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Identification of Data Analysis Methods and Focus Trends in Port State Control Inspections: A Comprehensive Literature Review

Arif Junaidi[1], Hartono Yudo[2], Hasnida Ab-Samat[1*]

[1]*School of Mechanical Engineering, Universiti Sains Malaysia, Engineering Campus, Nibong Tebal, Penang 14300, Malaysia*
[2]*Department of Naval Architecture, Engineering Faculty, Diponegoro University, Semarang 50275, Indonesia*

Abstract. This literature review focuses on research related to Port State Control (PSC) inspections carried out on board ships, with a particular focus on areas of interest and data analysis methods adopted during research. The five steps involved in the literature review process include: (1) determining the research questions, (2) gathering works of literature for review, (3) conducting selection and screening based on the inclusion and exclusion criteria, (4) analyzing the selected works of literature and ensuring the quality of the data, and (5) reporting the result of the literature review. Based on the comprehensive searches throughout various databases, the most high-impacted databases in sequence were Elsevier, Taylor & Francis Online, (Multidisciplinary Digital Publishing Institute) MDPI, Springer, and others such as Emerald Insight, Science Direct, and Google Scholar. There were 2,023 articles published between 2018 and 2022 gathered during the initial search process, and the 41 final papers were ultimately selected for in-depth analysis after a selection process. The four main research focuses found from this literature review were (1) the selection of ships for PSC inspection, (2) the New Inspection Regime (NIR), (3) the identification of findings during PSC inspection, and (4) detention of ships under PSC inspection. From the literature review, 37% of the final selected articles focused on vessel selection, 33% noted the findings, 23% focused on vessel detention, and only 7% explored the New Inspection Regime (NIR). From the review, most articles used the Bayesian networks (BN) method for data analysis, followed by traditional analysis, Ideal Solution Similarity Order Priority Technique (TOPSIS), Hierarchical Analytical Process (AHP), Apriori Algorithm, and Gray Relational Analysis (GRA). This result could provide valuable information to professionals in the maritime industry, and this literature review signifies the importance of Port State Control (PSC) inspections in fostering the better development of the global maritime transportation system especially to ensure maritime safety.

Keywords: Detention; Flag state; Maritime safety; Port State Control (PSC); Ship inspection

1. Introduction

Maritime transport constitutes a vital component of the broader transportation network and accounts for approximately 90% of all international freight, granting a substantial advantage over other modes of transport due to its cost-effectiveness. Maritime transport is a safer, cheaper, greener, and more energy-efficient than other modes of transport. This mode enables the simultaneous conveyance of large cargo volumes while effectively reducing transportation expenses. It is important to strengthen maritime safety

*Corresponding author's email: hasnida@usm.my, Tel.: +604-5996363; Fax: +604-5996912
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and protect the environment towards a cleaner environment (Chuah *et al.,* 2023). The importance of maritime transportation has further escalated, particularly with the advent and advancements in container transport (Emecen, Kara, and Oksas, 2016). There is growing concern around shipping and expectations in the shipping industry due to the technological revolution. In response to societal pressures, the maritime industry is facing an increasing demand to adhere to more stringent regulations and voluntary standards in the areas of health, safety, security, and the environment. This implies that health, safety, environment, and security expectations have a moderate impact on the future of the shipping industry. In the context of sustainable sea transportation, safety emerges as a critical aspect intricately linked to ship management and operation (Oloruntobi *et al.,* 2023). The ship management organization is responsible for ensuring the safe operation of the ship and, therefore, must develop a robust monitoring system. It is also imperative that the organization ensures compliance with all relevant international conventions and regulations (IMO, 2019a). To enhance maritime transportation safety, the relevant authorities in countries worldwide have established Port State Control (PSC), including ship inspection strategies aimed at evaluating the safety benefits of existing inspection regulations and identifying opportunities for further improvement (Heij, Bijwaard, and Knapp, 2011; Liou *et al.,* 2011). PSC inspections significantly enhance maritime safety in shipping (Knapp, Bijwaard, and Heij, 2011).

Port State Control (PSC) is the inspection of foreign ships in national ports to verify that the vessel's condition meets the requirements of international regulations. In that context, PSC is one of the criteria to determine the effectiveness of the flag State in complying with ratified international maritime conventions to protect the reputation and enhance competitiveness to do business in that country. These inspections are conducted by port states on foreign ships during their port visits to ensure shipping safety as well as prevent marine pollution. Furthermore, port states are crucial in supplementing the international conventions and regulations established by flag states. Conducting a series of PSC inspections reduce the number of non-compliant ships, ensuring shipping and maritime environmental safety (Chen *et al.,* 2019). PSC is an integral part of the conventions and codes developed and ratified by the International Labour Organization (ILO) and International Maritime Organization (IMO), Safety of Life at Sea (SOLAS), Marine Pollution (MARPOL), as well as Maritime Labour Convention (MLC), 2006, which specified the scope of PSC inspections for precise items onboard ships. The relevant instruments forming the basis of PSC inspections typically include the aforementioned conventions and codes in most MOUs. The Memorandum of Understanding (MoU) is intended to encourage shipowners to register their ships under a flag with a low retention rate as the flag State has taken appropriate measures to ensure compliance with its core obligations. International treaty. Large shipowners and flag registries, including the registry, recognize the importance of checking the MOU. The discovery of defects on board a ship due to non-compliance with IMO conventions may result in the detention of the vessel until the defects are rectified (Chuah *et al.,* 2021).

In response to a series of oil tanker tragedies in the 1970s, coastal states established ten regional Port State Controls (PSCs) and signed memorandums of understanding (MoUs) to conduct safety inspections on foreign-flagged ships upon their arrival at the port (Perepelkin *et al.,* 2010). Figure S1 in supplementary shows the execution of nine Memorandums of Understanding for port state control regional agreements (IMO, 2019b). Intergovernmental organizations have been given observer status at the IMO for several regional PSC regimes. Representatives from these regional agreements regularly engage in IMO meetings and provide the Sub-Committee on Implementation of IMO Instruments (III

Sub-Committee) with thorough reports on their annual activities. This information is utilized to evaluate their adherence to IMO standards. Port State Control inspections specifically target vessels that fall below the required standards and fail to comply with international maritime regulations. Although these inspections are costly, many do not result in any detentions, and many inspections do not uncover any deficiencies (Cariou and Wolff, 2015).

Ship detentions can significantly impact the maritime industry, causing delays in cargo delivery and affecting ship managers and operators. However, preliminary research has been conducted using PSC inspection data to identify the reasons behind ship detentions. A study examining data from the Indian Ocean MoU over five years aimed to explore the frequency of deficiencies and the probability of detention. The findings revealed that vessel age, recognized organization, and inspection location were factors influencing detentions, whereas ship flag and type were not significant contributors (Cariou, Mejia, and Wolff, 2008). In a separate study analyzing data from the Swedish Maritime Administration over six years, researchers identified a total of 4,080 deficiencies. The study specifically investigated the influence of vessel age, ship type, and registry flag on these deficiencies (Cariou, Mejia, and Wolff, 2009). Despite these analyses, there has been no research on the methods used for PSC detention analysis and the current trend in the last five years. This literature review would like to explore more about the data analysis method used and trends in the PSC inspection to gather valuable information for the further development of the PSC inspection. The study also aims to address the gap in understanding how data analysis methods and trends in PSC inspections influence their significance in maritime safety and their potential impact on future developments.

2. Methods

This research aimed to conduct a literature review on previous research related to port state control inspections on board ships to gain insight into the trends of focus and data analysis methods in PSC inspection in recent years. The review used a five-step approach which started by formulating research questions. The second step was to search for literature throughout the various database platform. It was followed by selecting as well as screening relevant articles. The fourth step was analyzing and synthesizing qualitative findings, and the last step was conducting quality control (Perry and Hammond, 2002). The data analysis used a qualitative approach through interactive models consisting of three stages, namely reduction, display, and conclusion or verification (Miles, Huberman, and Saldaña, 2014). During the reduction process, articles were selected based on pre-set inclusion and exclusion criteria to ensure all the necessary information for the desired goals. Furthermore, the data were sorted according to the research purpose by grouping articles based on topics and providing codes for easy identification.

The first step in a literature review is to establish research questions. This particular review aims to investigate the port state control inspections on ships global trend. This literature review's primary focus is to provide insights and answers to the following research inquiry:

RQ1. What is the current focus of the research on port state control inspection?

RQ2. What method was utilized in analyzing the data in the research?

In the second stage, the literature search was conducted by indexing databases and journal publishers. The search for articles used the keyword port state control inspection entered into the search field of various high-impact databases such as Taylor & Francis Online, Emerald Insight, Science Direct, and Google Scholar, as well as Springer Link. The

search was limited to articles published between 2018 and 2022. From the initial search, there were 2,023 journal articles retrieved. The third step was to screen the duplicate articles until they were reduced to 600 articles. It was further screened based on the research topic and filtered according to the criteria of relevance to the study's objectives, findings, and results, with a focus on articles containing relevant keywords. From 600 articles, there were 129 articles selected for full-text screening. Following the inclusion and exclusion criteria determined before the screening, an in-depth review based on research focus, unit of analysis, context, and quality assessment produced 41 articles fulfilling the requirement for analysis in this literature review. During the analysis of the 41 articles, the researcher maintains the quality of the data analyzed to ensure the information and the result inferred from the research.

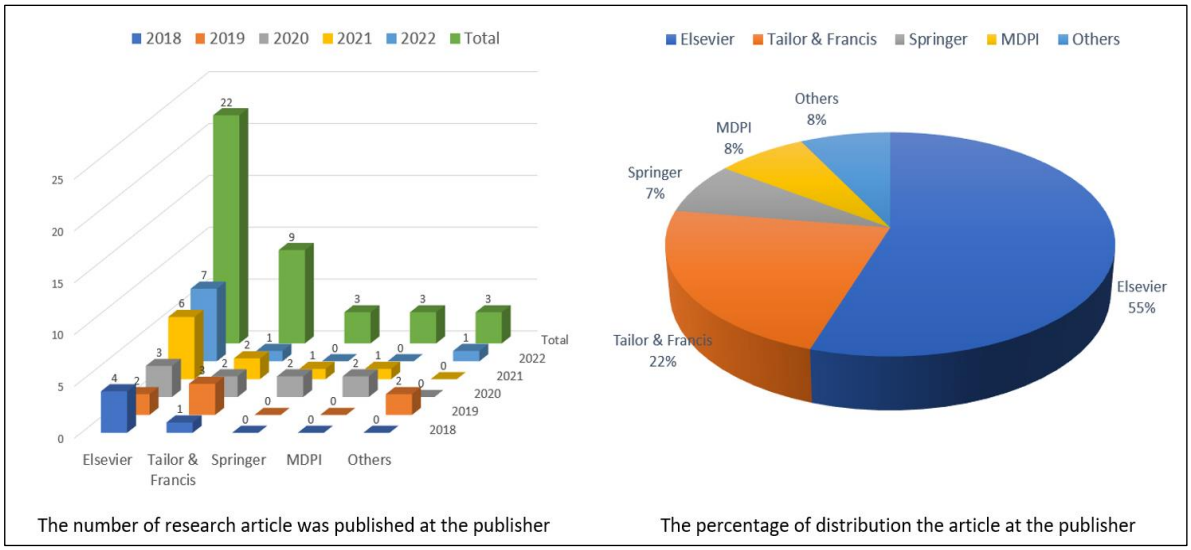

Figure 1 The Article and Publisher Distribution

3. Results and Discussion

The journal and publisher for this literature review were retrieved from the highly impacted database. Most articles were from Elsevier, followed by Tailor & Francis, MDPI, Springer, and others. To identify the trends in PSC inspections, the review focused on articles published between the years 2018 and 2022 to ensure relevance and novelty.

3.1. Ship selection for PSC Inspections

As port state control (PSC) inspection is crucial for ensuring safe ship operations, effective inspection planning and selection are vital, given the limited resources and inspection costs. However, to tackle this challenge, several approaches have been developed. One such method involves utilizing a classifier called balanced random forest (BRF) from the learning library (Yan, Wang, and Peng, 2021a) to set ships for inspection as well as take into account factors that impact the outcomes. Another approach is developing a combined model for ship risk prediction by Yan, Wang, and Peng (2021b), which considers ship deficiencies as well as detentions and employs a distinct methodology for ship selection. In the study conducted by Wang, Yan, and Qu (2019), a data-driven Bayesian network classifier known as the Tree Augmented Naive (TAN) Bayes classifier was employed to choose 250 ships for PSC inspection. The selection was made using information culled from Hong Kong and Tokyo's MoU databases, covering the period from January to July 2017, which yielded an average of 130% more deficiencies detected compared to the previous method. The same model was formulated by Yang *et al.* (2018),

incorporating a strategic game framework in empirical research, which provided insights and suggestions for port authorities. Similarly, Liu *et al.* (2022) utilized a Bayesian Network (BN) to assess detention risk and identify related factors, providing insights on ship selection priorities for ship owners and port authorities. Yan *et al.* (2022a) created two data-driven frameworks for predicting ship risk. These frameworks incorporated features from the existing ship selection scheme and utilized Shapley additive explanations to generate individual ship predictions, effectively addressing pertinent concerns in the field. Such as concern regarding the quality of ship maneuvering that is particularly important from a technical and operational point of view. The maneuverability of ships is very interesting by ship owners, operators, seaports and state management agencies. In addition to collision avoidance, ship maneuverability should be prioritized due to its importance and impact on ship safety and operability (Sunarsih *et al.,* 2023).

Another research focusing on container ships with inspection data in Taiwan from 2015 to 2018 utilized Statistical Process Control (SPC) to monitor and select PSC inspections due to a lack of effective tools for inspection and monitoring. SPC was reported to be useful in detecting time-dependent abnormal instances and monitoring maritime inspections (Yuan *et al.,* 2020). Additionally, a framework was developed employing the Analytical Hierarchy Process (AHP) to assess the priority of 14 factors and four subfactors that influence PSC operation and selection. This was done by collecting data through questionnaires and face-to-face interviews with 53 experts from Taiwan, including PSC officers at Ports of Keelung and Taipei in October 2019 (Yuan, Chiu, and Cai, 2020). Another analysis method involved using the Apriori Algorithm to produce rules for PSC inspection selection by analyzing two sets of data, one with 8,089 PSC inspections and the other recorded for five years from 2015 to 2019. This was retrieved from the online Tokyo MoU database. The research findings indicated a significant correlation between the number of detentions and the deficiencies discovered during inspections. Specifically, these frameworks were designed to address concerns related to ships registered under blacklisted countries (Osman *et al.,* 2020). A similar data mining method was applied to historical PSC inspection records, and the research identified rules that can help inspectors effectively (Chung *et al.,* 2020). Another research focused on ship accidents and their impact on safety levels, using the Bayesian Network (BN) to investigate the PSC inspection effect (Fan, Zheng, and Luo, 2022).

Given the limited resources and high costs associated with PSC inspections, improving their efficiency is paramount. However, to this end, Yan, Wang, and Fagerholt (2021) proposed mathematical optimization models that coordinate inspection resources across multiple ports, while Yan, Wang, and Peng (2021b) discussed the advantages and disadvantages of using different ports to improve ship selection efficiency in MoUs. Another approach was taken by Chuah *et al.* (2022), who identified the risk profile of the ship and designed the inspection area, proposing two coordinated inspection strategies for liner as well as tramp ship types. (Yan, Wang, and Fagerholt, 2021). An entropy-based Grey Relevance Analysis methodology was employed to analyze ship inspection trends between 2017 and 2020 using COVID-19 pandemic outbreak data (Akyurek and Bolat, 2020).

3.2. New Inspection Regime (NIR)

After thorough preparations, the New Inspection Regime (NIR), introduced on January 1, 2011, aimed to enhance the Port State Control (PSC) inspection system effectiveness. According to the official report of the Paris MoU, the NIR was considered the most significant and transformative change in the PSC system in recent years. It brought about substantial improvements compared to the previous system, which had been in place for 30 years based on an agreement. This modification was required to bring the Paris MoU

into compliance with shifting maritime patterns worldwide, new IMO instruments, and a more impartial approach to ship targeting and inspection. The NIR's primary goal was to promote high-quality shipping while tightening controls and imposing sanctions on ships with poor maintenance. NIR marks a notable departure from the previous regime's 25 percent inspection commitment and six-month inspection intervals, which placed undue strain on the maritime industry and PSC authorities. The research on its implementation was conducted using data from the Paris MoU and Bayesian Network models. A macroscopic comparative analysis was conducted to identify the areas where the NIR enhances the PSC inspection system, vessel quality, as well as maritime safety (Yang, Yang, anda Teixeira, 2020).

Another research identified additional parameters like the ship's age, type, deadweight, number of deficiencies, and other factors such as port State, flag State performance, and recognized organization. The study utilized data from the Tokyo MoU to conduct a binary logistic regression analysis, which aimed at examining detention decisions. Additionally, a multi-factor decision-making analysis was performed using the same dataset (Xiao *et al.,* 2020). According to recent literature, the New Inspection Regime (NIR) has been found to exhibit greater economic efficiency compared to other types of regimes. To assess and compare the efficiency of inspection implementation across ten Memorandums of Understanding (MoUs), a Super-Slacks-Based Measure (super-SBM), as well as the Malmquist Production Index (MPI), were employed. Three inspection regimes were analyzed in the evaluation process (Xiao *et al.,* 2021). The research of Buana, Yano, and Shinoda (2022) showed another alternative for another parameter to consider as all seagoing ships shall be equipped with adequate ballast water equipment in accordance with Regulation D-2, Section D, Standards for Ballast Water Management, International Convention for the Control and Management of Ships' Ballast Water and Sediments, promoted by the International Maritime Organization. Although it is difficult to choose the right equipment since the methods used to develop the device have similar advantages and disadvantages. To tackle this challenge, this research proposes an evaluation methodology for outfitting appropriate Ballast Water Management System (BWMS) equipment by applying multi-criteria analysis combined with the value engineering concept.

3.3. Evidence on inspections and deficiencies

PSC inspections aim to detect significant vessel deficiencies and reduce the likelihood of vessel casualties. Analyzing the findings on deficiencies realized during PSC inspections is crucial to reducing or preventing future detentions of ships. Various research has been conducted to analyze this data. A Bayesian Network (BN) was employed in a particular study to develop a PSC risk probabilistic model. This model emphasized the interdependencies and dependencies among the various risk factors that impact PSC inspections (Wang *et al.,* 2021). Another research used the same model to predict detention probabilities contingent on the risk factors influencing PSC inspection findings in bulk carrier vessels (Yang, Yang, and Yin, 2018). The Bayesian network model has also been used to examine the various factors' impacts on ship accidents and simplify the PSC inspection procedure by identifying key deficiency items (Fan *et al.,* 2019). Since deficiencies are a significant factor in ship detentions, research was conducted using harmonized deficiency codes to determine whether those identified during PSC inspections can forecast future accident risks. The outcomes of the study can be utilized by maritime authorities to enhance asset allocation by considering prediction scenarios associated with vessel traffic data (Heij and Knapp, 2018). Similarly, The Bayesian network method was employed to develop a ship accident model utilizing 17 deficiency items derived from the Tokyo MoU. The findings confirmed the three defect level variables' dynamics and their impact on vessel accidents.

Additionally, the study revealed the defect level improvement for ships detained during the initial inspection. (Fan *et al.,* 2022).

Various methods were utilized to analyze findings and deficiencies during port state control inspections. Graziano, *et al.* (2018) employed econometric analysis to account for differences in observable vessel characteristics between countries. Osman *et al.* (2021) used the Entropy Weight Method (EWM) as well as Grey Relational Analysis (GRA) model combination to examine PSC inspection findings between 2015 and 2019 from Tokyo MoU in five selected ports in Malaysia. Yan *et al.* (2021) constructed an XG Boost model that predicts ship deficiency numbers using ship generic, dynamic, and inspection history characteristics. The model was developed using data from the Tokyo MoU Port State Control (PSC) regime. Shen *et al.* (2021) employed fuzzy importance-performance analysis (F-IPA) and TOPSIS to examine data on ship deficiencies taken from the Tokyo MoU database. Graziano, Mejia, and Schröder-Hinrichs (2018) conducted a traditional analysis of PSC reports from March 2012 to April 2016, designed as a methodical process for assessing and evaluating printed and electronic documents. Fotteler, Andrioti Bygvraa, and Jensen (2020) extracted and analyzed deficiencies related to living and working conditions and certificates and documents from 2010 to 2017, finding an increasing focus on inspections conducted in European countries. Yan *et al.* (2022b) explored the COVID-19 influence on PSC inspections. They analyzed the deficiencies per inspection and detention rate average number to assess the impact.

3.4. Evidence on inspections and deficiencies

The maritime port authority conducts port state control inspections to target vessels not complying with international maritime regulations. Meanwhile, quantile regressions for count data were utilized to improve the vessel selection efficiency to evaluate the likelihood of having a high number of specific type deficiencies, and factors influencing the likelihood of vessel detention were identified. This method was found to be effective in identifying substandard vessels (Cariou and Wolff, 2015). In the Indian Ocean MoU, the age of the vessel (40%), recognized organization (31%), and place of inspection (17%) were identified as the main contributors to vessel detention (Cariou, Mejia, and Wolff, 2009). A comprehensive analysis was conducted on 32,206 Port State Control (PSC) inspections within the Paris MoU region, spanning from January 1, 2014, to December 31, 2015, and reported that the number and background of PSCOs on board and the inspection country could impact inspection outcomes. Econometric analysis was utilized to manage the differences in observable characteristics of vessels inspected in different countries (Graziano *et al.,* 2018).

From the summary in Figure 2, this literature review found that the trends from the selected articles were mostly focused on the PSC topics related to the inspection (37%), followed by topics of finding (33%), then topics about detention (23%), and the last discuss NIR (7%). While the trends of the analysis method used in PSC from these selected articles are composed of Bayesian Network (BN) (25%), Traditional analysis (15%), followed by Apriori Algorithm (10%), then TOPSIS, Mathematic & Logit Model, Grey Relational Analysis (GRA), and Computer-based Analysis, each mounted to 7%.

Various models have been developed to predict ship deficiencies during port state control inspections, with the aim of targeting substandard vessels. One such model is a ship deficiency prediction model that was developed using 1,974 initial Port State Control (PSC) inspection data at the Hong Kong port, employing the Tree-Augmented Naive Bayes (TAN) classifier. The data used for this model covered the period from January 2016 to December 2018. The study evaluated existing ship selection methods employed in various ports and put forward novel approaches for ship selection (Yan, Wang, and Peng, 2021b). Yan *et al.*

(2021) used the same data to develop a state-of-the-art XGBoost model that considers ship generic, dynamic, and inspection historical factors to predict ship deficiency numbers accurately. This model incorporates domain knowledge specific to the shipping industry, including ship flags, recognized organizations, and company performance. The Apriori Algorithm was used in another research (Osman et al., 2020) to produce valuable rules. A comprehensive model for predicting ship risk was developed and validated, taking into account both deficiencies and detention records (Yan, Wang, and Peng, 2021b). Ship selection before PSC inspection is not solely based on identifying substandard vessels but also takes into account other factors such as age, flag, recognized organization, and ship manager (Cariou, Mejia, and Wolff, 2009).

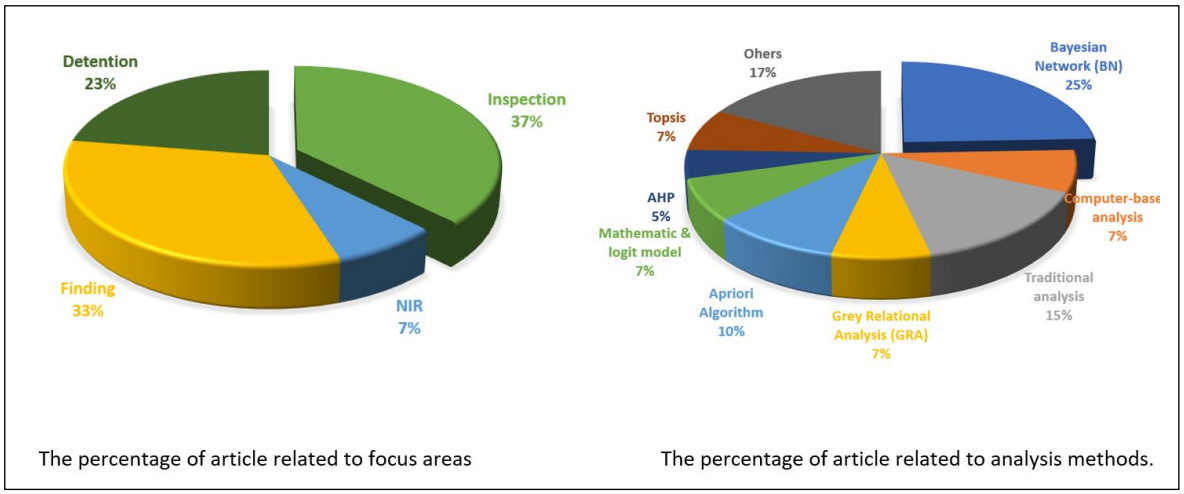

Figure 2 Summary of focus area and data analysis methods

3.5. Ship Detention Under Port State Control (PSC) Inspection

As previously discussed, the detention of a ship can significantly impact the maritime industry, particularly for ship managers or operators, due to cargo delivery delays. Consequently, several research studies have been conducted to identify the causes of ship detentions. One such investigation examined the deficiencies number, and the detention probability was analyzed using Port State Control (PSC) inspection data from the Indian Ocean Memorandum of Understanding (MoU) over a span of five years. The results indicated that vessel age, recognized organizations, and inspection location contributed to detention, but ship flag and type were not included (Cariou, Mejia, and Wolff, 2009). Preliminary research has employed various methods to assess ship detention and PSC efficiency, including the Bayesian network model, examining different deficiencies and factors influencing ship accidents (Fan *et al.,* 2019). Another research focused on bulk carrier vessels and developed a risk assessment model regarding related factors that influence PSC inspections. The data used in this research were recorded from PSC inspection results from the Paris MoU between 2005 and 2008, and a new way to predict detention probabilities was also identified. The results did not offer any method or solution to reduce ship detention (Yang, Yang, and Yin, 2018). One research that could provide guidance to ship owners or managers was based on a strategic management approach. The data used were recorded from 6,374 deficiencies found on 2,653 detained ships in the Black Sea Region detention list from 2005 to 2006 and were analyzed using the fault tree method (Akpinar and Sahin, 2019). Information from the Tokyo MOU region's PSC detention database from 2000 to 2016 was also evaluated, and each detention factor was subjected to additional pre-processing to identify regularity deficiencies during PSC detention. The results of the big data analysis, which used association rule techniques, provided

countermeasures that ship management could serve as a reference (Tsou, 2019). In another study, PSC regime data from various periods were utilized to conduct an empirical analysis using the Grey Rational Analysis (GRA) model with enhanced entropy weight. The study's goal was to offer suggestions for putting effective procedures into place in ship safety inspections carried out by port states (Chen *et al.,* 2019).

It is important to analyze PSC detention data from different PSC regimes to understand detention records globally. In the Black Sea Region (BS MoU), a computational analysis method was used to analyze 29,954 PSC data inspections from 2012 to 2017. The objective of this analysis is to identify the key factors that should be given primary consideration when selecting foreign vessels for inspection by Port State Control (PSC) authorities (Şanlıer, 2020). The Bayesian Network (BN) approach, widely used for data analysis, was integrated with the TOPSIS to analyze a novel methodology for controlling ship detention risk in PSC inspections. (Yang *et al.,* 2021). The Bayesian network approach was also used to conduct risk assessments in new building construction in shipyards (Basuki *et al.,* 2014). A different approach was proposed by Akyurek and Bolat (2021), who used the Analytical Hierarchy Process (AHP) approach to evaluate PSC detention ranking based on Paris Memoranda of Understanding (MOU) data inspection records from 15 countries in the EU. In other industries, the Analytic Hierarchy Process (AHP) approach was used for supplier evaluation and selection, combined with the Delphi Method (Al Hazza *et al.,* 2022). According to the results, the Safety of Life at Sea (SOLAS) and Fire Safety Systems (FSS) were identified as the top priorities for regulation in almost all countries. Research by Ravelo-Mendivelso *et al.* (2023) that was based on the AHP (Analytic Hierarchy Process) multi-criteria method identified the best alternatives to improve the thermal efficiency of the housing and the shell heat exchanger under actual operating conditions. A key motivation for conducting research based on identified needs, in partnership with oil, natural gas, and alternative energy industries, is to analyze and understand the key criteria that directly impact the thermal performance of heat exchangers. Emecen Kara (2022) employed the TOPSIS to assess flag states' performance in terms of marine safety based on PSC inspections. Each flag state's performance was evaluated in light of its detention rates and any issues associated with its PSC regimes. The results showed that just around half of the flag states performed at acceptable levels overall. To harmonize PSC regimes, TOPSIS was proposed as the uniform method for evaluating flag state performance. Furthermore, TOPSIS was utilized to assess the major port's connectivity and the competitiveness of container types in Southeast Asia (Nguyen and Woo, 2021).

The detention of ships can result in financial losses and harm the reputation of a company. However, to identify the root causes of detentions of different vessel types, investigations should include an analysis of the links between deficiencies and their impact on detentions. Chen *et al.* (2022) used Association Rules and PSC inspection data from 2014 to 2020 to identify critical deficiencies leading to vessel detentions. They suggested improving its safety, reducing environmental pollution, and minimizing shipping line losses. PSC was established to ensure vessel safety and prevent marine pollution through inspections of ships, equipment, crew, and operations for compliance with international conventions. Suhrab *et al.* (2022) applied association rule mining techniques in extensive data analysis to provide countermeasures and references for ship management to reduce or prevent its detention during PSC inspection. Various data analysis methods have been proposed to address the significant impact of ship detention on the maritime industry. There is limited use of combined methods for more useful results, such as the AHP-TOPSIS approach, which has not been applied to PSC detention data analysis.

Table 1 Author focus on A Literature Review

Author	Publisher	Method	Objective	Research Focus			
				1	2	3	4
Yang *et al.,* 2018	Elsevier	Bayesian network (BN)	Relationship between port authorities and ship owner, used Paris MoU database	x			
Graziano, Mejia, and Schröder-Hinrichs, 2018	Elsevier	Computer-based thematic analysis	Implementation of the Directive 2009/16/EC, used the Paris MoU database			x	
Yang, Yang, and Yin, 2018	Elsevier	Bayesian network (BN)	The impact of NIR, used Paris MoU database			x	
Graziano, *et al.,* 2018	Elsevier	An econometric analysis	Correlation of inspection outcomes each PSC, used Paris MoU database			x	
Heij and Knapp, 2018	Tailor & Francis	Index and logit model	Prediction of (PSC) inspections on accident, data from IHS Markit			x	
Wang, Yan, and Qu, 2019	Elsevier	Bayesian network (BN)	Identify substandard ships, used Tokyo MoU database	x			
Chen *et al.,* 2019	Elsevier	Grey relational analysis (GRA)	Identify ship detention's factor, used Tokyo MoU database				x
Akpinar and Sahin, 2019	Emerald	Fault tree analysis	PSC approach, used Black Sea MoU database				x
Tsou, 2019	Tailor & Francis	Apriori algorithm	Response of ship management on PSC, used Tokyo MoU database				x
Fan *et al.,* 2019	Sage	Bayesian network (BN)	The efficiency of PSC, used Tokyo MoU database			x	
Bai & Wang, 2019	Tailor & Francis	Traditional analysis	Polar Code on fishing vessels, used Paris MoU database	x			
Chung *et al.,* 2020	Tailor & Francis	Apriori algorithm	Association rule of PSC, Taiwan's PSC database	x			
Yang, Yang, anda Teixeira, 2020	Elsevier	Bayesian network (BN)	Comparation of NIR, used Paris MoU database		x		
Yuan *et al.,* 2020	MDPI	Statistical process control (SPC)	Monitoring on PSC, used Taiwan's PSC database	x			
Yuan, Chiu, and Cai, 2020	MDPI	The analytical hierarchy process (AHP)	Independent of PSC regime, used questionary data from expert	x			
Osman *et al.,* 2020	Tailor & Francis	Apriori algorithm	Association rule of PSC, used Tokyo MoU database	x			
Xiao *et al.,* 2020	Elsevier	A binary logit model	The effectiveness of NIR, used Tokyo MoU database		x		
Şanlıer, 2020	Elsevier	The computational analysis	Selection proses on PSC, used Black Sea MoU database				x
Akyurek and Bolat, 2020	Springer	Entropy-based grey relevance	PSC on pandemic outbreak, used Paris MoU database	x			
Fotteler, Andrioti Bygvraa, and Jensen 2020	Springer	Traditional analysis	Impact of MLC ratification, used 7 MoU's database			x	
Fan, Zheng, and Luo, 2022	Tailor & Francis	Bayesian network (BN)	Effect of PSC inspection on ship accident, used Tokyo MoU database	x			
Yan, Wang, and Fagerholt, 2021	Tailor & Francis	Mathematical optimization models	Identify PSC inspection strategy, used PSC data in mainland China	x			
Yan, Wang, and Peng, 2021b	Tailor & Francis	Tree-augmented naive Bayes (TAN)	The impact of NIR, used Paris MoU database	x			
Xiao *et al.,* 2021	Elsevier	Apply super-SBM and MPI	Efficiency of PSC regimes, used 8 PSC regime database		x		
Yan *et al.,* 2021	Elsevier	XGBoost model	Optimization in PSC, used Tokyo MoU database			x	

Akyurek and Bolat, 2021	Springer	The analytical hierarchy process (AHP)	Professional Judgement on PSC, used Paris MoU database			x
Wang *et al.*, 2021	Elsevier	Bayesian network (BN)	The risk factors influence on PSC, used Tokyo MoU database		x	
Yan, Wang, and Peng, 2021a	Elsevier	Balanced random forest (BRF)	Factors influencing the PSC result, used Hong Kong PSC database	x		
Osman *et al.*, 2021	Elsevier	Grey relational analysis (GRA)	Identify PSC in Malaysian ports, used PSC database at Malaysia port		x	
Yang *et al.*, 2021	Elsevier	Bayesian network (BN) + TOPSIS	PSC inspection scenarios, used Paris and Tokyo MoU database			x
Shen *et al.*, 2021	MDPI	F-IPA and TOPSIS	Identify hidden risk of target ship, used Tokyo MoU database		x	
Yan *et al.*, 2022	Elsevier	Shapley additive explanations (SHAP)	Efficiency on ship selection, used 9 PSC MoU database	x		
Chuah *et al.*, 2022	Elsevier	Traditional review/analysis	Safety assessment using PSC data, used PSC inspection data in Malaysia	x		
Emecen Kara, 2022	Elsevier	Similarity to an Ideal Solution (TOPSIS)	Performance of flag states, used Paris and Tokyo MoU database			x
Liu *et al.*, 2022	Elsevier	Bayesian network (BN)	Identify new risk factors on PSC, used Paris MoU database	x		
Fan, *et al.*, 2022	Elsevier	Bayesian network (BN)	Identify efficiency on PSC, used Paris MoU database		x	
Yan *et al.*, 2022b	Elsevier	Traditional review/analysis	Influence of the COVID-19 on PSC, used 8 PSC MoU database		x	
Chen *et al.*, 2022	Elsevier	CARMA algorithm	Identify PSC findings based on association rules, used Paris MoU database			x
Fan *et al.*, 2022	Tailor & Francis	A difference-in-differences (DID) model	Impact of Sulphur Emission Control Areas on PSC, used Tokyo MoU, Indian MoU, and Paris MoU database		x	
Suhrab *et al.*, 2022	Specialists Ugdymas	Computerized Information System	The potential regularity of ship detention, used the Tokyo MoU database			x
Chuah *et al.*, 2023	Elsevier	Bayesian network (BN)	Influence factors of PSC on the environment, used Tokyo MoU database			x

Research focus: (1) Ship inspection selection, (2) NIR, (3) Finding and deficiency, (4) Ship detention

According to Chuah *et al.* (2023), a Bayesian network model was developed to analyze the factors influencing testing leading to detention, viz. The flag State, ship type, recognized organization, inspection authority, and ship age. The flag country has the greatest influence, followed by vessel type, accredited organization, inspection agency, and vessel age in descending order of importance. These findings would guide PSC officers and ship owners to identify critical areas for improving maritime safety, promoting environmental sustainability, and achieving a cleaner environment.

This literature review aimed to confirm the trends of the main focus regarding port state control (PSC) inspection and identify the methods used to analyze the resulting data and generate outcomes. The adopted methodology consisted of a traditional review of the existing literature, which was then collectively analyzed to generate statistical results. The statistical findings indicated that, over the past five years, research publications had primarily focused on four key issues, namely ship selection for PSC inspection, the discovery of deficiencies during the inspection, implementation of the new inspection regime (NIR) for PSC, and ship detention under PSC inspection. Ship selection was the most

frequently researched area. The second most commonly researched issue focuses on identifying deficiencies during PSC inspection. However, less research has examined the implementation of NIR for PSC and highlighted related issues. Ship detention, which can impact multiple stakeholders beyond the manager, was another critical issue. Finally, substandard vessels, specifically those with inadequate maintenance, were identified as a potential area of concern that could lead to ship detention. Yet, the research on this topic is limited.

4. Conclusions

Sea transportation is one of the safe alternatives to travel and has an important role in the world economy. Ensuring its safety is crucial for both the global economy and the well-being of passengers and crews. Port State Control (PSC) inspections are to ensure that foreign ships entering their ports comply with international safety, security, and environmental regulations, as well as to offer suitable living and working conditions for their crews. The last line of defense against subpar shipment is sometimes cited as PSC inspections, which act as the international law's razor-sharp teeth. PSC inspections must adhere strictly to maritime laws and Memorandum of Understanding (MOU) guidelines dictating areas of the ship that needs to be examined more closely. In some cases, MOUs may launch a concentrated inspection campaign (CIC) to address specific issues or newly enacted laws. These agreements are crucial in establishing a consistent and rigorous approach to port state control inspections worldwide. The majority of the research relied on Bayesian Network (BN) to analyse the collected data across all the focus areas, including ship inspection selection, new inspection regime, deficiency during the inspection, and ship detention under PSC inspection. However, other analytical methods were also utilized, including Analytical Hierarchy Process (AHP), Apriori Algorithm, Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), binary logit model, Grey Relational Analysis (GRA), and traditional analysis methods. Some research also employed a combination of these methods to obtain precise data analysis results. There are no documented cases where the Analytical Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) combination has been utilized for data analysis, particularly in the context of Port State Control (PSC) inspection results. This method is particularly useful in achieving accurate results during data analysis and providing meaningful recommendations to stakeholders, especially ship management companies involved in shipping operations, to reduce or eliminate instances of ship detention during PSC inspection. Following the findings of this literature review, the direction for future research could explore more about the other focus area of the PSC inspection e.g. key factor of PSC detention and method to reduce it, which might be linked to the various changes such as the advanced development of technology and information and the combination of the data analysis method used in PSC according to the different situation and environment that might rise in the future.

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