



THE ROLE OF DIGITALIZATION IN SHIPPING SAFETY: HUMAN ERROR AND NEAR-MISS PREVENTION

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Abstract

This paper seeks to bridge the gap in academic literature by exploring the relationship between digitalization and maritime safety and quality management. The integration of various digital technologies and software applications have a significant impact on the shipping industry, aiming to enhance operational efficiency and competitiveness. Shipping companies increasingly view digitalization as an inevitable progression in the maritime industry and are actively involved in implementing various strategies to support this pivotal shift.

This research offers an examination of the current landscape regarding the utilization of digital technologies by leveraging real-time high-frequency data, incorporating also historic data from maritime casualties reports, collected from a sample fleet of a reputable shipping company operating 51 bulk carriers over a six-year period from 2017 to 2022. The goal is to identify and analyze the various characteristics linked to the digitalization implementation within the organization focusing on human error and its impact on operations and safety.

The results firmly suggest that the integration and execution of digitalization strategies by shipping companies can significantly reduce the likelihood of maritime casualties.

This empirical study seeks to analyze and evaluate the overall impact that digitalization has on the occurrence of maritime casualties.

Keywords

Digitalization, Shipping, Digital technologies, Maritime Casualties, Human Error, Near-miss

1. Introduction

Throughout seaborne trade history, ship casualties have left a persistent legacy, often resulting in devastating consequences for human life, societal welfare, and the marine environment (Eliopoulou *et al.*, 2016). Despite ongoing progress in science and technology, maritime incidents continue to lead to severe casualties, loss of property, and ecological degradation and pollution (Wang *et al.*, 2021).

Over the past 15 years, the number of ships in the global fleet has been increased by approximately 53% and a corresponding 47% gross tonnage, resulting in a notable rise in maritime casualties worldwide (Marino *et al.*, 2023).

Since a substantial share of maritime casualties originate from human factors, operational measures in shipping have proven highly effective in reducing accident frequency, whereas measures related to ship design and technology, such as digitalization and telemetry, have mainly played a role in mitigating the accidents consequences (Eliopoulou *et al.*, 2016).

Despite considerable drops in mortality rates over the 20th century, being a seafarer remains one of the riskiest professions. Merchant shipping continues to record a high incidence of fatalities linked to both onboard occupational accidents and maritime casualties such as collisions, groundings and pollution incidents (Naevestad, 2017).

Historical evidence reveals multiple devastating incidents arising from the interactions between technology and operators across various industries. To effectively reduce such risks within the maritime sector, it is vital to gain a thorough understanding of officers' perspectives, skills and decision-making processes, while on duty, along with their overall impact on the evolution of automation systems and their overall effect on the likelihood of maritime casualties. Various research studies have identified a range of emerging factors contributing to maritime casualties, such as human errors due to the improper use of electronic navigation tools, overreliance on sensor data, inadequate awareness of the limitations of electronic navigation devices, deficiencies in system ergonomics, as well as challenges with human-computer interfaces. Moreover, the complexity of automation systems, combined with the possibility that watchkeeping officers may still take insufficient or wrong decisions despite their familiarity with these technologies, can potentially cause catastrophic accidents. Considering all the above, it becomes quite clear that identifying and evaluating human errors is crucial for preventing future maritime casualties (Kaptan *et al.*, 2021).

The effective management of the human factor is significant in all shipping operations (Pantouvakis and Syntychaki, 2022), given that the seafaring profession possesses unique characteristics that set it apart from land-based professions (Karakasnaki *et al.*, 2023). Despite this, the maritime industry often gives priority on emissions reduction, thus overshadowing the human-related issues (Pantouvakis and Vlachos, 2020). Recent statistical data and research have highlighted the important role human errors play in maritime casualties. According to Yilmaz and Karadayi-Usta (2025), human error is a leading contributor in the majority of maritime accidents, resulting in an annual cost of \$541 million to the maritime sector. These figures underscore that human error constitutes a major challenge for maritime engineering, impacting the safety, efficiency, and reliability of maritime operations.

Human factors are estimated to account for the majority maritime casualties, comprising between 75% and 96% of the total incidents. To provide further elucidation, they are involved in roughly

84% to 88% of oil tanker accidents, approximately 79% of tugboat grounding incidents, 89% to 96% of collision accidents, around 75% of fire and explosion accidents (Ma *et al.*, 2024). Hence, identifying, analyzing and preventing human errors by applying human factors principles and methods is essential in the design, operation, and management of ships and marine systems.

In management and organizational studies, time is considered an influential factor. Blagoev *et al.* (2024) introduced the temporal lens analytical framework to explore how time shapes behaviors, processes and decision-making within organizations, positioning time as a fundamental dimension of management and then demonstrating its paramount importance. In the context of shipping casualties, time is a critical factor, as swift response is essential for effectively addressing and managing challenging situations.

On the other hand, within the Industry 4.0 framework, digitalization offers a wide range of benefits to industry. These include not only increased profit margins, improved innovation potential, improved production control and increased labor productivity, but also accelerated product development (Grybauskas *et al.*, 2022). In this respect, digitalization acts as a catalyst in managing shipping incidents by enhancing both the speed and efficiency of response times (Crittenden *et al.* 2019, Proksch *et al.*, 2021).

As the maritime industry confronts increased pressure to improve safety and operational efficiency, digitalization has become a key transformation driver. The adoption of real-time monitoring systems, automated reporting, and decision-support systems offers the potential to mitigate human error. Near-miss incidents, a critical safety performance indicator, act as early signals of system vulnerabilities and human-related risks. Assessing the impact of digital tools on the frequency and characteristics of near-misses can provide meaningful insights regarding the extent to which digitalization enhances safety culture and maritime situational awareness during operations. In this respect, the study aims to shed light on the following research question:

RQ: How does digitalization, including the adoption of digital monitoring and telemetry systems, impact decision-making processes and the prevention of human error in day-to-day shipboard maritime operations, and is this associated with a measurable reduction in near-miss incidents across a ship fleet?

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 Human Error

Human factors remain the predominant causes of maritime casualties, often involving factors such as high stress levels, crew fatigue, flawed decision-making under pressure and inadequate training. These risks are often compounded by organizational deficiencies, including insufficient compliance with international regulations and poor safety culture. While developments in digital systems, such as automation and electronic navigation tools, have mitigated some risks, human error continues to be the primary driver of maritime incidents (Jovanovic *et al.*, 2025).

Publications in the maritime industry that focus on human element analysis focus on issues related to impact, and enhancement of human factors in maritime safety and operations. These studies explore the root causes and consequences of human errors in marine casualties and propose

prevention and mitigation strategies utilizing various analytical methods including Bayesian Networks (Fan *et al.*, 2025), Systematic Literature Review (Sepehri *et al.*, 2022), Human Factor Analysis and Classification System (Kaptan *et al.*, 2021), Fuzzy Fault Tree Analysis (Gurgen *et al.*, 2023) and Success Likelihood Index Method (Ozturk *et al.*, 2024). Researchers also emphasize the importance of clearly defining these concepts and establishing a standardized approach to their usage to ensure consistency and clarity across various maritime studies (Yilmaz and Karadayi-Usta, 2025).

Human error is a widely defined term that encompasses errors in human performance that can negatively affect system safety, performance and human well-being. Given its significance and multifaceted nature, the study of human error extends across various disciplines, including psychology, cognitive science, industrial engineering, safety management, ergonomics, and human-computer interaction (Gursel *et al.*, 2025).

A considerable number of studies have been carried out for the analysis of human errors in maritime accidents (Weng *et al.*, 2019). As per Mejsner *et al.* (2024), seafarers face a high risk of accidents and occupational hazards. In an effort to enhance maritime safety and minimize accident rates, extensive efforts have been made to identify the contributing factors to marine accidents with human error recognized as a major key factor (Wang *et al.*, 2021). Human factors contributing to maritime accidents form a complex system that encompasses not only the unsafe behaviors of crew members onboard but also a range of underlying risk factors influencing those behaviors. These factors include poor equipment or job design, use of improper tools, personal stressors, inadequate training or skill of personnel, insufficient layout or ergonomics, poorly written maintenance and operation procedures, unfavorable environmental conditions and bad management (Gursel *et al.*, 2025, Ma *et al.*, 2024).

Moreover, maritime research focuses on how neurophysiological factors such as fatigue, stress, workload, and situation awareness affect human performance and reliability during navigation as well as methods to assess and enhance these factors using tools such as electroencephalography and eye-tracking (Yilmaz and Karadayi-Usta, 2025).

Statistical analysis indicates that 13,46% of maritime accidents involving human errors are linked to fatigue, which is associated with sleep deprivation and tiredness during navigation (Fan and Yang, 2024). Fatigue definition refers to tiredness and physical discomfort caused by prolonged activity and according to Fan and Yang (2024), it plays a critical role in waterborne transport being closely connected with maritime operations and accidents.

Further to fatigue, Rajapakse and Emad (2025) identify also frustration as another influential factor which is linked to human error. While fatigue results from physical tiredness and prolonged activity, frustration in the workplace can arise from various sources, often leading to lower job satisfaction, reduced productivity, and higher turnover rates.

Weng *et al.* (2019) claimed that human errors in shipping operations can be classified into three categories: negligence error alone, judgement/operational errors alone, and the simultaneous occurrence of negligence and judgement/operational errors. Hereafter, negligence errors refer to failures such as insufficient vigilance and watch-keeping, whereas judgement/operational errors include faulty situation assessment, unsafe sailing speeds, improper collision avoidance maneuvers and non-compliance with navigation rules.

Various authors have thoroughly identified up to fourteen distinct physical and psychological factors closely linked to human errors. These factors include but are not limited to illness, fatigue, boredom, recklessness, overconfidence, poor or miscommunication, risky behaviors and insufficient operational procedures. While some safety studies favor the term "human variability"

over "human error", arguing that human error is often a result rather than a cause of other factors, it is undeniable that the role of humans is essential to the emergence of maritime casualties (Stepien, 2023).

2.2 Near-Misses

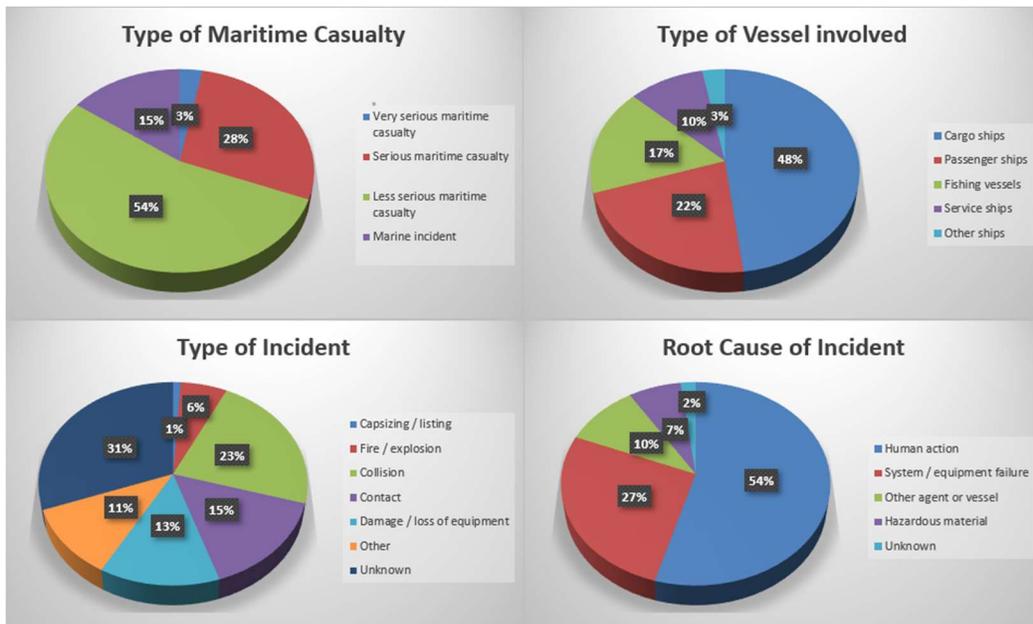
Ship losses have significantly declined over the past decade; however, the frequency of maritime accidents has remained largely consistent or has shown only minimal variation (Sepehri *et al.*, 2022). Marine accidents continue to pose serious risks to society and the environment, particularly through the loss of human life and property (Zhang *et al.*, 2024). Ships operating in complex marine environments are exposed to various risk factors, including unfavorable weather conditions, ocean currents, mechanical failures and human operating errors (Wu *et al.*, 2025). A structured approach to analyzing and forecasting incidents is essential for improving maritime safety and reducing future incidents (Chen *et al.*, 2025).

As per Wu *et al.* (2025), conventional ship safety management approaches largely rely on historical accident records and human judgement. Nonetheless, researchers and industry experts are increasingly exploring advanced data analytics and computational modeling to enhance the accuracy and reliability of their predictions.

It is important to clarify the meaning of three buzzy words that are often mentioned in the casualties' reports: the incident, the accident and the near-miss. Bicen and Celik (2022) define incident as an event that disrupts normal operations or triggers a crisis, typically causing damage to equipment, infrastructure, or the environment but not resulting in injuries while an accident is an unplanned or unintended event that generally leads to damage or harm. Examples of accidents include unintentional collision or falls, injuries from contact with sharp, hot or electrical objects, or poisoning through ingestion of harmful substances.

Various types of maritime accidents display unique characteristics in terms of human-related causal mechanisms. **Figure 1**, presents a summary of key insights derived from the statistical analysis of maritime casualties, categorized by type of maritime casualty, type of vessel, type of incident and root cause of incident.

Figure 1: Marine Casualties and incidents categorized by type of maritime casualty, type of vessel, type of incident and root cause of incident (European Maritime Safety Agency, 2024)



Less severe casualties represent the majority at 54%, which indicates that minor issues do not threaten vessel safety. Serious casualties account for 28%, while very serious casualties are relatively rare at 3%. Marine incidents account for the remaining 15%, underscoring the importance of continuous monitoring through telemetry and detailed incident reporting to identify emerging patterns at an early stage.

Cargo ships account for almost half of all maritime incidents (48%), due to their extensive presence in global shipping operations. Passenger ships (22%) and fishing vessels (17%) also contribute to a significant portion, emphasizing the importance of safety measures and protocols in sectors where human lives are directly involved. Service ships (10%) and other vessels (3%) experience fewer incidents, possibly due to their more specialized roles or smaller fleet sizes.

Collisions (22%) and contacts (15%) are the most common incident types, reflecting ongoing challenges in navigation, maneuvering, or spatial awareness. Damage or loss of equipment (13%) further underscores the importance of effective maintenance and monitoring systems. Although fires and explosions (6%) and capsizing or listing (1%) are rare, they are typically high-impact events and demand constant attention. Notably, 30% of incidents are classified as unknown, indicating substantial gaps in data accuracy or shortcomings in incident investigation processes.

Human factor is the primary root cause in 55% of cases, underscoring the critical need for improved crew training, promote a safety culture, improve decision-making support, and manage fatigue effectively. System and equipment failures contribute to 27% of incidents, stressing the importance of preventive maintenance, system reliability, and continuous condition monitoring. External factors such as other agents or vessels (10%) and hazardous material handling (7%), also play smaller but notable roles. Only 2% of causes remain unidentified, suggesting that most root causes can be traced when sufficient data is collected.

In summary, minimizing the frequency and severity of maritime incidents requires a focused approach that includes addressing human factors through training and digital decision support, enhancing situational awareness and collision avoidance systems, strengthening maintenance programs, and improving data quality in reporting and investigations. Special emphasis should be given to cargo, passenger, and fishing vessels, which represent the majority of reported cases.

A near-miss refers to an unplanned event that had the potential to cause injury, illness, or damage but ultimately did not. It is an accidental occurrence where harm or property damage, or even fatality was narrowly avoided. In safety terms, near-misses can result from human errors or stem from weaknesses in an organization's safety systems or procedures. The term of a near-miss is also referred to as a close call, a near collision, or a near impact (Saleh *et al.*, 2013). Incidents encompass both accidents and near-misses with the key difference being that accidents result in physical damage and injuries, whereas near-misses do not (Raviv *et al.*, 2017).

Heinrich's law suggests that major accidents do not occur abruptly but are preceded by a series of minor events, which serve as a warning sign of an impending accident. These minor events, commonly referred to as near-misses, foreshadow the likelihood of more significant accidents (Yoo, 2018). The term "near-miss", according to Khajehei and Chandrasekhar (2024), is defined as an event with a significant likelihood of leading to disaster, where the adverse outcome is mostly avoided by chance while Chen *et al.* (2025) define "maritime near-miss" incident as a critical event that causes no actual harm but indicates potential hazards, providing valuable opportunities for proactive risk management thus improving safety protocols.

There are several reasons to utilize near-miss reports, one being the lack of comprehensive accident databases in certain areas such as ship collisions. Additionally, near-misses happen more frequently, allowing analyses to be conducted using less than a year's worth of data. Therefore, assessing areas of interest based on near-misses, which have the potential to lead to marine accidents, is often a more practical approach (Yoo, 2018).

Wu *et al.* (2025) argue that while near-misses do not result in immediate losses, they may conceal underlying safety risks and frequently act as warnings for more severe maritime incidents. Ignoring near-miss in shipping operations may cause captains to unintentionally increase the likelihood of such risky operations. Over time, as risks accumulate without a serious accident occurring, captains may fail to revise operating procedures or safety measures, which can ultimately lead to an actual marine accident. Therefore, recognizing and addressing these precursors can significantly reduce the risk of future incidents, including property damage and loss of life. To provide a comprehensive view of maritime safety incidents and improve risk assessment accuracy, Chen *et al.* (2025), identified occurrence patterns and potential risk factors by leveraging maritime open-source intelligence (OSINT), a method for collection and processing of open-source information (Gonzalez-Granadillo *et al.*, 2021), alongside cooperative surveys to collect and analyze a vast volume of near-miss reports.

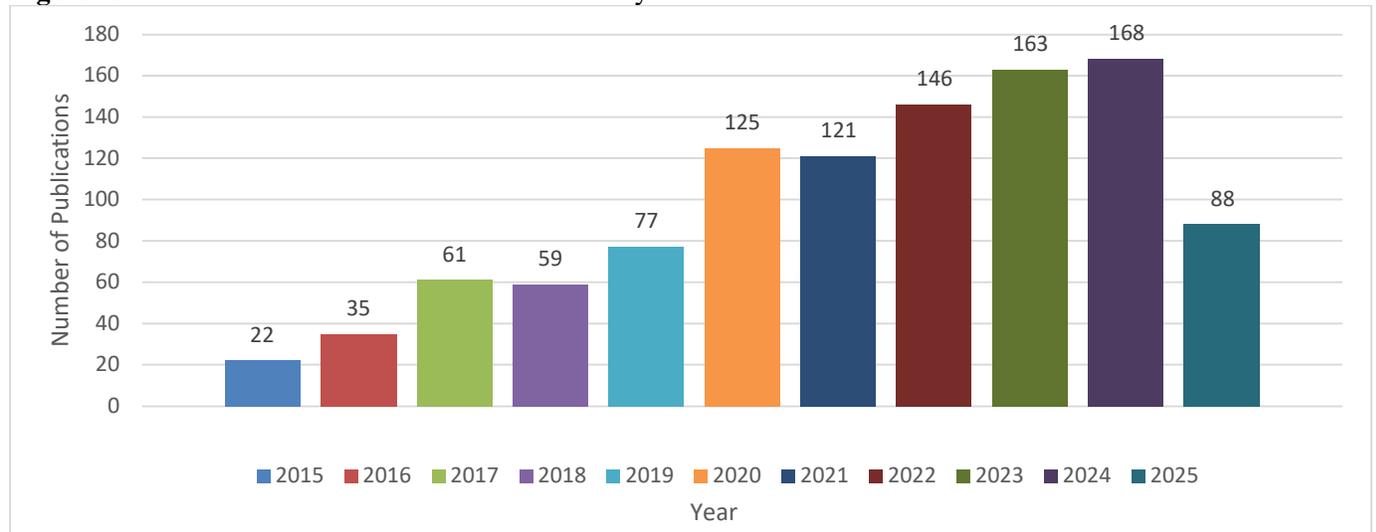
International Maritime Organization (IMO) mandates that shipping companies prepare and submit detailed near-miss reports. Beyond being a regulatory requirement, near-miss reporting contributes to enhance maritime industry's efficiency and economy by promoting improved crew and vessel performance, ultimately leading to reduced associated costs. For this reason, managing near-miss incidents has proven an effective safety strategy in various areas (Wu *et al.* 2025). The combination of near-miss data with other safety-related data sources, such as sensor readings and operational logs, offers a more thorough insight into risk factors and enhances predictive capabilities (Chen *et al.*, 2025).

Despite initial reluctance from companies to report near-misses, often due to overloading, overwork, and fear of blame (Yoo, 2018), effective collection of near-miss data is crucial for meaningful analysis. Nowadays, many industries have established reporting systems specifically designed to collect such data (Chen *et al.*, 2025).

In recent years, research focusing on near-misses in the shipping industry has grown considerably (see **Figure 2**). This trend was identified through a search in the Scopus database using the

following query: “near-miss AND shipping OR maritime AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE , "English"))”.

Figure 2: Publications for near-miss studies over the years.



2.3 Digitalization in safety

The global economy has undergone rapid digitalization with digital products, services and technologies becoming essential to everyday life (Chen *et al.*, 2025). Digital place-based policies focus on data as a core element, driving the shift of regional economies from traditional models toward digitalization and intelligence by developing digital infrastructure, applying digital technologies and fostering digital industries (Nie *et al.*, 2025). Digitalization has emerged as a key catalyst of global economic growth and innovation, driving the transformation of organizations, institutions and societies (Kumara *et al.*, 2025) and this widespread digital shift is reshaping industries worldwide, prompting companies to invest in advanced digital technologies to remain competitive (Zahid *et al.*, 2025)

Although digitalization has gathered increasing attention from both academia and industry, its concept remains unclear, particularly because it is often used interchangeably with related terms. Often, the terms digitization, digitalization and digital transformation are frequently mixed up or treated as synonyms. Digital transformation is defined by Singh *et al.* (2020) as the application of digital technologies to drive significant business improvements, including enhanced customer experience, streamlined operations and the development of new business models. It is also considered as a strategic change, since it reshapes a company’s value creation, potentially altering the scope of its operations and leading to revised or entirely new business models. While digitization is defined as the process of converting physical objects or attributes into digital formats (Gong and Ribiere, 2021), digitalization involves the progression of ICT systems linked to organizational changes, where socio-technical frameworks previously supported by non-digital tools are transformed into systems facilitated by digital technologies (Kumara *et al.*, 2025). Along similar lines, Raza *et al.* (2023) define digitalization as the use of digital technologies and digitalized data to modify socio-technical structures.

Moreover, digitalization is essential for achieving digitization, which can subsequently drive digital transformation and convert traditional businesses into fully digital enterprises (Kumara *et al.*, 2025). Digitalization goes beyond a mere technical process of encoding analogue information into a digital format; it makes digital content programmable, traceable, accessible and shareable

(Fahnrich, 2023) aiming to enhance the efficiency and productivity of the existing processes by minimizing costs and maximizing profits (Raza *et al.*, 2023). In the context of shipping, Ichimura *et al.* (2022) describe digitalization as transformation of the conventional business model through the effective implementation of new technologies associated with Industry 4.0.

In essence, "Digitalization" broadly refers to the application of digital technologies across multiple fields, including business, society, and the economy, encompassing the aforementioned definitions. Digital technologies such as AI, big data, and machine learning hold great promise for sustainable advancements in decision-making, product monitoring, and risk management but bring also challenges, including rising costs, higher energy consumption and concerns over data security (Wang *et al.*, 2025). This study is motivated by the increasing acknowledgement of digitalization as a key driver for advancing safety.

While the widespread adoption of digital technologies has clearly boosted production efficiency, it also presents challenges and risks related to occupational safety and health, given that a firm comprises both tangible assets and human resources (Pantouvakis *et al.*, 2017). Statistics from the International Labor Organization (ILO) reveal that more than 2.78 million workers worldwide succumb to occupational accidents on an annual basis. Additionally, around 374 million workers suffer from non-fatal workplace injuries. Alarmingly, 60% of these fatalities can be attributed exclusively to the construction industry, highlighting the sector's significant safety challenges (Luo *et al.*, 2023).

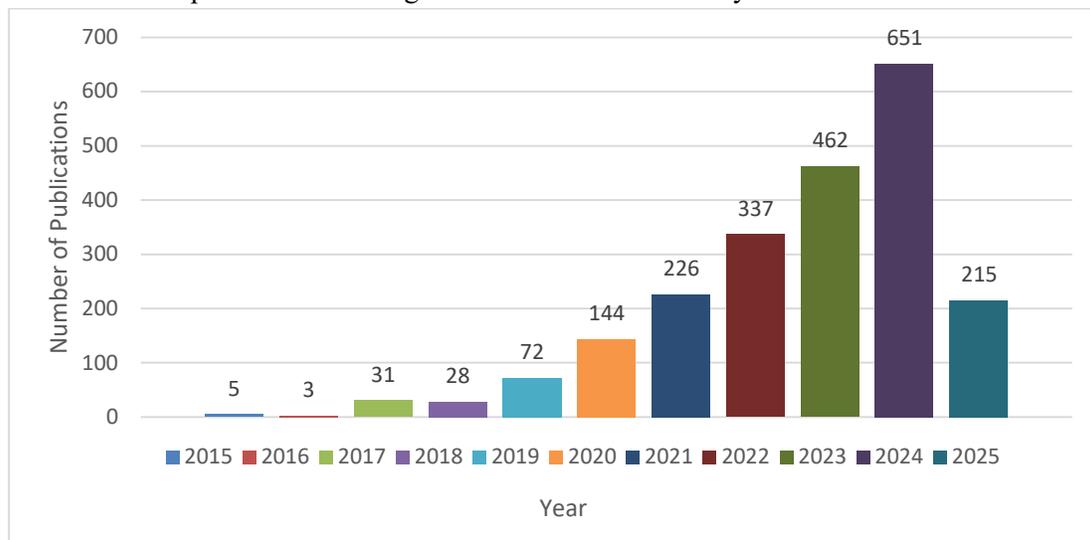
Industries marked by high risk and hazardous conditions encounter unique challenges due to their intricate operations and interconnected systems. This intricacy increases the likelihood of accidents, which may result in severe environmental harm, considerable financial losses and significant human casualties (Zou *et al.*, 2025) often stemming from human error (Ma *et al.*, 2024). Ma *et al.* (2024) explain that human factors contributing to maritime accidents constitute a multifaceted system that includes not only the unsafe actions of crew members onboard but also various risk factors affecting these behaviors, such as workplace conditions, physical and natural environments, procedures, technology, training, and management. Gulen *et al.* (2025) argue that existing safety protocols for ship operations, such as the International Safety Management (ISM) Code, are crucial for maritime safety but have notable drawbacks because they depend heavily on traditional, manual processes. This reliance on human judgement often leads to inconsistencies, errors, and gaps in both implementation and documentation.

The absence of real-time monitoring tools and the preference for a reactive instead of proactive safety approach further elevate risks, as dangerous situations cannot be promptly identified or addressed. In addition, reliance on paper-based systems hinders procedural traceability, auditability, and data integration, making it difficult to maintain compliance and accountability. These challenges underscore the urgent need to incorporate digital technologies to enhance procedural compliance, minimize human error, support comprehensive, dynamic risk management, proactive accident prevention and informed decision-making, thereby fostering a safer operational environment (Gulen *et al.*, 2025, Zou *et al.*, 2025). However, digital transformation has yet to be fully integrated into safety protocols. The potential benefits of digital transformation, such as improved efficiency, accuracy, and real-time monitoring, could significantly advance safety management practices (Gulen *et al.*, 2025).

In **Figure 3**, the number of studies made for digitalization over the last 10 years is presented. The Scopus database was utilized for this search, employing the following query to retrieve relevant results "digitalization OR digitalisation AND marine OR maritime OR shipping AND ship OR

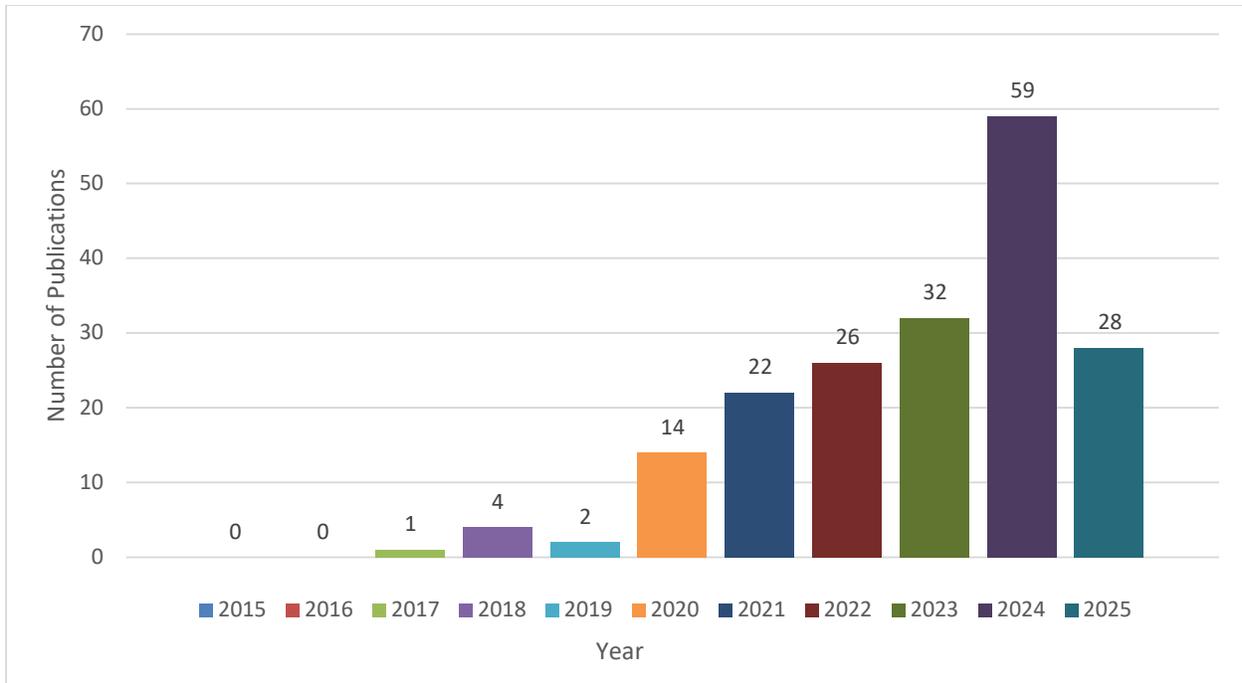
vessel AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE,"English")).

Figure 3: Number of publications for digitalization studies over the years.



Furthermore, a more focused search in the Scopus database was conducted, employing the following query to retrieve relevant results “digitalization OR digitalisation AND shipping OR maritime OR ship OR vessel AND human AND error AND accidents OR casualties AND PUBYEAR > 2015 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE , "English")). This revealed a rising number of studies examining the connection between accidents caused by human error and digitalization over time (see **Figure 4**).

Figure 4: Number of publications for studies on digitalization and accidents due to human error over the years.



3. Methodology

This study explores how the implementation of digital tools impacts maritime safety, with a particular emphasis on human error. It investigates whether digitalization implementation contributes to reducing human error by analyzing maritime casualty reports—particularly near-miss reports.

Accident investigation reports are important resources for collecting detailed accident data providing a vital basis for understanding and preventing future incidents (Ma *et al.*, 2024).

This study employs grounded theory, where researchers begin without preconceived theoretical assumptions, starting instead with direct observations. They then extract insights from the raw data and develop theories grounded in this empirical evidence (Ma *et al.*, 2024). The utilization of a data collection and analysis approach focused on the maritime near-miss reports of a shipping company. This methodological approach has the potential to uncover new, innovative insights and a wealth of information that might not be readily available or captured in existing databases. By leveraging raw data procured directly from maritime near-miss reports, this approach significantly deepens the understanding of maritime near-miss analyses, consequently facilitating a more comprehensive and in-depth comprehension of the fundamental factors that contribute to the occurrence of casualties.

To address the research question outlined in section 1, quantitative data was utilized based on real-time maritime near-miss reports gathered from a sample fleet of a reputable bulk-carrier shipping company. Additionally, the majority of the vessels in the shipping company's fleet are equipped with telemetry and high-frequency data collection systems.

We collected the data for our study from a total of 1846 near-miss reports. These reports originated from a fleet that consisted of 51 bulk carriers, all of which were operated by a single shipping company within a 6-year period from 2017 to 2022. Then, we refined our dataset to 1100 near-miss reports all stemming from 31 bulk carriers within the fleet. For the purposes of our study, we specifically focused on a subset of 31 vessels that were equipped with telemetry and high-

frequency data collection systems, categorizing them as being digitally equipped, and it was this subset of data that formed the basis of our analysis.

The rationale behind selecting a single shipping company for the present empirical study is essentially grounded in the common management scheme implemented across the sample fleet. All selected vessels were under the same management, adhering to identical Safety Management System (SMS) procedures, to the same digital strategy, and they were flying under the same flag and manned by crews who had embraced a collective mindset fostered by the crew office of the shipping company. This specific selection of vessels under a unified management umbrella ensures a consistent operational environment and minimizes variables that could potentially skew the study results, thereby enhancing the reliability and validity of the empirical findings.

4. Empirical analysis results

As shown in **Table I**, the vessels were built between 2010 and 2021, with an average year built of 2014.9 (SD = 3.23). Before telemetry implementation, near-misses averaged 5.70 (SD = 3.41, Min = 0.17, Max = 12.8) while after telemetry near-misses had an average value of 4.35 (SD = 2.53, Min = 0.50, Max = 9.17).

Table I: Descriptive statistics of near-miss maritime casualty data.

Description	N	Mean	Median	SD	SE
Near-Misses before telemetry	31	5.70	5.73	3.41	0.61
Near-Misses after telemetry	31	4.35	4.21	2.53	0.46

Table II presents the results of a left-tailed paired samples t-test, used to determine whether there is a statistically significant difference in the number of near-miss incidents before and after the implementation of telemetry systems across a fleet. The average near-misses before telemetry (Mdn = 5.73) had a greater value compared to the near-misses after telemetry (Mdn = 4.21). The mean reduction of 1.52 incidents suggests a practical improvement in operational safety.

Table II: Left-tailed Paired Samples T-Test of data regarding maritime near-misses

		t-crit95%	t-statistic	p-value	Mean difference	SD difference	95% Confidence Interval		Test Power	Cohen's Effect Size
							Lower	Upper		
Near-Misses before telemetry	Near-Misses after telemetry	-1.6973	-1.899	0.034	-1.349	3.954	-13.58	10.98	0.8589	0.34

More particularly, the left-tailed paired sample t-test showed that this reduction was statistically significant, $t(30) = -1.899$, $p = 0.034 < 0.05$, with the test statistic falling below the critical value ($t_{\text{critical}} = -1.6973$), indicating strong evidence of improvement after telemetry. The effect is small-to-moderate in size (Cohen's $d = 0.34$), but the test was well powered (86%), meaning the finding is reliable.

5. Discussion and implications

This study makes several contributions to existing literature. To the best of the author's knowledge, it is the first in the shipping industry to highlight the implementation of digitalization and telemetry, specifically in the context of near-miss incidents. Through this approach, this research presents a comparison of the rate of near-miss incidents before and after the implementation of telemetry onboard the vessels of a shipping company, measuring the quantitative impact of digitalization on incidents caused by human error. The statistically significant decline in near-miss incidents following the adoption of digital monitoring and telemetry systems indicates that digitalization positively influences decision-making and strengthens the prevention of human error routine shipboard operations. This reduction suggests that crew members gain from improved situational awareness and data-driven decision-making, which enhance their ability to identify and manage potential risks more effectively. The impact is both statistically significant and practically meaningful, reinforcing the conclusion that digitalization plays a pivotal role in the market decline of near-miss incidents across the fleet, thus directly addressing the study's research question.

The findings outlined in the previous section of this paper are considered novel, as the existing literature lacks empirical studies directly linking digitalization to maritime near-miss incidents. While numerous studies discuss the potential of digitalization to improve maritime operations, this study provides empirical, statistically significant evidence that digital monitoring and telemetry systems are associated with a considerable reduction in near-miss occurrences. The application of paired samples analysis—comparing data before and after telemetry implementation across a large dataset of 434 cases—adds methodological rigor and clarity often missing in more speculative or qualitative studies.

Furthermore, this study underscores the human factors dimension—particularly decision-making and human error prevention—rather than focusing solely on technical efficiency or system performance. This focus bridges a critical gap between technology implementation and human-centered outcomes, which is often underexplored in the maritime domain.

It is also worth noting that few studies explicitly relate telemetry systems to safety outcomes such as near-miss incidents. Our research establishes a direct statistical linkage between telemetry adoption and safety improvements, demonstrating how real-time digital feedback loops can effectively enhance human performance and mitigate operational risk.

This marks a significant transition towards adopting technological advancements in the maritime field, where traditional practices are increasingly being replaced by modern, data-driven methods. The integration of digitalization and telemetry in addressing maritime accidents reflects the industry's growing recognition of the safety, efficiency, and data management benefits these technologies can offer. Unlike studies that rely on simulations, self-reported surveys, or limited-case studies, our research draws real operational data from an entire ship fleet, comparing conditions before and after a targeted digital intervention. This provides strong external validity and practical relevance for both the industry and policymakers.

The use of digitalization and telemetry in the shipping industry represents an important advancement, signaling a broader move toward technology-driven maritime operations. It reflects the industry's commitment to innovation and continuous improvement in safety standards. This growing reliance on advanced technologies underscores efforts to prevent accidents and minimize their impact on human life and the environment.

6. Limitations and directions for future research

As with any research, this study has certain limitations that should be acknowledged. While the findings indicate a statistically significant reduction in near-miss incidents following the implementation of digital monitoring and telemetry systems, attributing this outcome solely to digitalization is challenging. Other concurrent factors—such as crew training initiatives, shifts in safety culture, or regulatory developments—may also have contributed to the observed improvements.

Additionally, external operational variables such as weather conditions, voyage routes, and workload intensity during the “before” and “after” measurement periods were not controlled for. These factors could have independently influenced the frequency of near-misses and introduce potential confounding effects.

Another important consideration is the accuracy and consistency of the near-miss reporting. Since such data often depends on both human reporting and system-based logging, variations in crew behavior or familiarity with reporting protocols could affect the results. It is also possible that digitalization improved the quality of incident detection and reporting, rather than reducing the actual number of events.

The study was conducted on a specific fleet under particular operational and technical conditions, which may limit the generalizability of the findings to other maritime contexts. Different vessel types, company policies, or geographic regions may yield different outcomes.

Finally, this research primarily utilized quantitative data and did not capture the subjective experiences or perceptions of crew members regarding the use of digital systems. As a result, potentially valuable insights into how digitalization influences decision-making, situational awareness, or perceived safety were not explored.

Future studies should aim to isolate the specific contribution of digital systems by controlling for external variables such as crew training, weather, and operational differences. Employing mixed-method approaches—combining quantitative incident data with qualitative interviews or surveys—would offer deeper insights into the human factors influenced by digitalization. Additionally, replicating the study across diverse fleets, vessel types, and geographic regions would enhance the generalizability of the findings. Finally, future research could explore the long-term behavioral adaptations of crew members to digital systems and their influence on sustained safety performance.

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8. List of References

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