Digitalization impact on Port State Control and Classification Deficiencies

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Abstract

Maritime companies are progressing digital transformation by adopting various digital strategies and implementing technologies emerging from Industry 4.0. Port State Control (PSC) and Classification Societies play a critical role in maritime safety and protection of the environment through ship inspections. This research aims to explore the connection between digitalization and telemetry and their impact on Classification and PSC deficiencies and detentions with a focus on maritime safety. This is achieved by collecting real-case data from the fleet of a reputable bulk carrier shipping company which serves as a case study. The goal is to identify and analyze all the various factors related to the digital transformation within the organization, both prior to and post-implementation of digital monitoring systems. The results highlight that when digital technologies, such as telemetry, are implemented by shipping companies, this can significantly reduce the likelihood of Classification and PSC deficiencies and detentions being imposed.

Keywords

Classification, Digitalization, Port State Control, Deficiencies

1 Introduction

Waterborne transportation has experienced considerable growth over the past two decades, regarded as the backbone of international commerce and the global economy. More than 80% by volume and over 70% by value of global merchandize trade is carried by sea, with these percentages being even higher for many developing countries. Despite the ramifications of the COVID-19 pandemic, the maritime volumes declined less than expected and recovered by the end of the year 2021, establishing a robust framework for ship logistics and new maritime trade dynamics. Nevertheless, the escalation of maritime transportation and the enlargement of the global fleet, alongside seafarers of diverse qualifications from over 150 nations pose potential risks (i.e., loss of property, life and navigational environment) to maritime and port safety, reflected by the increasing number of maritime accidents [23], which pose a threat to human lives, economic assets and maritime pollution. Structural failure is one of the major causes contributing to severe marine accidents, typically resulting from the effects of gradual deterioration mechanisms, including structural overloading, errors in ship design, the utilization of substandard materials, inadequate alignments or welding, degradation of coating and vibrations induced by hydrodynamic loads or the machinery.

To avoid the occurrences of these factors, ships are built according to strict safety and pollution prevention standards. In this respect, ships have to undergo detailed inspections both during construction and throughout their operational periods. This allows for timely ship maintenance and repairs based on the identified defects and faults [3].

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 delineates the scope of the study, while Section 4 describes the methodology utilized. The findings of the study are presented in Section 5, followed by an analysis of their contribution to addressing the research questions in Section 6. Lastly, Section 7 provides an overview of the key conclusions, addresses any limitations, and suggests potential approaches for future research.

2 Literature

2.1 Port State Control

Regulatory frameworks governing the inspection and oversight of foreign vessels by port states have been a key aspect of maritime enforcement since 1929 SOLAS Convention. Nonetheless, through the introduction of regional agreements – commonly referred to as the 'Memoranda of Understanding on Port State Control (PSC MoU)' – such practices evolved into a structured approach to promoting maritime safety [2]. The foundation of PSC was initially laid in 1978 through the Hague Memorandum.

However, its official implementation was driven by the disastrous accident of super oil tanker Amoco Cadiz. This incident triggered the adoption of stricter regulations and the development of a more detailed memorandum addressing life safety at sea, the prevention of maritime pollution as well as the improvement of working and living conditions on board ships. Port State Control (PSC) serves as a regulatory mechanism established to prevent the operation of substandard vessels that fail to meet international maritime standards from navigating worldwide [17].

The first Paris Memorandum of Understanding (MoU) was signed in 1982, there are totally nine current regional MoUs over the world, namely alphabetically Abuja MoU, Black Sea MoU, Caribbean MoU, Indian Ocean MoU, Mediterranean MoU, Paris MoU, Riyadh MoU, Tokyo MoU and Vina del Mar MoU. On top of that, the United States Coast Guard (USCG) maintains the tenth inspection regime [16].

The main objective of PSC inspections is to enhance the maritime safety standards of the international trade fleet by eliminating substandard vessels [5]. In alignment with PSC protocols, vessels that fail to comply with various international regulations and conventions, as governed by the International Maritime Organization (IMO) and International Labour Organization (ILO), are classified as substandard ships. During a PSC inspection, any onboard conditions that are not in compliance with the requirements are identified as deficiencies that necessitate rectification [18]. Should there be significant deficiencies that render a ship unsafe to navigate, the PSC officer is authorized to detain the vessel and mandate the rectification of subject deficiencies prior departing. Ship detention is the most critical decision generated during an inspection and can be perceived as the most severe result of PSC inspection. Ship detention not only signifies inadequate ship conditions and increased likelihood for future incidents but may also result in severe delays of the vessel [14].

In the process of selecting the vessel for inspection, it is of paramount importance to examine the classification societies, the inspecting authority, the records kept at previous inspections, the number and type of the deficiencies as well as the vessel's principal characteristics. The age of the vessel is considered, if not the most, one of the most important factors in the selection process for the inspection of the bulk carrier cases. This consideration is followed by criteria such as the number of deficiencies recorded during last inspection, the recognized organization or classification society, and the flag under which the vessel is sailing [12].

It is worth mentioning at this point that there is a link between PSC deficiencies and maintenance cost and accidents [11], [24], [7] as many accidents occur due to vessel deficiencies, many of which are identified and recorded during PSC inspections. According to PSC inspection records, a large number

of vessels consistently demonstrate non-compliance with the regulations reckoned by port authorities each year, leading to unsuccessful inspections. This phenomenon exposes the shortcomings and deficiencies of the PSC system in motivating ship owners to enhance vessel quality. Due to the high maintenance associated cost, some shipowners postpone addressing the safety loopholes of their vessels [24]. However, this aspect falls beyond the scope of this paper and will not be subjected to further examination.

2.2 Recognized Organizations/Classification Societies

Recognized Organizations (RO) or Classification societies constitute essential entities that advocate for the highest standards in maritime safety and the quality of shipping operations. ROs are pivotal contributors within the regaulatory framework of safety and quality in shipping regulatory serving as the shipping industry as an internal regulatory mechanism for the maritime sector. Their authoritative capacity is evidenced by the classification certificates they issue during vessels construction and ongoing maintenance, which is verified through periodic surveys conducted throughout the vessel's operational lifecyrcle. In the absence of a classification certificate, ships are unable to secure insurance coverage resulting in minimal commercial value. Moreover, ROs represent the most significant technical resource within the shipping industry. As Recognized Organizations affiliated with flag states, classification societies play a vital role in the governance of maritime safety and pollution prevention [8]. It is imperative for ROs to remain abreast of the latest developments and oto provide guidance, while also formulating rules and regulations, to guarantee that all vessels systems have been developed properly ensuring both reliability and efficacy [12]. However, it is worth mentioning that ROs lack any legal authority for enforcement beyond withdrawing their services/certification [8].

There are more than 50 classification societies, who are actively operating worldwide, the larger of which to the International Association of Classification Societies (IACS), established in 1968. The primary objectives of IACS are to uphold and improve standards accross the industry, thereby promoting maritime safety and fostering cleaner seas through pollution prevention. In pursuit of these goals, IACS collaborates closely with the IMO as well as with other national regulatory entities and industry stakeholders. In 1969, IMO granted IACS a "consultative status", and the fact that IACS is the sole non-governmental organization holding observer status at the IMO, underscores the role of ROs as intermediaries between the commercial shipping sector and governmental bodies. IACS now comprises the twelve major classification societies including the American Bureau of Shipping (ABS), the Bureau Veritas (BV), the Nippon Kaiji Kyokei (ClassNK), the Det Norske Veritas (DNV), the China Classification Society (CCS), the Lloyd's Register (LR), the Indian Register (IRS), the Croatian

Register of Shipping (CRS), the Polish Register os Shipping (PRS), the Korean Register (KR), the Registro Italiano Navale (RINA) and the Turk Loydy Foundation (Tyrk Loydy). Among the major classification societies, Lloyd's Register (LR) was the first in history to establish a Register of Ships in 1764 [8].

Ship Classification is a collaborative process involving a RO, the shipowner and the operator. It must be conducted with due dilligence and in strict accordance with classification rules. This process ensures the adequate structural strength of all essential parts of the vessel, including the hull, propulsion system, steering system, and auxiliary equipment and machinery. It maintains the vessel's overall condition, ensuring the safe transportation of cargo and crew while at sea, anchored, or moored in port [8].

### 2.3   Digitalization Definition

To define digitalization, it is essential to consider the suffix "-ization." Applying this affix to create an innovative concept can introduce significant challenges. When a verb is transformed into a noun by adding "-ization," it can lead in dual signification. The modern terminology signifies both the process outlined by the original verb and the final state that results from it. In this view, digitalization embodies both the condition of being digitalized and the process of transitioning into a digital state [4].

Sustaining a clear distinction between the process and the final state of a phenomenon with the affix "ization" can be quite challenging, as it may lead to overlapping connotations. Therefore, it is recommended to focus digitalization on the outcomes that result from the adoption and integration of digital technologies, emphasizing its major impact on services, products and relationships [4].

In their paper Ichimura et al. [21] 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 significant increase in research examining and discussing the role and impact of digitalization on shipping (see **figure 1**). The Scopus database was utilized for this search, employing the following algorithm to retrieve relevant results "digitalization OR digitalisation OR telemetry AND maritime OR shipping AND ship OR vessel AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024))".

Figure 1: Number of publications for digitalization in shipping over the years
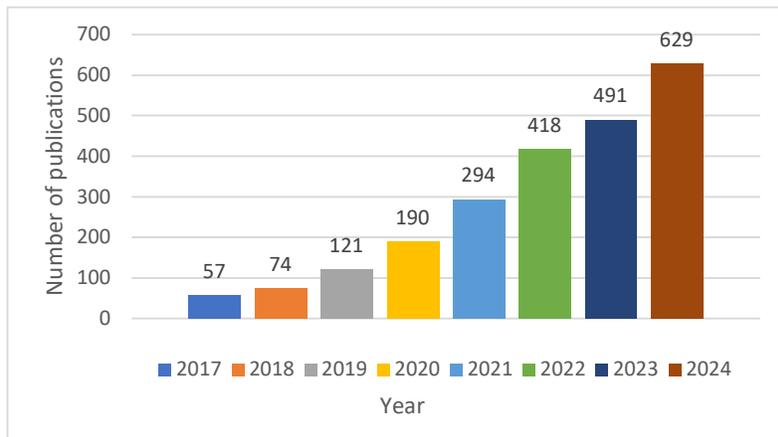
3   Scope of the study

Numerous studies highlight the positive effects of digitalization across various domains [1], [6], [9], [19], [21]. Additionally, several research studies [10], [22], [20] indicate that digital technologies play an important role in marine accidents, which are indirectly linked to Classification and PSC deficiencies and detentions. Digital transformation has prompted stakeholders to implement monitoring systems onboard, facilitating the collection and transmission of monitoring data [12]. R. Puise et al. [13] noted that next-generation fire alarm systems utilize intelligent sensors—an application of digital technology—to enhance the monitoring of safety systems and prevent potential accidents on vessels. This underscores the crucial necessity to further explore the specific mechanisms linking to PSC deficiencies while Q. Liang et. al. [12] highlight the significance of sensors and monitoring systems, which many vessels are equipped with. These systems allow real-time data collection and analysis, supporting maintenance decisions and thereby minimizing the likelihood of an equipment failure and preventing potential maritime accidents. These practices contribute to augmenting the reliability and safety of vessels while also reducing maintenance cost and downtime. Nevertheless, there are high costs associated with installing and maintaining sensors and data acquisition equipment on ships and this poses additional challenges. In this respect, the study aims to shed light on the following research questions:

RQ1: Are there any statistically significant differences in PSC deficiencies in a shipping company's fleet before and after telemetry implementation?

RQ2: Are there any statistically significant differences in Classification deficiencies in a shipping company's fleet before and after telemetry implementation?

4   Methodology

4.1   Data Acquisition

The utilization of a data collection and analysis approach focused on the PSC and Class Inspection reports of a shipping company. This methodological approach possesses the potential to yield novel, groundbreaking insights and a plethora of information that may not be readily accessible or present in existing databases. By leveraging raw data procured directly from PSC and Class Inspection reports, this approach significantly deepens the understanding of the PSC and Classification reporting systems, consequently facilitating a more comprehensive and in-depth comprehension of the fundamental factors that contribute to the occurrence of deficiencies and detentions.

To address the research questions mentioned above, a set of quantitative data was used. It relies on real-time data, including PSC and Classification inspection reports, collected from a sample fleet of a shipping company operating 51 bulk carriers over a six-year period from 2017 to 2022. Additionally, the majority of the vessels in the shipping company's fleet are equipped with telemetry and high-frequency data collection systems.

Our study analyzed data from 234 PSC inspection reports containing 750 deficiencies and detentions imposed as well as 1014 Classification inspection reports containing 449 deficiencies, collected from a fleet of 51 bulk carriers operated by a single shipping company over a six-year period from 2017 to 2022. Additionally, the majority of the vessels in the shipping company's fleet are equipped with telemetry and high-frequency data collection systems. The analysis has been conducted on a fleet level before and after the implementation of telemetry. Then, we refined our dataset to 138 PSC inspection reports containing 371 deficiencies and detentions imposed, as well as 597 Classification inspection reports containing 325 deficiencies all stemming from 31 bulk carriers within the fleet. For the purposes of our study, we concentrated on a subset of 31 vessels outfitted with telemetry and high-frequency data collection systems, categorizing them as digitally equipped.

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.

4.2   Data Description

The vessels were built between 2010 and 2021, with an average year built of 2014.84 (SD = 3.21). The descriptives for PSC deficiencies are presented in **Table 1** and the descriptives for Classification deficiencies are presented in **Table 2**.

Table 1

Descriptives for PSC Deficiencies and Detentions

	N	Mean	Median	SD	SE
PSC Deficiencies Before Telemetry	31	8.52	4.58	8.42	1.51
PSC Deficiencies After Telemetry	31	3.29	1	4.96	0.89
PSC Detentions Before Telemetry	31	0.03	0	0.18	0.03
PSC Detentions After Telemetry	31	0.13	0	0.72	0.13

Table 2

Descriptives for Classification Deficiencies

	N	Mean	Median	SD	SE
Classification Deficiencies	31	7.64	2.92	10.07	1.81

	Before Telemetry				
Classification Deficiencies After Telemetry	31	2.84	1.83	3.3	0.59

5   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 3 and Table 4.

The number of PSC Deficiencies was compared before and after the installation of telemetry. The average PSC Deficiencies before telemetry (Mdn = 4.58) had a greater value compared to the PSC Deficiencies after telemetry (Mdn = 1). A Wilcoxon Test indicated this improvement, was statistically significant, (Z=302, p=0.007, rb=0.60).

The number of Detentions was also compared before and after the installation of telemetry. However, the average Detentions before telemetry (Mdn = 0) had the same value compared to the Detentions after telemetry (Mdn = 0).

The number of Classification Deficiencies was compared before and after the installation of telemetry. The average Classification Deficiencies before telemetry (Mdn = 7.64) had a greater value compared to the Classification Deficiencies after telemetry (Mdn = 1.83). A Wilcoxon Test indicated this improvement, was statistically significant, (Z=233, p=0.018, rb=0.55).

The large values of the rank biserial correlation indicate a strong relationship between the telemetry implementation and the PSC and Classification deficiencies. By incorporating telemetry systems on board a vessel, the likelihood of a deficiency imposed by PSC or by the RO can be significantly reduced, thus augmenting the overall condition of the vessel enhancing the safety of the crew members. The results have shown that there are indeed statistically significant differences in PSC and Classification deficiencies before and after telemetry implementation answering the two research questions of this study. The study achieves this by leveraging the power of digitalization and telemetry, which are instrumental in collecting and analyzing relevant data.

The integration of digitalization and telemetry in relation to PSC and Classification deficiencies within the shipping industry can be considered a significant progression and represents a pivotal achievement in the direction of a maritime sector that is technologically advanced and characterized by enhanced safety measures.

The above-mentioned results emphasized the importance of incorporating telemetry, leading the company to strategically opt for digitalization.

Table 3

Paired Samples T-Test for PSC Deficiencies and Detentions

			Statistic	p	Mean difference	SE difference	95% Confidence Interval			Effect Size
							Lower	Upper		
PSC Deficiencies Before Telemetry	PSC Deficiencies After Telemetry	Wilcoxon W	302	0.007	6.39	1.86	1.92	10.58	Rank biserial correlation	0.6
PSC Detentions Before Telemetry	PSC Detentions After Telemetry	Wilcoxon W	1	1	-1.5	0.13	-1.5	-1.5	Rank biserial correlation	-0.33

Note. H$_a$ μ $_{Measure 1 - Measure 2}$ ≠ 0

[a] 1 pair(s) of values were tied

[b] 16 pair(s) of values were tied

[d] 4 pair(s) of values were tied

[e] 29 pair(s) of values were tied

Table 4

Paired Samples T-Test for Classification Deficiencies

			Statistic	p	Mean difference	SE difference	95% Confidence Interval			Effect Size
							Lower	Upper		
Class Deficiencies Before Telemetry	Class Deficiencies After Telemetry	Wilcoxon W	233*	0.018	5.17	1.82	0.75	9.75	Rank biserial correlation	0.55

6 Discussions and Implications

6.1 Theoretical and practical contributions

This study contributes to literature in several ways. According to the author's best knowledge, this is the first time in the shipping industry where the use of digitalization and telemetry, specifically in the context of PSC and Classification inspections, is mentioned. By doing so, a comparison, before and after application of telemetry onboard the vessels of a shipping company, is presented, in which the impact of the various dimensions of digitalization in PSC and Classification deficiencies and human factor, concerning its onboard safety, is measured quantitatively. The results have shown that there are statistically significant differences in PSC and Classification deficiencies before and after telemetry implementation answering the two research questions.

The results presented in the previous section of this paper are considered new, particularly because the literature does not offer any study in which digitalization and PSC and Classification deficiencies are related. This signifies a significant shift towards implementing technological advancements in the maritime sector, where traditional practices are being replaced by more modern and efficient methods. The incorporation of digitalization and telemetry in relation to PSC and Classification deficiencies highlights the industry's recognition of the potential benefits and advantages that these technologies can bring in terms of safety, efficiency, and data management. This reference to digitalization and telemetry in the shipping industry sets a precedent for future developments and advancements in the field, emphasizing the growing importance of technology in maritime operations and marine accident prevention as PSC and Classification deficiencies are linked to the latter. The recognition and adoption of these technologies also indicate a willingness within the industry to adapt and embrace innovation, as well as a recognition of the need to continually improve and enhance safety practices in order to prevent any kind of accident and mitigate their impact on both human lives and the environment. This milestone serves as an important starting point for further research, development, and implementation of digitalization and telemetry in the shipping industry, as it opens up new possibilities and opportunities for improved safety, efficiency, and sustainability in maritime operations. It also highlights the increasing interconnectedness of various industries and sectors, as well as the potential for cross-pollination of ideas and technologies between different fields. Overall, this reference to digitalization and telemetry in relation to PSC and Classification deficiencies in the shipping industry marks a significant development and represents a steppingstone towards a more technologically advanced and safer maritime sector.

6.2 Main Conclusions

The findings of this study emphasize the critical elements of digitalization that are essential in order to guarantee the safety of vessels while at sea. More particularly, these findings provide valuable and clear perspectives on the urgent need for shipping companies to place greater emphasis on incorporating digital integration into their operations. This focus on increased digitalization is crucial for improving the safety of crew members, especially seafarers, as it can significantly reduce the occurrence of accidents and injuries minimizing any kind of deficiencies through the effective implementation of digital technologies.

The next step of this study is to investigate if there is any correlation in the same sample between, PSC deficiencies and marine accidents, injuries and near misses as well as between PSC deficiencies and maintenance/repairs/service and spare parts cost taking into consideration the period before and after the implementation of the telemetry digitalization system.

7   Limitations and directions for future research

As with every research, our study also has some limitations. Primarily, the data was collected from a single shipping company, which may limit the generalizability of the findings. Future researchers should aim to address this limitation by gathering data from a larger sample encompassing multiple shipping companies. By doing so, researchers can enhance the generalizability and robustness of their findings, thus further contributing to the body of knowledge in this field.

Secondly, it is important to acknowledge that the scope of our research is limited in two significant ways. Firstly, our study is confined to a dataset that covers only a six-year period, thus restricting the temporal dimension of our analysis. This temporal constraint limits the ability to capture long-term trends and fluctuations in the data, potentially leading to an incomplete picture of the phenomenon under investigation. Moreover, by focusing solely on a specific type of vessel, namely bulk carriers, our study fails to account for the heterogeneity and diversity present within the broader maritime industry. Therefore, in order to provide a more comprehensive understanding of the subject matter, future studies should aim to overcome these limitations by extending the timeframe for data collection, allowing for a more nuanced analysis of long-term patterns, and including data from various types of vessels to account for the inherent heterogeneity within the industry. This would enable researchers to obtain a more holistic and robust understanding of the factors influencing the performance and dynamics of the maritime sector.

Thirdly, some vessels have installed their digitalization system during 2022. For future research, refining further the same dataset, either by excluding these vessels or by defining better the period prior and post digitalization implementation could enhance the accuracy of the results.

8 Acknowledgements

9 References

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