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Marine environment and maritime safety assessment using Port State Control database

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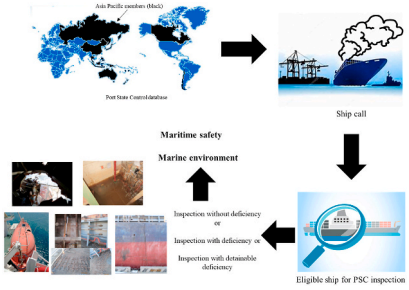
HIGHLIGHTS

- PSC is the inspection of foreign ships in foreign ports to remove substandard ship.
- The inspections conducted by maritime authorities from 2016 to 2021 was used.
- Analysis to ascertain the influence of each risk factor on the number of arrests.
- Study the relationship between risk factors and the type of detain deficiency.

GRAPHICAL ABSTRACT



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ABSTRACT

Port State Control (PSC) is the inspection of foreign ships in national ports assists in the removal of substandard ship commerce from the global sea and ensures that no ship poses a threat to maritime safety and the marine environment. When a clear ground is discovered during an inspection, the inspector has the authority to detain the ship until the flaws are corrected in order to assure safety and reduce pollution hazards. This paper adopted a traditional literature review method using the selected six (6) years data from the inspections conducted by maritime authorities from 2016 to 2021 and incorporate with qualitative and quantitative analysis to ascertain the influence of each risk factor on the number of arrests, including the relationship between risk factors and the type of detain deficiency, which is a critical part of the study. This study's findings provide important insights into how to facilitate an effective way in selecting the ship to be inspected, followed by identifying the ship's risk profile and designing the inspection area, which plays a critical role in assisting the inspector in terms of time efficient and effective inspection (especially for the ships, which have a short duration at berth) during inspection to further strengthen maritime safety, ship's safety, seafarers' health and marine environmental protection.

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Author contribution statement

Lai Fatt Chuah: Project administration; Conceptualization; Writing –original draft. Kasypi Mokhtar: Data curation; Writing – review & editing. Anuar Abu Bakar: Formal analysis; Writing – review & editing. Mohamad Rosni Othman: Project administration; Methodology; Writing – review & editing. Nor Hasni Osman: Validation; Project administration; Writing – review & editing. Awais Bokhari: Methodology; Visualization; Writing – review & editing. Muhammad Mubashir: Software; Investigation; Writing – review & editing. Mohd Azhafiz Abdullah: Software; Writing – review & editing. Mudassir Hasan: Validation; Writing – review & editing.

1. Introduction

When compared to other modes of commercial transportation, maritime shipping is the most secure, cost-effective, energy-efficient and ecologically friendly. International Maritime Organisation (IMO), which has produced broad international maritime safety laws, is in charge of enforcing shipping safety requirements (Bai et al., 2018). The international shipping sector is responsible for over 90% of all business activity as well as being an important component of the global economy (Chuah et al., 2021). Over the past few decades, it can be seen that how maritime trade has continued to grow throughout the world, fuelled by competitive rival shipment rates that not only contribute to industrial prosperity, but also pose threats and risks to the maritime safety and marine environment (Han et al., 2019, 2020) such as ship collisions (Samudra Sakti I), fires (Scandinavia Star), groundings (Ever Given), oil spills (Exxon Valdes), capsizes (Herald of Free Enterprise), and other disasters that have resulted in significant property losses. There are 92,647 merchant ships conveying every form of cargo and employing around 1.6×10^6 seafarers (International Labour Organisation, 2019). An effective mechanism of the ship inspection process before the ship sails is vital to reduce the occurrence of maritime accidents, and also ensure maritime safety and enhance the marine environment protection. This mechanism should include the shipowner, flag State control officer and port State control officer (PSCO) (Dock et al., 2020).

Port State Control (PSC) is the inspection of foreign ships in national ports to ensure that the ship's condition and equipment meet the requirements of international norms, and that the ship is staffed and managed in accordance with these regulations (Chen et al., 2019). When shipowners, classification societies, and flag State administrations fail to comply with the requirements of the international maritime conventions. Member States have the authority to inspect and regulate foreign ships to ensure that any defects discovered are corrected before the ships are permitted to depart. About 17% port calls (94 different flag administrations) of the world enter to the Asia-Pacific ports.

Nine regional agreements on PSC Memorandum of Understanding (MoU) have been signed viz. Europe and the north Atlantic (Paris MoU-1982), Latin America (Vina Del Mar Agreement-1992), Asia-Pacific (Tokyo MoU-1993), Caribbean region (Caribbean MoU-1996), West and Central Africa (Abuja MoU-1999), Black Sea (Black Sea MoU-2000), Mediterranean Sea (Mediterranean MoU-1997), Indian Ocean (Indian Ocean MoU-1998) and Persian Gulf (Riyadh MoU-2004). The United States Coast Guard maintain the tenth PSC regime. All regional PSC regimes have been granted observer status at IMO in their capacity as intergovernmental bodies. Their representatives attend IMO meetings provide vast amounts of information on their annual activities to the Sub-Committee on Implementation of IMO Instruments (III Sub-Committee). The information supplied can be used to evaluate their performance in complying the IMO standards. IMO is an observer body to all regional PSC regimes (Xiao et al., 2021).

The Tokyo MoU was signed on December 1, 1993, and became effective on April 1, 1994. The Tokyo MoU is represented by 21 maritime authorities such as Malaysia, Australia, Canada (only for the Pacific ports), Hong Kong, Fiji, Papua New Guinea, Chile, Peru, China, Philippines, Indonesia, Republic of Korea, Marshall Islands, Japan, New Zealand, Russian Federation (only for the Pacific ports), Panama (only for the Pacific ports), Viet Nam, Thailand, Singapore and Vanuatu (Xiao et al., 2021).

A comprehensive data-base called the Asia-Pacific Computerised Information System (APCIS), which is based in Moscow and operated under the auspices of the Russian Federation's Ministry of Transport, is being built up from all of the information about inspected vessels that visit Asia-Pacific ports. This system makes the information on ship inspections in other regional ports available to all member authorities in order to assist PSCO in the selection of foreign ships to be inspected, as well as effective information exchange on the PSC inspection history of a ship, which can be viewed easily by each Member State in this system.

Section 1.9 of IMO Resolution A.1138 (31) specifies that PSC inspection should be carried out only by competent PSCO who meet the credentials and training requirements. Inspectors should be free of any commercial, financial, or other demands that may be placed on them. Several MoU have introduced the New Inspection Regime (NIR) as an inspection regime to replace the existing ship target factor system, which consists of risk-based targeting systems with particular inspection rates. Upon arrival in port, the inspector will conduct a thorough examination of all eligible ships (ships that fall within the NIR) to ensure safety and prevention of pollution caused by the ship. It is designed to serve as a backup to flag State implementation, a "second line of defence" against substandard ships, and experience has shown that it may be quite successful in this capacity. The NIR approach will be used to choose the target ship for further investigation. Before boarding a ship, a PSCO must first undertake an exterior hull examination, which includes checking the load line, hull conditions, the ship's name, IMO number and so on (Yang et al., 2020). Following the boarding of a ship, inspectors shall present an identity card to the master or owner representative. Prior to beginning an inspection of a ship, the inspectors shall conduct a certificate and document control inspection of the ship in order to assess the ship's condition and condition of the crew. A more detailed and thorough inspection will be carried out if the ship does not have the required certificates or if there is an obvious defect or clear ground discovered during the inspection. A detailed report, which includes the ship name, IMO number, MMSI, ship type, flag of registry, port of registry, year of construction, classification society, company IMO and address, as well as the nature of deficiencies with its code and convention (if any), will be recorded on each PSC inspection. As part of the report, inspectors shall include the date and location of the ship's detention if the defects discovered are sufficiently significant (pose a risk to maritime safety and marine environmental protection). Before allowing the ship to sail, the port State should promptly ensure that corrective action is taken to protect the safety of the ship and its passengers and crew, as well as to eliminate any possibility of harm to the marine environment that may have occurred.

There is virtually little scholarly literature available on the data analysis of the PSC inspection in Asia-Pacific ports by addressed the interaction among the influential factors. No much qualitative and quantitative analysis on the relationship between different risk factors and type of detainable deficiency leading to ship detention has been carried out. In this study, the inspection data compiled by the Tokyo MoU in APCIS on foreign ships that calling to the Asia-Pacific ports from 2016 to 2021 with a total number of 164,374 merchant ships was analysed (Tokyo MoU, 2022). The detail inspection with detentions was recorded such as ship type, age, port of registry, flag of ship, classification organisation and inspecting authority. These variables relation to the detainable deficiencies were investigated. The objectives of this article are to analyse the raw data of the inspection carried out by maritime authorities from 2016 to 2021 and then determine the impact of each risk factors on arrests, including the relationship of risk factors to type of detain deficiency, which is a critical part of the study.

This valuable analytical information might aid maritime authorities in conducting an effective measure and inspection by identifying the

ship risk profile and the possible area to be examined, which are more likely to be detained during the selection process on target ships. This deed could prevent substandard ships from navigating the world's oceans because they do not meet the requirements of international maritime regulations. It could also assist flag States, shipowners, and classification societies in identifying and correcting deficiencies in necessary measures.

The paper is organised as follow. Section 2 provides a literature review on the previous studies related to PSC inspection in the Tokyo MoU region and other regions in order to determine the characteristic of ship under performance. In Section 3, materials and methos are described to develop the study design and data collection. In Section 4, raw data of PSC inspection from 2016 to 2021 were thoroughly analysed including its relationship between the factor and type of detain deficiencies. Finally, the conclusion and suggestions for further research are presented in Section 5.

2. Literature review

When it comes to maritime safety and marine environmental protection (Han et al., 2021a, 2021b), PSC ship detention has always been a major concern. The detention of a vessel at port causes delays in a regular shipping line and may necessitate the charter of an alternative vessel. Furthermore, the shipowner may take legal action to recover the loss on his or her behalf due to the increased operating costs. Because of this, several scholars conducted studies on the issue of ship detention under the PSC. For the Tokyo MoU region, Chen et al. (2019) studied the elements that contribute to ship detention under PSC regulations. It was discovered that the ISM, emergency systems, and fire safety measures were the most important elements in ship detention when a grey rational analysis model with better entropy weight was used.

A data-driven Bayesian Network (BN) based technique is proposed by Yang et al. (2018) to analyse risk variables impacting PSC inspections and forecast the likelihood of vessel detention. In order to do this, inspection data from bulk carriers in seven key European nations from 2005 to 2008, obtained under the Paris MoU, is being analysed in order to identify significant risk indicators. According to the findings of the study, the most significant risk variables in PSC inspection are the inspection group, the number of flaws, the type of inspection, the vessel group, the classification society, and the vessel age, in that order.

Wang et al. (2021) also developed a new BN-based PSC risk probabilistic model in order to analyse the dependency and interdependency among the risk factors influencing PSC inspections based (but only involving 7 Member States out of 21) on big data derived from the inspection database of the Tokyo MoU for the period between 2014 and 2017. The findings suggest that inadequacies in the ship's safety condition, as well as technical characteristics of the assessed vessel, are among the most relevant variables in PSC inspections and ship detention. Cariou et al. (2009) studied the number of defects and the possibility of detention by utilising data from 26,515 PSC inspections conducted within the Indian Ocean MoU region from 2002 to 2006. According to the findings, the age of the vessel at the time of inspection (40%), the classification society (31%), and the location where the inspection takes place are the most important factors in detention (17%).

Cariou and Wolff (2015) employed the quantile regressions for count data to estimate the chance of having a high number of deficits of a certain type, which they found to be effective. It is recommended that inspectors focus more time and effort to older vessels, as well as to dry bulk cargoes, RoRo vessels, and bulk carrier vessels, while looking for flaws and detentions relating to fire safety systems, based on the results of this technique. The results of 29,954 inspections performed in the Black Sea region between 2012 and 2017 were analysed by Sanlıer (2020), who looked at the flaws that were discovered on ships and the records of detention. He discovered that the age of the vessel was the most common factor for the 1325 detention instances. Researchers have used a variety of methodologies to evaluate the effectiveness of ship detention and PSC efficiency in order to develop a ship selection mechanism to target the substandard ships. When compared to typical PSC inspection mechanisms, it has been demonstrated to provide superior performance. The BN model is one of the most used of these approaches. One publication (Sanlier, 2020) made use of raw data from the database system to identify the variables necessary by applying qualitative and quantitative analysis for priority consideration in the selection process of foreign ships to be inspected by the PSCO, and this was the only study to do so. Only a few pioneering studies have been conducted with the use of PSC inspection data, and even fewer have examined the interplay between the significant components in a qualitative and quantitative manner. The link between numerous circumstances that contribute to ship detention has not been subjected to a great deal of quantitative investigation to yet.

In this paper, the research data of PSC inspection from 2016 to 2021 under Tokyo MoU region was thoroughly examined, including the relationship between the factor and type of detainable deficiencies. The findings of this study will be useful to PSCO when ships call at their ports, as well as policymakers in establishing an effective ship selection, identifying high-risk ships and inspection design in order to further strengthen maritime safety and marine environmental protection.

3. Materials and methods

PSC inspection is carried out by authorised inspectors with the goal of verifying that the calling foreign ships satisfy the standards of safety and pollution legislation. It includes of numerous inspection issues, such as living & working conditions, pollution control, the safety of life & property on board and so on. If any major faults were discovered, the ship would be delayed and directed to correct the defects prior to its departure. Tokyo MoU region consists a total 21 maritime authorities was chosen for the study. The Asia-Pacific is an important waterway for both Asia and other countries.

If the eligible foreign ships calling to the Asia-Pacific ports, the maritime countries of the Tokyo MoU inspecting the foreign ships and all the ship inspections information will be recorded by using APCIS system. In the present study, 164,374 number of inspections conducted from 2016 to 2021 were analysed including detention ship.

Many elements are crucial to ship detention and their influence to the decision to hold a ship. Based on the findings of the literature research, the following risk variables have been identified for additional investigation: flag of registry, type of ship, age of ship, classification society, inspection authority, and the nature of the technical flaws. Following that, the impact of these factors on detention was examined. The numerical magnitude of this effect, as well as the rate at which each of these six criteria had an impact on individual arrests, were determined as a percentage of total arrests. An investigation of the association between the five primary risk variables (inspecting authority, classification society, type of ship, flag of ship, and age) and the several forms of detain deficiency was also carried out. The method of doing research in this work is depicted in Fig. 1. In order to evaluate the numerous archive sources, Google Alert was also used to find relevant information on PSC. According to Neuman (2014), qualitative research is based on the notion of interpretation. Documents, papers, and studies were chosen as reputable sources in this context based on the reputation of the website, organisation, or institute that published them, as well as its contribution to the marine industry. The data gathered was analysed using RapidMiner and Minitab 19 to determine whether or not there is a statistically significant difference between risk variables. As a result, the outcomes of the first and second objectives are presented and examined in detail in Section 4.

4. Results and discussion

In many IMO conventions, provisions are made for administrative inspects the foreign ships calling at their ports to ensure that they

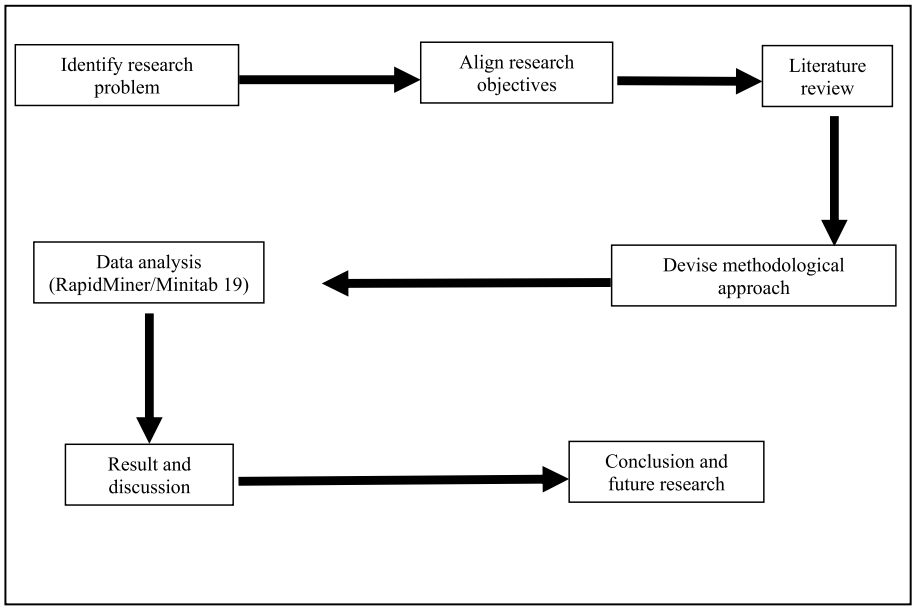

Fig. 1. Methodology approach (Source: Own elaboration).

comply with IMO standards (Cai et al., 2019) contained in instruments to which the port State is a Party, while taking into consideration the concept of no-more-favourable treatment. Inspectors shall conduct a more thorough examination if there are clear ground to believe that the condition of the ship or its equipment does not substantially correlate with the details of the certifications or that the master or crew are not conversant with critical onboard procedures. When exerting control, every effort should be taken to prevent a ship from being unnecessarily detained. A ship's master and owner are responsible for repairing and rectifying any detainable deficiencies before the ship can sail again.

The number of inspections, inspection with deficiency and inspection with detainable deficiency including deficiency number were all sourced from the APCIS database system. The computational analysis in this study depends on the original data from PSC inspections conducted by Tokyo MoU members. About 17% port calls (94 different flag administrations) of the world to Asia-Pacific ports.

From 2016 to 2021, members of the Tokyo MoU will have carried out around 164,374 inspections. According to the results of this figure inspection, about 345,402 defects were discovered, with 12,857 of these deficiencies resulting in ship arrests. This inspection resulted in the detention of 4,912 ships, which is around 3% number of ships that were examined overall (Table 1). According to Table 1, the inspection number, inspection with deficiencies rate and detention rate across Tokyo MoU members were more uniform with an average, i.e. 31,489, 58.44% and 3.13% from 2016 to 2019. Due to the global pandemic (Covid-19), the inspection number, inspection with deficiencies rate and detention rate were down to an average of 19,210, 49.59% and 2.51% in 2020 and 2021. The rates of deficiencies and detentions were very marginally reduced, and the difference was not statistically significant. It is cleared that the PSCO's attempts to stop the hazardous and substandard ships from trading around the region's waters will never be thwarted.

The quality and performance of shipping in the region has generally improved in recent years, although there are still hazardous and substandard ships operating around the region's ports and waterways. According to PSC inspection statistics from 2010 to 2021, the number of inspections with detentions varied; nonetheless, the detention rate has been decreasing, and has been less than 4% since 2015, compared to 5.5% in the year 2010. It could be due to hard work of the Tokyo MoU's authorities on increasing PSCO knowledge via technical co-operation programmes such as general training courses (GTC), specialised training courses (STC), expert missions (EM), PSCO exchange and seminar to produce quality and standard inspection. Despite the declining detention rate, the factors have led to varied detention number and contribution.

Table 1
Inspection, deficiencies and detentions data from 2016 to 2021.

Analysed data	2016	2017	2018	2019	2020	2021
Total inspection	31,678	31,315	31,589	31,372	19,415	19,005
Number of inspection with deficiencies	18,943	18,113	18,091	18,461	9,763	9,291
Inspection with deficiencies/ Total inspection	0.60	0.58	0.57	0.59	0.50	0.49
Number of deficiencies	82,895	77,453	74,957	74,550	35,547	40,470
Deficiencies/ Inspection	2.62	2.47	2.37	2.38	1.83	2.13
Number of detainable deficiencies	2,826	2,600	2,343	2,726	1,180	1,182
Number of inspection with detentions	1,090	941	934	983	493	471
Inspection with detention (%)	3.44	3.00	2.96	3.13	2.54	2.48
Detainable deficiencies/ Inspection with detention	2.59	2.76	2.51	2.77	2.39	2.51

Source: Author's own elaboration from compilation database.

According to the Tokyo MoU's statistics, vessels carrying the flags of around 94 different nations were confirmed to access Asia-Pacific ports between 2016 and 2021, with the majority of them coming from Panama (26.6%), Hong Kong (10.4%), Liberia (9.4%), Marshall Islands (9.3%), Singapore (7.3%) and Malta (3.6%) were the most higher inspection rate (Fig. 2). Within the time period examined, the flags with the highest detention rates were significantly different from the flags with the highest inspection rates: Comoros (17.3%), Mongolia (14.5%), Togo (13.2%), Nieu (12.3%), Korea, Democratic People's Republic (11.6%), Palau (11.1%), Dominica (10.8%), Barbados (10.2%), Jamaica (9.8%), Sierra Leone (9.9%), Pakistan (8.8%), Croatia (7.7%), Kiribati (7.2%), Cook Islands (7.1%), Belize (6.5%), and Indonesia (6.4%).

After classification society data was analysed between 2016 and 2021, the majority of inspected vessels were classified by Nippon Kaiji Kyokai (30.8%), DNV GL AS (10.7%), Lloyd's Register & Korean Register (9.0%), Bureau Veritas (8.6%) and American Bureau of Shipping (8.5%) (Fig. 3). The average inspection with defect rate exceeding 90% was determined to be generated mostly from the medium performance classification society, which did not belong to the International Association of Classification Societies (IACS) at the time of the research. This tendency was also noticed in the inspection with deficiency profiling.

The age distribution of detained vessels was determined using a scale with age groups ranging from 0–4, 5–9, 10–14, 15–19, 20–24, 25–29, and ≥30, where 0–4 years means $0 \leq x < 5$, and so as others (Fig. 4). Most of the detention deficiency rates were less than 5% for ship age 0–4, with the exception of bulk carriers, container ships, and general cargo/multipurpose vessels. The detention rate for general cargo/multipurpose vessels increases when one year is added to the vessel's age. The following age ranges were observed for the detained ships: 10–14 (21.6%) > 15–19 (20.0%) > 20–24 (16.1%) > 5–9 (14.3%) > 30 and over (13.9%) > 25–29 (9.4%) > 0–5 (4.8%). Ships 30 years or over represent the largest percentage was passenger ship (40.9%), refrigerated cargo (50.6%), RoRo cargo (30.6%), special purpose ship (27.3%) and tug boat (30.8%).

As shown in Fig. 5, about 92,662 inspections with defects and 4,912 inspections resulting in detention were distributed by ship type and year of inspection, with percentages determined for each ship type and year of inspection. Over the years, the following top five ship types have been inspected the most: bulk carrier (19.7%), general cargo/multipurpose (13.0%), container ship (7.7%), chemical tanker (2.9%), oil tanker (2.6%) and so on. Over the period 2016–2021, the average detention rate across all types of ships was 3.5%, with the factory ship having the highest rate at 12.2%.

Australia, China, Indonesia, Japan, the Republic of Korea, the Philippines, and Viet Nam were the inspecting authorities with inspection rates of 6% or higher (Fig. 6). Among them, China (19.3%), Japan (15.5%) and Australia (11.4%) were the top three, accounting for a total of 46.2%. The inspections with deficiencies rate had varied from zero to 28.6%. While inspection with detainable deficiencies rate were found in zero to 34.4%. It was discovered that the majority of detainable defects occurred at the ports of China (34.4%), Australia (21.8%) and Japan (11.7%).

Following the identification of the deficiencies type among the inspected flags, the deficiencies were classified under seven areas in order to conduct an analysis on the types of deficiencies discovered during each inspection. The certificates and documentation, SOLAS 74/78, MARPOL 73/78, ballast water, antifouling, ISM, labour condition/ILO/MLC, and other categories are included. The most common types of deficiencies during inspections over the 6 years period from 2016 to 2021 were related to ISM (19.0%), MARPOL 73/79 Annex I (8.6%), MARPOL 73/79 Annex IV (8.4%), conditions of employment (7.9%), ship certificates (6.7%), Alarms (4.8%), crew certificates (4.5%), emergency systems (4.4%), and fire safety (3.8%) (Fig. 7). Other categories were found to have lower rates (less than 3.5%), and therefore the characteristics of the vessels detained because of the deficiency types over 3.5% were compared to five main risk factors in the relation analysis later.

From the analysis, combination of these 5 risk factors have found a significant impact on detentions. In order to further detail the analysis, the correlation analysis among the risk factors such as flag of registry, type of vessel, age of vessel and inspecting authority and classification society to the selected type of detainable deficiency were investigated using detainable deficiencies number rather inspections number as shown in Table 2. Detainable deficiency rate with 3.8% or over, i.e. ship certificates, crew certificates, emergency systems, fire safety, alarms, MARPOL 73/78 Annex I, MARPOL 73/78 Annex IV, ISM and conditions of employment was selected as the detainable deficiency parameters for the relation analysis between the risk factors.

The percentage of risk indicators found in this study provides preliminary information on the capacity of a PSCO authorised by Member States of the Tokyo MoU to designate high-risk vessels prior to inspection. Ship detained in the Tokyo MoU region were aged 20 and over on passenger ships, refrigerated cargo, RoRo cargo, RoRo passenger ships, special purpose ships, tug boats, and woodchip carriers. According to the

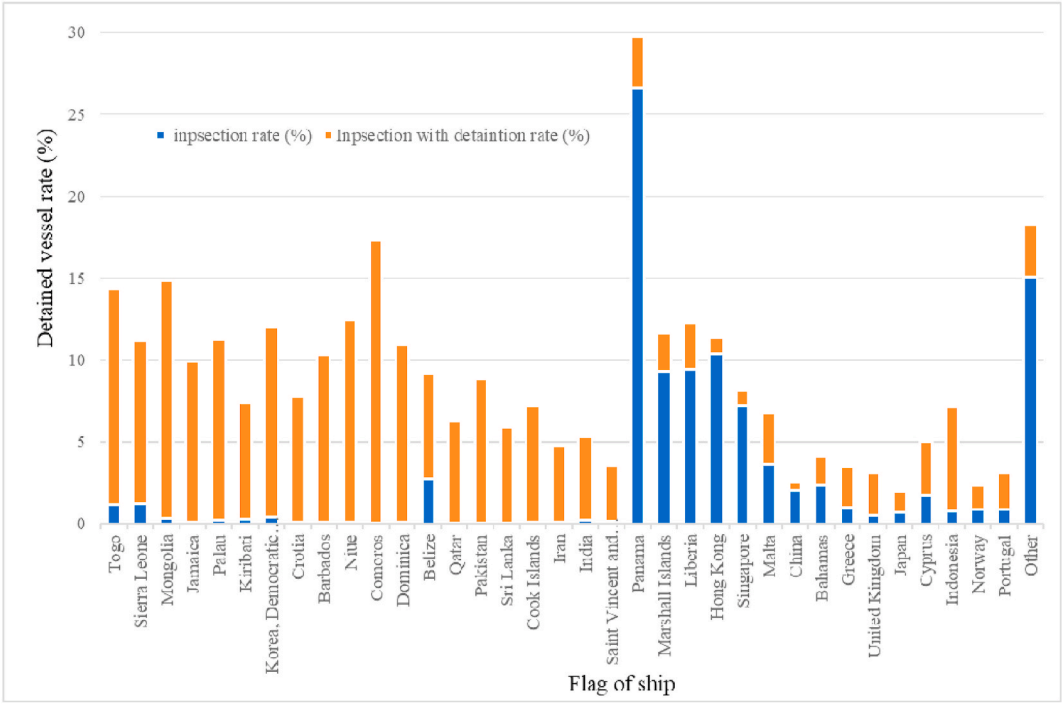

Fig. 2. Breakdown of the number of inspections including detention by year and flag from 2016 to 2021. Source: Author's own elaboration from compilation database.

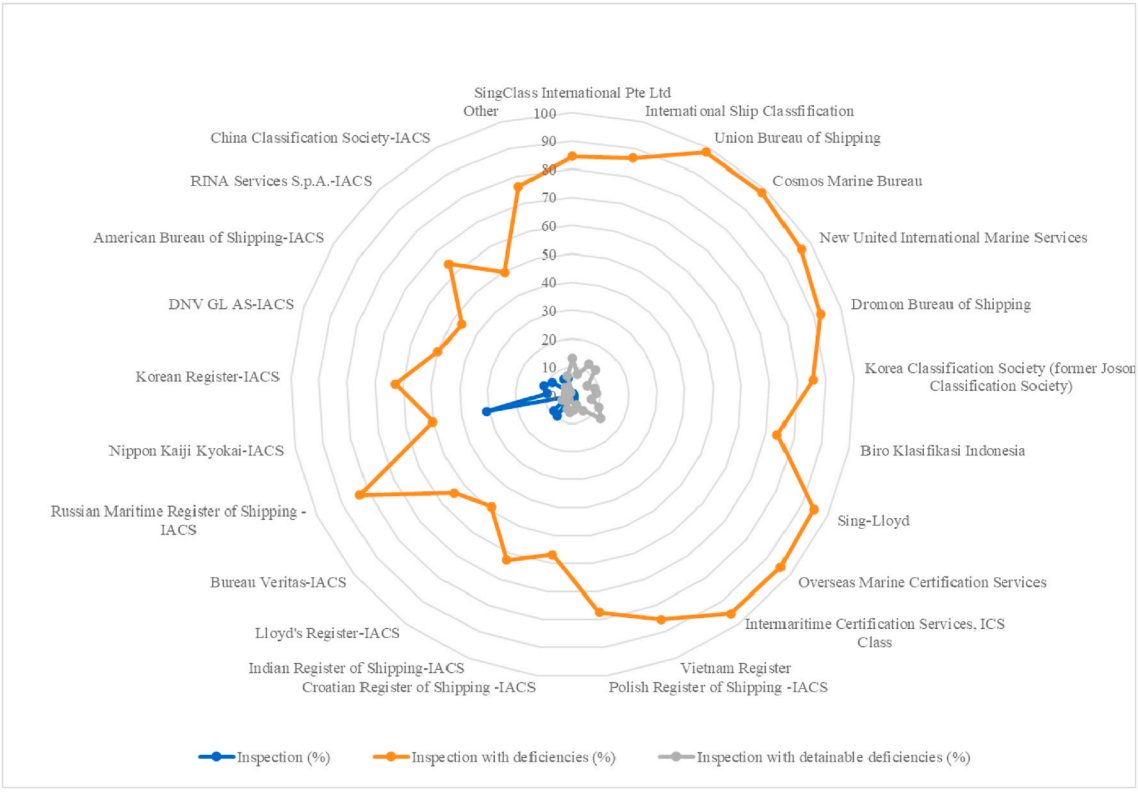

Fig. 3. Breakdown of the inspection with deficiencies including detention rates by classification society from 2016 to 2021. Source: Author's own elaboration from compilation database.

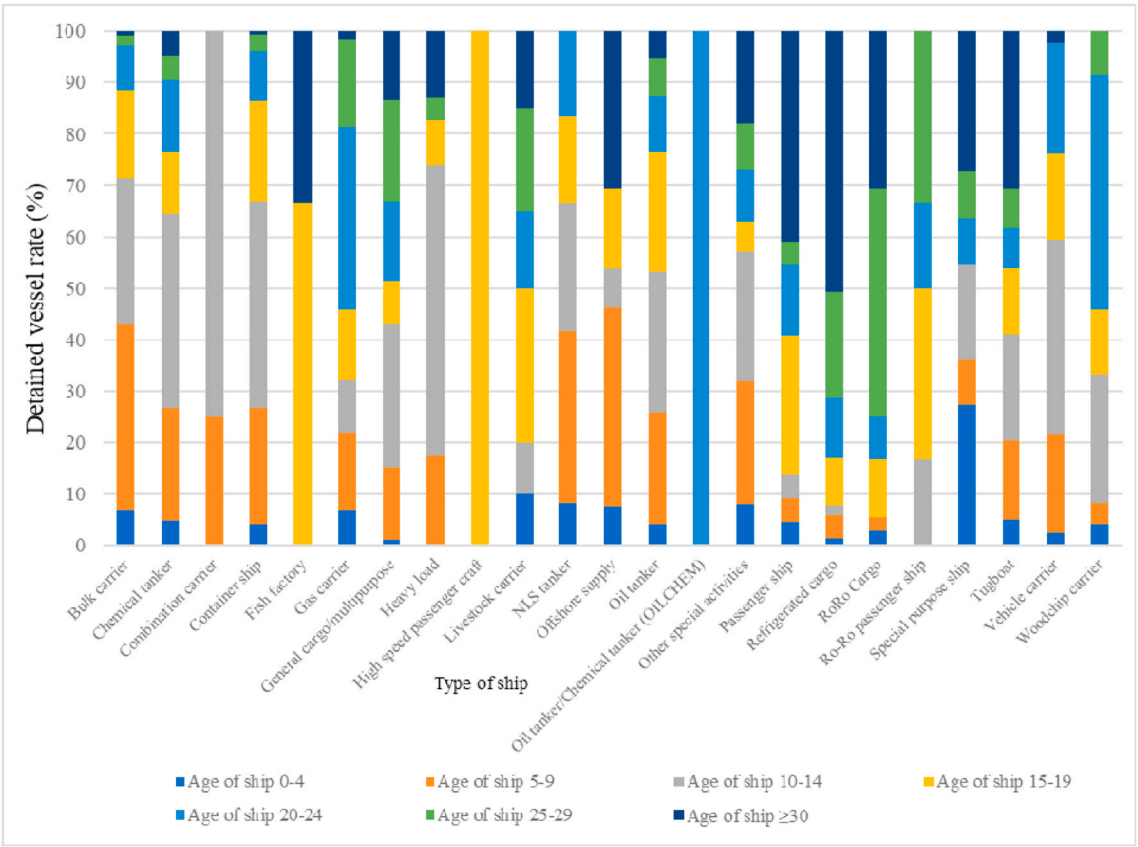

Fig. 4. Breakdown of the inspection with detention rate by age and type of ship from 2016 to 2021. Source: Author's own elaboration from compilation database.

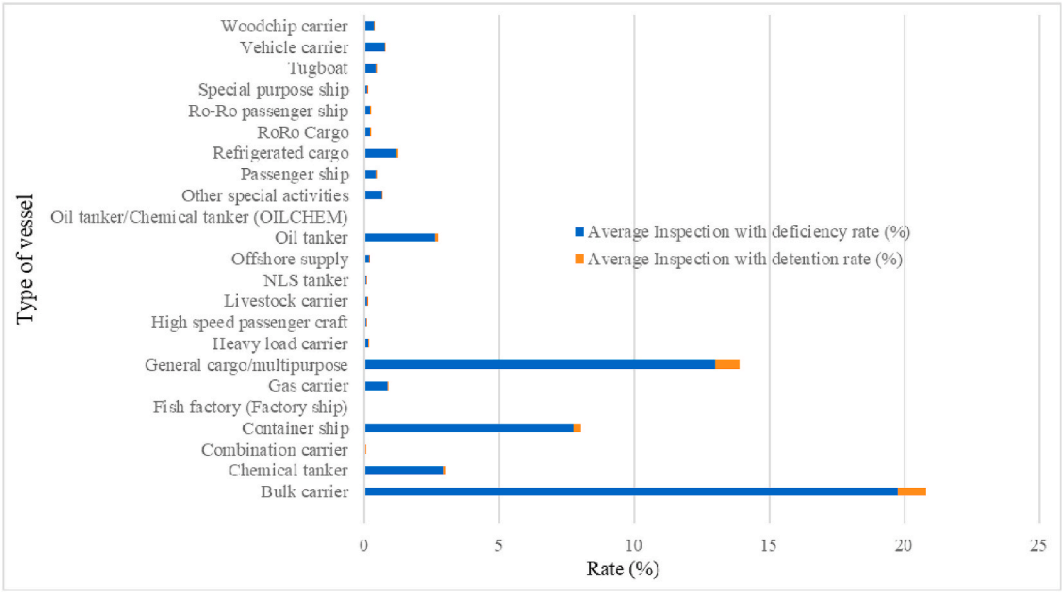

Fig. 5. Breakdown of the deficiencies and detentions rates by year and type of ship from 2016 to 2021. Source: Author's own elaboration from compilation database.

Fig. 6. Breakdown of the inspection with deficiencies including detention rates by inspecting authority from 2016 to 2021. Source: Author's own elaboration from compilation database.

relationship study of ship detention factors and detainable deficiency type, majority of the highest detainable deficiency rate over the type of detainable deficiency was the ship at the age between 10 and 14 except ship and crew certificates. It could be due to majority of the shipowners built their ship in low standard and quality of the shipbuilding to save the cost and also register their ship at flag of convenience and not in the white list of Tokyo MoU to evade stringent regulations. To minimise them do so, financial support and benefit national policy regards to shipping industry from government could keep shipping healthy for all to survive. The ship & crew certificates have highest deficiency rate when the age of the ship age reaches 30 years or more. It could be due to majority of the shipowners could not comply the regulation of IMO instruments such as SOLAS, MARPOL, STCW, Load line, etc. As a result, these substandard ships fail to meet the criteria for safety and security, cannot be operated in the markets of Europe and North America. In addition, the majority of seafarers prefer to join on to a new ship rather than an old ship, which may make it difficult to deploy crews from all over the world. According to these findings, shipowners who seek to engage their old ship in world commerce routes must either meet the requirements of international maritime regulation or demolish the old ship and replace it with a new ship built at a qualified and standard shipyard. It is the responsibility of the government to convince shipowners that it is in their best interest to buy a newly built ship rather than a used ship (<15 years). Because of this, additional expenditure (allocation) is actually required, and the additional spending is delayed, the worse the challenge will be.

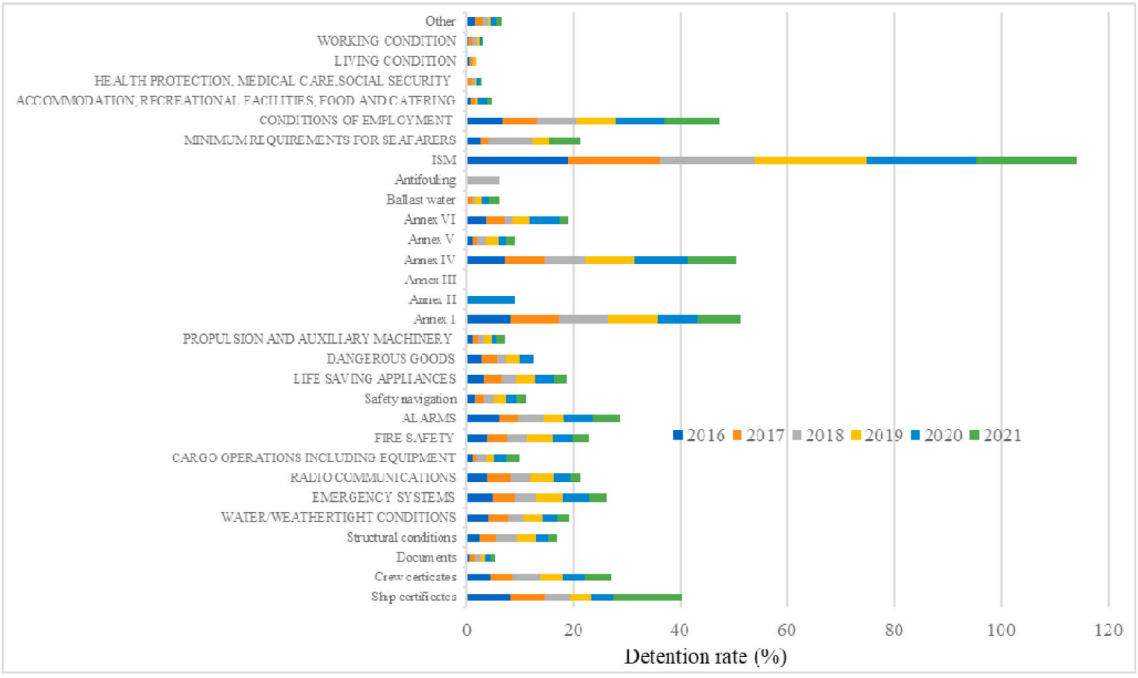

Fig. 7. Breakdown of the deficiencies with detention rates by year and type of deficiency from 2016 to 2021. Source: Author's own elaboration from compilation database.

Regarding flag of registry, the majority of detainable defects found in practically all ships under flag of registry, particularly those on the black and grey lists, have a significant association with fire safety and ISM. This analysis found that the total average of fire safety (32.5%), ISM (16.8%), ship certificates (13.7%) and emergency systems (13.3%) over all the flag of registry, which lead to ship detention was 76.3%. The ships flying with the Korea, Democratic People's Republic, Kiribati, Niue and Barbados were arrested at highest percentage related to fire safety (48.0%), ISM (21.6%), ship certificates (55.1%) and emergency systems (38.1%). This finding has demonstrated that the effect of the flag of registration on detention is far more than the influence of the ship's age, but the latter is still significant. It is consequently recommended that shipping firms improve their safety management systems in order to deal with these shortcomings. The relationship within flag of registry related to the pollution prevention was small. Clearly, shipping companies' safety awareness on pollution prevention was kept at a more satisfactory level compared to ship certificates and emergency systems. Those vessels entering the ports of Tokyo MoU region by flying the black list flags such Togo, Sierra Leone, Mongolia, Jamaica, Palau, Kiribati & Korea Democratic People's and also from grey list such Croatia, Barbados, Niue, Comoros, Dominica, Belize, etc. Under the non-IACS classification society were most arrested with the highest level of deficiency regarding fire safety, ISM, ship certificates and emergency systems in order. With these findings, unduly delay will be avoided if PSCO have more efficient ship selection mechanism. This has a significant impact on motivating the flag State, shipowner, and registry operator to make the required measures to keep their ships in high-quality rather than subpar condition.

When the relationship between type vessel and detainable deficiency is taken into account, it found that all the highest detainable deficiency rate with an average of 34.5% was fire safety at all type of ship and then follow by ISM with an average of 19.7%. The ships of bulk carrier (32.5%), chemical tanker (43.9%), general cargo/multipurpose (35.9%), oil tanker (33.8%), passenger ship (35.2%) and refrigerated cargo (34.9%) were arrested at highest percentage related to fire safety, while for container ship was 34.6%. This result also revealed the second highest detention percentage related to ISM was 24.4% (bulk carrier), 13.9% (chemical tanker), 21.4% (general cargo/multipurpose), 16.3%) oil tanker, 16.7% (passenger ship) and 16.2% (refrigerated cargo), but container was 30.6% related fire safety. It also found that bulk carrier, general cargo/multipurpose and refrigerated cargo similar top 3 detainable deficiency rate related to ISM follow by emergency systems, considering the type of cargo these ship carry. In other view of the analysis, it found that general cargo/multipurpose (average $\approx$ 35.5%) and bulk carrier (average $\approx$ 31.4%) were the highest level of detainable deficiencies compared to other type of vessel. Both add up together was about 66.9%. The percentage of lowest detainable deficiency rate was in passenger ship (0.8%) and follow by chemical tanker (3.8%), refrigerated cargo (4.3%), oil tanker (6.4%) and container ship (7.4%). This could be due to the low number of inspection rate when the entering to the Asia-Pacific ports. As projected, chemical and oil tankers have a low deficiency rate of less than 3%. A tanker ship has a high-risk profile in terms of the environment, safety and security, navigation and health, among other things. In order to transport the hazardous cargo, this ship must undergo a thorough and stringent examination by accredited Ship Inspection Report (SIRE) and Chemical Distribution Institute (CDI). As a result, the detainable deficiency rate and the deficiency rate were much lower as compared to the container, bulk carrier, and general cargo/multipurpose shipping sectors.

When comes to the relation assessment between the classification society and type of detainable deficiency, 12 IACS members and 12 medium performances (from the lowest) of classification society were selected. The main type of detainable deficiency resulted in the highest detention rate was fire safety (36.4%) follow by ISM (18.4%), emergency systems (11.7%) and ship certificates (10.0%). The ship with highest detention rate related to the ship certificates were under International Ship Classification and SingClass international. The classification society involving Cosmo Marine Bureau, Brio Klasifikasi Indonesia, Sing-Lloyd and Russian Maritime Register of Shipping were also causes the detention rate at second higher related to ship certificates. This assessment led to conclude that the Russian Maritime Register of Shipping one of the IACS members were more careless in matters related to ship certificates. Among the 12 IACS members, 3 classification society has shown a poor performance i.e. Polish Register of Shipping, Croatian

Table 2
Breakdown of detain deficiencies type percentage by ship characteristics from 2016 to 2021.

Variables	ISM (%)	MARPOL 73/78 Annex I (%)	MARPOL 73/78 Annex IV (%)	Condition of employment (%)	Ship certificates (%)	Alarms (%)	Emergency systems (%)	Crew certificate (%)	Fire safety (%)
Flag of registry:									
Comoros	8.3	8.3	8.3	16.7	8.3	0.0	8.3	16.7	25.0
Togo	18.9	6.8	2.8	6.1	11.7	1.5	7.4	3.8	41.1
Mongolia	10.6	11.7	1.1	4.4	22.2	1.1	11.1	12.2	25.6
Palau	12.0	6.5	5.6	2.8	27.8	0.9	11.1	3.7	29.6
Korea, Democratic People's Republic	16.0	14.7	2.0	0.0	6.0	4.0	9.3	0.0	48.0
Croatia	19.0	0.0	9.5	9.5	9.5	0.0	9.5	0.0	42.9
Barbados	19.0	9.5	4.8	0.0	4.8	0.0	38.1	0.0	23.8
Jamaica	20.0	10.0	0.0	3.3	6.7	6.7	20.0	0.0	33.3
Niue	11.2	9.0	2.2	0.0	55.1	1.1	2.2	3.4	15.7
Sierra Leone	18.7	8.0	4.7	3.0	7.1	0.0	12.8	7.7	38.0
Dominica	19.2	3.8	7.7	0.0	7.7	0.0	15.4	23.1	23.1
Kiribati	21.6	11.8	3.9	0.0	5.9	0.0	13.7	0.0	43.1
Others	23.3	8.4	6.7	2.9	5.5	1.7	14.4	3.6	33.4
Classification society:									
SingClass International Pte Ltd	4.8	14.5	1.2	3.6	28.9	0.0	12.0	15.7	19.3
International Ship Classification	15.8	8.3	1.5	0.0	39.1	1.5	5.3	2.3	26.3
Union Bureau of Shipping	18.6	9.5	3.8	2.8	10.7	0.6	11.0	3.8	39.1
Cosmos Marine Bureau	13.7	2.6	0.0	19.7	21.4	0.0	6.0	1.7	35.0
New United International Marine Services	10.5	15.8	10.5	0.0	5.3	5.3	0.0	0.0	52.6
Dromon Bureau of Shipping	17.6	0.0	5.9	14.7	5.9	2.9	8.8	2.9	41.2
Korea Classification Society (former Joson Classification Society)	16.0	14.7	2.0	0.0	6.0	4.0	9.3	0.0	48.0
Biro Klasifikasi Indonesia	4.9	8.8	2.9	0.0	23.5	2.9	10.8	7.8	38.2
Sing-Lloyd	17.3	8.2	6.1	0.0	20.4	0.0	8.2	5.1	34.7
Overseas Marine Certification Services	16.4	5.2	4.8	2.8	6.8	1.2	14.0	8.4	40.4
Intermaritime Certification Services, ICS Class	14.9	14.0	10.2	3.3	1.4	3.3	10.2	1.9	40.9
Vietnam Register	15.9	12.8	3.1	0.4	5.7	2.6	15.4	1.3	42.7
Polish Register of Shipping -IACS	16.7	8.3	12.5	8.3	12.5	0.0	12.5	0.0	29.2
Croatian Register of Shipping -IACS	26.3	0.0	10.5	0.0	5.3	0.0	10.5	0.0	47.4
Indian Register of Shipping-IACS	13.8	3.4	10.3	0.0	0.0	3.4	17.2	3.4	48.3
Lloyd's Register	27.3	7.5	4.3	3.6	5.8	1.1	13.2	4.5	32.8
Bureau Veritas	24.3	8.9	8.5	2.6	5.1	1.8	12.0	2.0	34.9
Russian Maritime Register of Shipping	16.5	11.0	12.1	6.6	18.7	1.1	6.6	1.1	26.4
Nippon Kaiji Kyokai	26.5	7.7	8.4	2.8	2.2	1.5	16.5	2.3	32.0
KOREAN REGISTER	31.1	6.2	6.2	2.3	4.8	0.8	15.5	2.0	31.1
DNV GL AS	29.9	9.6	5.5	2.8	2.8	1.2	13.9	2.2	32.2
American Bureau of Shipping	24.7	8.1	9.2	3.3	5.3	1.1	15.8	4.4	28.1
RINA Services S.p.A.	17.0	7.4	6.9	4.8	1.1	2.7	13.3	4.3	42.6
China Classification Society	23.1	7.7	4.6	4.6	0.8	0.0	21.5	4.6	33.1
Other	17.4	8.5	4.1	3.0	11.8	2.0	13.2	7.6	32.4
Type of ship									
Bulk carrier	24.4	9.0	6.5	3.1	3.5	1.7	16.7	2.7	32.5
Chemical tanker	13.9	9.7	10.6	1.6	6.1	1.3	10.0	2.9	43.9
Container ship	34.6	10.6	5.5	2.7	2.2	1.0	10.9	1.8	30.6
General cargo/multipurpose	21.4	7.5	5.4	3.7	6.3	1.9	13.8	4.1	35.9
Oil tanker	16.3	8.9	7.6	2.6	14.4	1.1	9.8	5.4	33.8
Passenger ship	16.7	5.6	0.0	1.9	20.4	1.9	11.1	7.4	35.2
Refrigerated cargo	16.2	11.3	9.2	1.2	9.8	0.6	10.4	6.4	34.9
Others	14.1	6.9	3.6	2.8	23.3	1.3	10.3	8.0	29.6
Age of ship									
0–4	4.5	3.3	2.1	3.8	4.4	0.0	4.8	6.6	2.5
5–9	24.8	22.5	16.4	19.2	17.2	18.7	22.6	15.5	19.4
10–14	28.2	27.7	30.7	23.0	20.6	27.6	27.3	17.1	31.8
15–19	15.0	11.9	15.8	15.5	9.2	19.5	14.2	15.1	13.7
20–24	11.1	13.4	19.6	8.4	8.3	17.1	14.3	16.1	13.2
25–29	9.5	10.0	6.8	12.6	13.7	9.8	10.0	9.5	10.7
≥30	6.9	11.1	8.5	17.6	26.6	7.3	6.8	20.1	8.7
Inspecting authority									

(*continued on next page*)

Table 2 (*continued*)

Variables	ISM (%)	MARPOL 73/78 Annex I (%)	MARPOL 73/78 Annex IV (%)	Condition of employment (%)	Ship certificates (%)	Alarms (%)	Emergency systems (%)	Crew certificate (%)	Fire safety (%)
Australia[3)]	37.6	6.6	5.6	7.0	1.9	0.2	19.4	1.0	20.7
Canada[4)]	35.6	10.0	1.1	3.3	1.1	1.1	27.8	10.0	10.0
Chile	4.0	8.0	2.0	0.0	28.0	6.0	26.0	18.0	8.0
China	17.1	10.8	6.7	0.2	6.3	3.1	12.4	1.9	41.6
Fiji	0.0	0.0	0.0	0.0	58.3	0.0	16.7	8.3	16.7
Hong Kong, China	27.5	6.4	6.4	0.7	3.4	1.0	13.8	6.0	34.9
Indonesia	13.7	8.5	19.7	0.9	2.5	1.1	11.1	0.5	42.1
Japan	30.4	2.4	0.6	8.1	1.8	0.1	19.4	10.5	26.6
Republic of Korea	22.8	9.7	2.9	2.6	7.8	0.8	11.6	5.4	36.4
Malaysia	1.9	11.1	3.0	2.6	45.9	1.1	7.0	15.2	12.2
Marshall Islands	14.3	25.0	7.1	0.0	10.7	0.0	3.6	0.0	39.3
New Zealand	16.7	6.7	0.0	6.7	13.3	0.0	36.7	0.0	20.0
Panama[4)]	0.0	0.0	0.0	12.0	64.0	0.0	4.0	16.0	4.0
Papua New Guinea	6.5	12.9	3.2	0.0	6.5	3.2	19.4	9.7	38.7
Peru	27.3	4.5	0.0	0.0	59.1	0.0	4.5	0.0	4.5
Philippines	8.7	2.2	0.0	23.9	41.3	0.0	6.5	17.4	0.0
Russian Federation[4)]	28.2	4.4	3.2	9.3	10.1	0.4	8.2	2.8	33.4
Singapore	12.8	6.1	7.4	1.4	1.4	0.7	12.8	6.1	51.4
Thailand	8.3	16.7	0.0	0.0	8.3	0.0	8.3	0.0	58.3
Vanuatu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Viet Nam	34.7	20.0	1.3	1.3	8.0	2.7	6.7	5.3	20.0

Source: Author's own elaboration from compilation database.

Register of Shipping and Indian Register of Shipping although Nippon Kaiji Kyokai (30.8%), Bureau Veritas (8.6%), DNV GL AS (10.7%) and Lloyd's Register (9.0%) were the highest detention rate due to the top 4 inspection rate with a total about 60%. The authority should pay more attention (revised the classification society instruction and stern audit) to their appointed RO, who on behalf them to give statutory services which are in accordance with international maritime regulations as they played an important role in ensuring that their inspection and monitoring of vessels is up-to-standard in order to avoid the vessel's deficiency being listed in the ranking of port State detentions.

An average inspection rate over all the maritime authorities from 2016 to 2021 was 48.3%, with the top 3 highest being that of China, Japan and Australia in order, while lowest that of Vanuatu at about close to zero. Eight (China-14,722 $\times$ 10^9 USD; Japan-5,057 $\times$ 10^9 USD; Canada-1,645 $\times$ 10^9 USD; Korea-1,637 $\times$ 10^9 USD; Russian-1,483 $\times$ 10^9 USD; Australia-1,327 $\times$ 10^9 USD; Indonesia-1,058 $\times$ 10^9 USD) out of twenty-one maritime authorities have highest Gross Domestic Product (GDP), while medium GDP viz. Thailand-501 $\times$ 10^9 USD, Philippines-361 $\times$ 10^9 USD, Singapore-339 $\times$ 10^9 USD, Malaysia-337 $\times$ 10^9 USD, Hong Kong-346 $\times$ 10^9 USD, Chile-252 $\times$ 10^9 USD, New Zealand-210 $\times$ 10^9 USD and Peru-202 $\times$ 10^9 USD. The lowest GDP among the 21 maritime authorities is Papa New Guinea-24 $\times$ 10^9 USD, Panama-53 $\times$ 10^9 USD, Fiji-4x10^9 USD, Vanuatu-0.88 $\times$ 10^9 USD and Marshall Islands-0.24 $\times$ 10^9 USD. From the view of GDP, it is cleared that there are different levels of economic, social and politic development among the member authorities. It is always be differences in member authorities' capability due to geographical, economic, culture different and social among Tokyo MoU members. It would not be possible to achieve an even inspection rate over all the maritime authorities. When the relationship between inspecting authority and detainable deficiency is taken into account, it found that Australia, Canada, Viet Nam and Japan were more focus on the ISM deficiency, but China Hong Kong, Indonesia, Republic of Korea, Marshall Islands, Papua New Guinea, Russian Federation, Singapore and Thailand were more concentrated in fire safety area. The inspecting authority who pays more attention to ship certificates during the PSC inspection were Chile, Fiji, Malaysia, Panama, Peru and Philippines, while New Zealand focus on emergency systems. Based on the number of detainable deficiencies, China (36.4%), Australia (12.5%), Japan (9.8%), Republic Korea (9.1%) and Indonesia (7.8%) were the top 5 (up to 75.6%) giving the detainable deficiency number. According to Knudsen and Hassler (2011), there were a variety of procedures in PSC that change from country to country. They also advise that inspectors from the IMO who are not tied to any one country be included in the inspection mechanism at ports. However, because of the expensive expense, it is difficult to put into effect unless the PSC seminar is held in that nation and hands-on practise is performed on board with IMO inspectors.

Depending on the flag of the ship, a different study found that PSC can easily be used as a political tool by some flag Sates, and that it is possible that the professional decisions of PSCOs will be influenced by the general policies of their countries, resulting in unjust detention. Even if the shipowners have the right to demand compensation in such a situation, shipowners often choose a more practical way since it does not eliminate custody decision while introducing a long process.

Using this data analysis, shipowners will be able to evaluate their expenditure in repair and maintenance to avoid detention. For the purpose of improving the inspections and governance strategies in order to optimise the maritime safety operation and marine pollution prevention, government and policy makers should take into account these high impact risk factors and areas of detainable deficiency that may result in ship detention. Following this research, shipping companies should maintain ISM compliance, fire safety, timely self-inspection, and crew education in order to limit the likelihood of ship detention, which might result in economic loss as well as possible environmental problems.

5. Conclusion and future research

Proper study of ship detention variables provides a good reference for ships in order to assure safe sailing before departure, standard operation, and efficiency of the PSC while undergoing inspection. In order to facilitate the study, the detailed analysis of the big data of ship detention from 2016 to 2021 by the Tokyo MoU, the numerical value of this effect, and the rate of each of these six factors (identified through the literature review and PSC inspection record) on individual arrests were calculated as a percentage. The importance of several elements in arrests was established on an individual basis. The relationship between each selected risk factor and detainable deficit has been attempted to be elucidated within each specified risk factor group.

About 94 to 102 ships flying the flags of various countries enter the Asia-Pacific ports each year between 2016 and 2021. Over the period 2016–2021, the flags with the highest detention rate over 10% from 2016 to 2021 were Comoros (17.3%) follow by Mongolia (14.5%), Togo (13.2%), Niue (12.3%), Korea, Democratic People's Republic (11.6%),

Palau (11.1%), Dominica (10.8%), Barbados (10.2%), Sierra Leone (9.9%), Jamaica (9.8%), Pakistan (8.8%) and so. All of these flags were not in the white list.

In the Asia-Pacific region, about 86.9% of the fleets that enter the ports was under IACS classification. The majority of detention rates were less than 4%, with the exception of the Croatian Register of Shipping (6.4%), the Indian Register of Shipping (5.3%) and the Polish Register of Shipping (5.2%), all of which had low inspection rates less than 0.3%. The classification society with the greatest proportion of detention rates exceeding 10% was SingClass International (13.1%), followed by the Union Bureau of Shipping (12.5%), Cosmo Marine Bureau (12.1%) and Sing-Lloyd (10.6%). In the yearly report of the Tokyo MoU, all of them were classified as having medium performance. Some of the non-IACS member have shown lower detention rate i.e. Vietnam Register (3.7%), New United International Marine Services (6.4%) and Intermaritime Certification Services (6.8%), but with low inspection rate over the total feet, viz. 1.9%, 0.2% and 1.1%. Ensure that the classification society's inspection and monitoring of vessels is up to standard in order to avoid the vessel's shortcoming being noted in the ranking of port State detentions has played an essential part in preventing the vessel from being detained. Self-regulation classification societies to which flag States delegate are the future of shipping in offering effective solutions to the current and future needs of the shipping industry.

Majority of the researchers stated that the main risk factor causes the ship detention was the age of ship. This fact was contradicted with this analysis. The greatest detention rates were fluctuated over the age of ship subject to the type of ship. Bulk carrier, NLS tanker, offshore supply vessel and Other special activities have shown the highest detention rate at age of 5–9, while Chemical tanker, combination tanker, container ship, General cargo/multipurpose, heavy load vessel, oil tanker and oil/chemical tanker and vehicle carrier were at 10–14. This could be due to the fact that the vast majority of shipowners built their ships to a low standard and quality of shipbuilding in order to save money and register their ships under a flag of convenience rather than under the white list of the Tokyo MoU. The gas carrier, woodchip carrier, Ro-Ro passenger ship, passenger ship, refrigerated cargo, RoRo Cargo, special purpose ship, and tugboat were found to have the highest detention rates among those over the age of 20.

The highest rate of inspection that carried out by the Tokyo MoU authorities when the ships enter to the Asia-Pacific ports was China (19.3%) follow by Japan (15.5%) and Australia (11.4%), but the highest detention rate was Marshall Islands (11.3%) follow by Australia (5.7%) and China (5.3%).

According to the results of the analysis based on the type of vessel, factory ships had the highest average detention rate (12.22%), followed by RoRo cargo (6.53%), other special activities (5.49%), and general cargo/multipurpose (5.20%). However, bulk carriers had the highest average inspection rate, viz. 37.1%.

The most common detainable deficiencies were ISM (19.0%), followed by MAROL 73/78 Annex I (8.6%) and Annex IV (8.4%), conditions of employment (7.9%), ship certificates (6.7%), alarms (4.8%), crew certificates (4.5%), emergency systems (4.4%), and fire safety (3.8%). These nine detainable defect types were chosen for further investigation into their relationships with the five primary risk variables, which were the authority, classification society, type of ship, flag of ship, and age. According to the results of the relationship analysis, the flag of the ship was the most significant risk factor, but the combination of other factors such as the age of the ship, the type of vessel, the RO, and the inspecting authority had a significant impact on the likelihood of detention. The education and training are important factors and are essential to enhance skills, abilities and competency of seafarers in reducing the non-conformities due to the fire safety and ISM related safety issues.

The results of prediction analysis reveal that the important risk factors in PSC inspection were flag of registry, classification society and type of ship, but age of ship and inspecting authority still remained important. However, this result leads to recommend PSCO to devote more effort to bulk carrier, General cargo/multipurpose, container and tanker ship aged 5–14 when searching for deficiencies and detentions related to fire safety and ISM, particularly in ship registers with black and grey list countries under medium classification societies as a result of this finding. Last but not least, it is recommended that the maritime authorities from Chile, Fiji, Malaysia, Panama, Peru, and the Philippines concentrate on areas such as fire safety, ISM, and emergency systems while conducting possible detention inspections in their respective ports. Using a panoramic perspective of the Tokyo MoU inspection, this study seeks to evaluate the influence of each risk factor on detention deficiencies found during inspections conducted by PSCO of the Tokyo MoU between 2016 and 2021. When selecting the ships to be inspected, this result will aid PSCO in selecting the most likely type of defect, which will allow PSCO to be more efficient during the PSC inspection and minimise unnecessary delays. This will allow flag State, shipowner and classification society to manage their ships with an overall picture of the identified shortcomings. The shipping industry and governments can take appropriate and effective steps in the prevention and management of ship detention if they operate in accordance with safety procedures and marine pollution prevention. Shipowners can use this projected analysis to determine the impact of risk variables associated with various detainable deficiencies on the likelihood of a ship being detained. This renders an assistance to shipowner in selecting the standard and quality shipyard to build or repair their ship, as well as the flag under which their ship will be registered. For those existing ship, the shipowners can use this information to rectify the deficiency precisely in a cost-effective manner although the outbreak of war between Russia and the Ukraine may spike shipping costs in terms of ship maintenance, freight rates, etc. For shipping companies, it is beneficial to reduce the risk of detentions as well as improve the company's PSC performance.

For further research, it is recommended to be further consider the ship-related information such as gross tonnage and type of inspection in determining the implication on ship detention. Secondly, data in the duration of 2010–2015 is being collected to conduct a comparative study to demonstrate the effectiveness of NIR since 2014 in later study for better understanding of the policy gap and improvement of PSC inspection. For the third, similar replicated studies and comparison can also be carried out by using the grey rational analysis model with improved entropy weight and BN model for the testing the accuracy order of risk factors and detainable deficiency. Finally, further efforts should take into account detention time, which is the severity of penalty for vessels that fail to pass the inspection.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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