 3: Co-occurrence network in full counting

Basis on the above graph, the close association between 'digitalization' and 'shipping performance' highlights the increasing application of digital technologies in vessel operations. This connection suggests that digital monitoring tools, such as telemetry, predictive maintenance, and AI-driven monitoring systems, are being integrated to enhance efficiency and decision-making, while also reducing fuel oil costs through optimized fuel consumption.

2.3 Ship Operational Performance

To better understand the importance of maritime operational performance and how this is connected to the measured parameter of fuel oil consumption it is essential to define maritime operations which are considered as the processes involved from a vessel's arrival to dock until the completion of its cargo transfer (*Aguero-Tobar et al. 2023*).

In the literature, fuel oil consumption is closely linked to maritime operations (*Wang et al. 2023*) and is influenced by multiple variables, such as ship sailing speed, draught, wind, waves and currents (*Luo et al. 2025*). According to the findings of *Sang et al. (2023)*, considering these conditions, the fuel oil consumption of a ship diesel engine is the result of several complex factors, which can be categorized into ship operation factors and environmental factors. Ship operation factors not only include ship speed but also main engine power, draft-trim configuration, hull roughness and displacement, while environmental factors include wave direction and height, wind force, temperature, current and salinity. One of the most significant factors in reducing fuel consumption is the selection of the favourable operating parameters, ie speed, draft and trim of the ship, both at a fleet level (fleet management and logistics) and at a vessel level (route selection, optimization of load and water ballast. As per *Fan et al. (2022)*, for every 10% speed decrease, the fuel oil consumption decreases by 27%, highlighting the strong linkage between the operational optimization and the accurate and regular monitoring of fuel oil consumption.

As per *Sakalis (2022)*, the power loads required during ship operations can be categorized into three main types: propulsive power ($\dot{W}_p$), electric power ($\dot{W}_e$), and thermal power ($\dot{Q}_{th}$) Among these, propulsive power has the highest magnitude and is primarily influenced by ship size, cargo loading conditions, and service speed. Electric power demand varies depending on the ship type; for instance, container ships typically require more electrical power than tankers or bulk carriers of similar size. Additionally, substantial thermal power is necessary for preheating the fuel used by the main engine and diesel generators, as well as for other applications (e.g. heating for accommodation, freshwater generator etc.).

To reduce ship fuel costs and related greenhouse gas emissions, scientists and engineers consistently work on minimizing fuel oil consumption through optimal ship design, advancements in ship energy systems, voyage optimization, and the adoption of new green energy sources (*Sang et al. 2023*).

Solakivi et al. (2022) argue that shipping firms have strong financial and environmental incentives to optimize fuel oil use due to fluctuating fuel oil prices and increasing regulatory pressures to reduce pollutant emissions. Fuel oil consumption acts as an economic performance indicator (*Chen et al. 2024*), and effective fuel oil management not only reduces operational costs but also ensures compliance with stricter IMO regulations, such as MARPOL Annex VI, which mandates the use of low-sulphur fuels and the reduction of SOx and NOx emissions (*Schoinas and Stefanakos 2014*).

Various solutions have been proposed to address issues associated with ship fuel oil consumption and emissions including route optimization, hull optimization, post-incident repairs, planned maintenance of ship equipment, the development of predictive techniques, routine maintenance, and the use of alternative fuels. However, these approaches entail significant financial burdens. Alternatively, maritime companies often adopt speed reduction as a key strategy to lower CO2 emissions and fuel oil consumption, as it involves no additional costs for energy- or fuel-efficient operations although this method presents certain challenges in fleet management (*Bassam et al. 2022*). Due to this reason, the adoption of cutting-edge technologies such as artificial intelligence (AL) and machine learning (ML) has been recognized as an effective to managing ship fuel oil consumption and emissions. According to *Gupta et al. (2022)*, these AI and ML technologies enable data-driven insights into ship performance, environmental conditions, and operational parameters. By leveraging predictive analytics, ML models can identify optimal operating conditions, improve route planning, and provide more accurate fuel oil consumption estimates. In addition, the Internet of Things (IoT) has gained attention in studies on fuel oil consumption, as IoT-enabled sensors and devices facilitate real-time data collection on ship operations, environmental conditions, and fuel usage (*Nguyen et al. 2025*).

The increasing adoption of digital technologies and IoT further underlines the need for research on fuel oil consumption. These technologies enable continuous monitoring and performance optimization of ships, guaranteeing compliance with environmental regulations while reducing overall costs. Fuel oil consumption also serves as an economic performance indicator, as by analysing it alongside other operational parameters, enables the development of predictive maintenance strategies (*Nguyen et al. 2025*).

2.4 Sensor data

Over the past few years, advancements in digital technologies have radically transformed various sectors (*Chizubem et al. 2025*). The maritime sector is keen to utilize large amounts of ship measurement data made available through shipping telemetry digital systems, research into advanced machine learning methods, and the development of more accurate data-driven fuel oil consumption prediction models (*Cai et al. 2024*). These models can effectively incorporate various inputs, including ship operational data, navigational environmental factors, and additional relevant information such as drydocking records. However, the performance of these sophisticated models largely depends on the volume of specific training data. A key challenge is that ship operational data is often limited due to extended data collection intervals (*Luo et al. 2025*).

The inconsistent development of ship monitoring equipment has increased the collection of single-source data. Additionally, challenges such as remote transmission issues and equipment failures contribute to poor data quality (*Cai et al. 2024*). Due to restricted access to ship data, only low-resolution information—such as noon reports with a single daily record—can be obtained, limiting data collection to a maximum of 365 records per year. The availability of operational data is even more limited for newbuildings and vessels undergoing major retrofits due to shorter operating periods. Since the collected data is insufficient to fully capture ship operating characteristics, utilizing high-frequency data becomes essential (*Luo et al. 2025*).

Recent advancements in sensor technologies, data acquisition and storage systems enable the monitoring of ship operational performance to be more efficient and reliable by enhancing data quality and integrity (*Bassam et al. 2022*). Digital platforms have revolutionized industries by facilitating real-time data collection, advanced analytics and seamless stakeholder communication (*Chizubem et al. 2025*). Proper processing and analysis of this data can provide deeper insights into ship operational performance, extract valuable information, and reveal correlations and patterns within the measured data. To this end, machine learning and statistical approaches have gained significant momentum in the shipping industry in recent decades (*Bassam et al. 2022*).

3. METHODOLOGY

3.1 Data acquisition

To address the research question mentioned above, a set of quantitative data was used. This data collection and analysis approach incorporated historical data from annual reports, noon reports, and high-frequency sensor data collected over a six-year period from Laskaridis Shipping Co. LTD operating 51 bulk carriers. The resolution of noon report data is every 24 hours, whereas high-frequency data is recorded every minute. This study focused on fuel oil consumption measured in tonnes per nautical mile. The parameter focused on this study was the fuel oil consumption in tonnes per nautical mile. This methodological approach has the potential to produce novel and valuable insights, providing a wealth of information that may not be readily available in existing databases.

Notably, most vessels in the shipping company's fleet are equipped with telemetry and high-frequency data collection systems. Initially, the analysis was performed at the fleet vessel level, comparing data before and after the implementation of telemetry. Since the installation period of the telemetry system varied for each vessel, we calculated the mean value of each measured parameter for the period before digitalization and compared it with the mean value for the period after digitalization. This approach allowed us to analyse the data at a fleet level more effectively. Then, we refined our dataset to include data from 31 bulk carriers within the fleet. For the purposes of our study, we focused on this subset of 31 vessels outfitted with telemetry and high-frequency data collection systems, classifying them as digitally equipped.

The decision to focus on a single shipping company for this empirical study was mainly to concentrate on telemetry-related issues and eliminate other variables that could impact the data, as common management practices apply across the entire fleet. All selected vessels were managed by the same company, followed identical Safety Management System (SMS) procedures, implemented a common digital strategy, sailed under the same flag, and manned by crews who shared a collective mindset nurtured by the crew department of the shipping company. Selecting vessels under a unified management structure ensures a consistent operational environment, minimizing potential variables that could skew the study results and thereby strengthening the reliability and validity of the empirical findings.

3.2 Data description

The vessels were built between 2010 and 2021, with an average year built of 2015 (SD = 3.21). The descriptives for fuel oil consumption parameter are presented in Table 1 as well as in Figure 4, a box plot is presented to display the distribution of the dataset.

Table 1: Descriptives of fuel oil consumption

	N	Mean	Median	SD	SE
Fuel Oil Consumption Before Telemetry	31	0.113	0.107	0.022	0.004
Fuel Oil Consumption After Telemetry	31	0.106	0.103	0.013	0.002

Figure 4: Box plot for the fuel oil consumption median before and after telemetry implementation

Pre vs Post Installation Mean Tonnes per nm
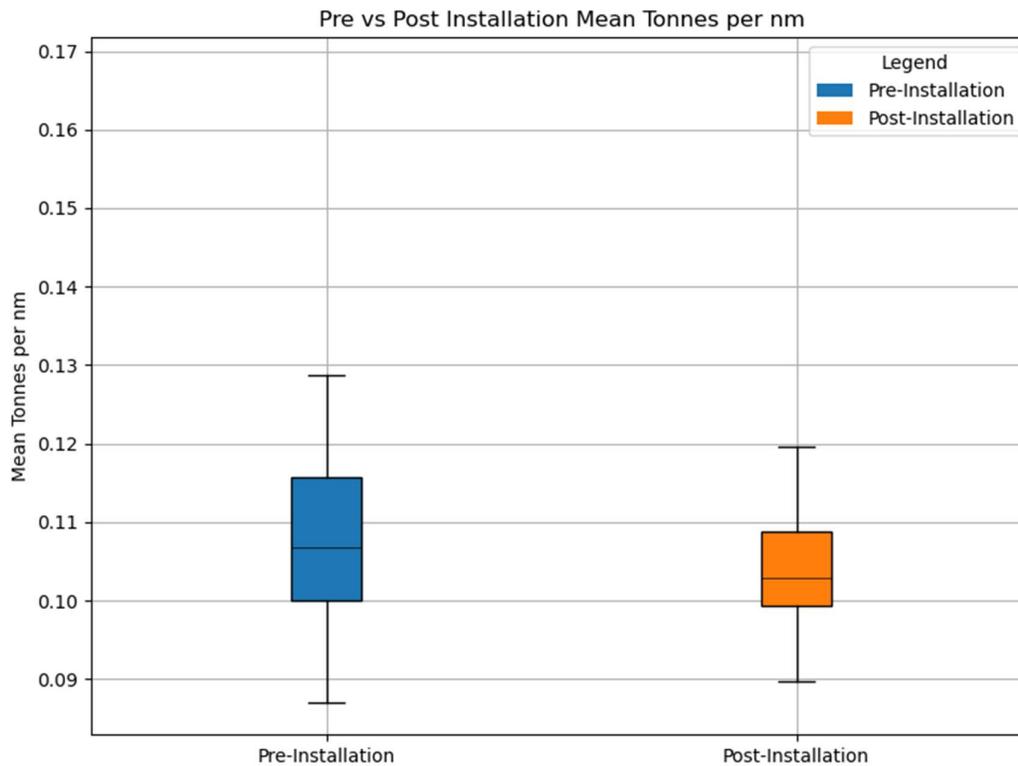
4. EMPIRICAL ANALYSIS RESULTS

For the purpose of this study, the non-parametric Wilcoxon Signed Ranks Test was applied, and the rank biserial correlation (rb) index was calculated as an effect size. In this index, values close to 0.10 are considered as small, close to 0.30 as medium and close to 0.50 as large, as demonstrated in Table 2.

The value of fuel oil consumption per nautical mile was compared before and after the installation of telemetry. The average fuel oil consumption per nautical mile before telemetry (Mdn = 0.113) had a greater value compared to the fuel oil consumption per nautical mile after telemetry (Mdn = 0.106). A Wilcoxon Test indicated that this improvement was statistically significant, (t=2.086 (t>2), p=0.045 (p<0,05), rb=0.375).

The rank biserial correlation values demonstrate a strong relationship between telemetry implementation and fuel oil consumption. The integration of telemetry systems on board enables accurate monitoring of fuel oil consumption, leading to its reduction, which in turn lowers emissions and minimizes fuel oil costs. As a result, the vessel operates at optimal performance.

The study achieves this by leveraging the power of digitalization and telemetry, which are instrumental in collecting and analysing relevant data.

The integration of digitalization and telemetry in fuel oil consumption and ship performance within the shipping industry represents a significant progression and a pivotal achievement toward a technologically advanced maritime sector with enhanced monitoring systems.

The results mentioned above highlight the significance of incorporating telemetry, prompting the company to strategically embrace digitalization.

Table 2: Paired samples t-test for fuel oil consumption

			t-value	p-value	Mean difference	SE difference	Effect Size
Fuel Oil Consumption Before Telemetry	Fuel Oil Consumption After Telemetry	Wilcoxon W	2.086	0.045	0.007	0.003	0.375

Note. H_a μ Measure 1 - Measure 2 ≠ 0

5. DISCUSSIONS AND IMPLICATIONS

5.1 Theoritical and practical contributions

This study makes several contributions to the literature. It presents a comparison of ship performance before and after the application of telemetry on the vessels of a shipping company, measuring the impact of various digitalization dimensions on fuel oil consumption. The results show statistically significant differences in fuel oil consumption before and after telemetry implementation, answering the research question of this study.

The results presented in the previous section of this paper are considered new, particularly because existing literature lacks studies that directly relate digitalization to ship performance. This marks a significant shift toward adopting technological advancements in the maritime sector, where conventional practices are being modernized for improved efficiency. The integration of digitalization and telemetry highlights the industry's recognition of the substantial benefits these technologies provide, optimizing fuel oil consumption monitoring, enhancing ship performance, improving operational efficiency, and enabling data-driven decision-making. This reference to digitalization and telemetry in the shipping industry lays the groundwork for future innovations, highlighting the increasing role of technology in maritime operations. This milestone marks an important starting point for further research, development, and implementation, unlocking new opportunities for enhanced ship performance, efficiency, and sustainability in the sector. This significant transition serves as a crucial steppingstone toward a more technologically advanced and efficient maritime sector while also contributes to the overarching goal of fostering a safer and more sustainable environment for all stakeholders involved in maritime operations.

5.2 Main Conclusions

The findings of this study emphasize the key aspects of digitalization that are essential for enhancing ship performance monitoring. Specifically, they provide valuable insights into the urgent need for shipping companies to prioritize digital integration in their operations. The strategic implementation of digital technologies plays a vital role in improving various operational parameters beyond just fuel oil consumption, ultimately leading to cost reduction, lower emissions, enhanced performance, and improved service quality. The next step of this study aims to explore potential correlations within the same sample between fuel oil consumption and other parameters such as Engine RPM, ship speed and emissions produced.

6. LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

As with academic research, our study has also certain limitations. The primary limitation lies in the fact that the data was sourced from a single shipping company, which may constrain the generalizability of the findings. Future researchers should address this limitation by collecting data from a broader sample that includes multiple shipping companies. Expanding the dataset in this way would improve the generalizability and reliability of the results, contributing to a more comprehensive understanding of the subject.

Secondly, it is important to acknowledge two more significant limitations in the scope of our research. First, our analysis is limited to a dataset that spans merely a six-year timeframe, thereby constraining the temporal scope of our analysis. This limitation affects the ability to identify long-term trends and variations in the data, potentially leading to an incomplete representation of the phenomenon under investigation. Additionally, by focusing solely on one vessel type—bulk carriers—our study does not capture the diversity and variability present across the broader maritime industry. Therefore, to enhance the comprehensiveness of future research, extending the data collection period would allow for a more in-depth analysis of long-term trends. Additionally, incorporating data from various vessel types would better capture the industry's inherent diversity. This approach would provide researchers with a more holistic and robust understanding of the factors influencing maritime sector performance and dynamics.

Thirdly, some vessels installed their digitalization system during 2022. For future research, refining the dataset—either by excluding these vessels or by more precisely defining the periods before and after digitalization implementation—could improve the accuracy of the results.

Fourth, the fuel oil consumption parameter has been considered in relation to the sailing distance. In future research, fuel oil consumption could instead be analysed based on the vessels' engine power or sailing speed.

Finally, instead of fuel oil consumption, which is measured in tonnes per hour in our study, specific fuel oil consumption (SFOC), measured in grams of fuel per kilowatt-hour (g/kWh), could be used in the analysis. While fuel oil consumption refers to the total amount of fuel used by a ship's engine or system over a given period or distance, specific fuel oil consumption indicates the amount of fuel consumed per unit of power output, providing insight into the engine's efficiency in converting fuel into useful power.

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