Marine Policy 115 (2020) 103857

Contents lists available at ScienceDirect

Marine Policy

journal homepage: http://www.elsevier.com/locate/marpol

The effectiveness of the New Inspection Regime for Port State Control: Application of the Tokyo MoU

Yi Xiao [a], Grace Wang [b,1], Kun-Chin Lin [c], Guanqiu Qi [d], Kevin X. Li [a,*]

[a] Ocean College, Zhejiang University, No. 1 Zheda Road, Zhoushan, 316021, Zhejiang, China
[b] Federal Maritime Commission, 800 North Capitol Street, N.W Washington, USA
[c] Department of Politics and International Studies, University of Cambridge, Alison Richard Building, 7 West Road, Cambridge, CB39DT, United Kingdom
[d] Department of International Trade and Logistics, Chung-Ang University, 84 Heuk Seok-Dong, Dong jak-Gu, Seoul, South Korea

ARTICLE INFO

Keywords:
Port state control
New inspection regime
Tokyo MoU
Big data
Binary logistic regression

ABSTRACT

Port State Control (PSC) ensures that foreign ships do not sail until they can proceed at sea without posing a danger to maritime safety and environment. Since 2011, a New Inspection Regime (NIR) has been implemented by the PSC of the Memorandum of Understandings (MoU) member countries to identify potential substandard ships and increase the effectiveness of inspections. The NIR process and whether the target factors in the NIR can effectively reduce risks at sea are worth exploring. We take the Tokyo MoU as an example and retrieve 125,259 cases from 2015 to 2017 using computer programing. Based on the big data, we adopt a binary logistic regression to analyze detention decisions, which we then supplement by applying a decision tree to conduct a multi-factor decision-making analysis. The ships' characteristics such as age, type, deadweight, number of deficiencies, and others, namely, port State, performances of flag State, and recognized organization, may also shed light on the risks associated with detentions. Based on the empirical results, we derive three conclusions. First, the following factors are essential: ship age, ship type, performance of flag States, and the number of deficiencies that NIR considers significant. Second, ships older than 6 years seem more likely to be substandard. If a ship has five or more deficiencies, the probability that it will be detained is high. Third, discrepancies exist when carrying out the PSC among port States in the Tokyo MoU.

1. Introduction

The International Maritime Organization (IMO) first proposed Port State Control (PSC) and the Annex I regulation 8A of the International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 that highlighted the ship's operational requirements. PSC should be regarded as complementary to national measures taken by flag States that cannot exercise full and continuous control over ships flying their flags to safeguard maritime safety and security and ensure the prevention of pollution [1]. The Memorandum of Understanding (MoU) on PSC was first established by European countries under the 1982 Paris MoU, which dates back to an oil spill accident in France caused by Amoco Cadiz under the Liberian flag of convenience. The resources lost from that accident could have fueled a car for 57,200 years or powered 15,398 homes for a year [2]. To improve maritime safety, pollution prevention, and onboard living and working conditions, ten MoUs on PSC have been established. PSC, as an internationally agreed-upon regime for inspecting foreign ships, must identify substandard ships coming into their ports based on international conventions and protocols such as the International Convention on the Control of Harmful Anti-fouling Systems on Ships 2001, the International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004, the International Convention for the Safety of Life at Sea 1974, the Maritime Labor Convention 2006, and so on. The ten international MoUs include the Paris MoU (1982) in Europe and the North Atlantic region, the Acuerdo de Vina del Mar in the Latin American region (1992), the Tokyo MoU in

* Corresponding author.
E-mail addresses: zoeyxiao@zju.edu.cn (Y. Xiao), gw77539@gmail.com (G. Wang), kcl35@cam.ac.uk (K.-C. Lin), xiao20107@cau.ac.kr (G. Qi), kxli@zju.edu.cn (K.X. Li).

[1] Grace Wang is the Director of Economic Studies at the Federal Maritime Commission (FMC) whose mission is to ensure a competitive and reliable international ocean transportation supply chain. The author's personal email is gw77539@gmail.com. This paper is the result of the author's independent research and does not represent the views of the FMC or the US government.

https://doi.org/10.1016/j.marpol.2020.103857
Received 9 April 2019; Received in revised form 31 January 2020; Accepted 3 February 2020
Available online 24 February 2020

the Asia-Pacific region (1993), the United States Coast Guard MoU (USCG) (1994), the Caribbean MoU (1996), the Mediterranean MoU (1997), the Indian Ocean MoU (1998), the Abuja MoU in the West and Central African regions (1999), the Black Sea MoU (2000), and the Riyadh MoU in the Arab States of the Gulf (2004). The number of member countries varies, with the smallest being 6 in the Arab States of the Gulf, 10 in the Mediterranean MoU, 20 in the Tokyo MoU, and up to 27 in the Paris MoU. In total, 116 countries and regions have entered MoUs, and 14 countries comply with more than one MoU.

The MoUs on PSC can be divided into three categories: (1) a risk-based targeting system implemented by the Abuja MoU, the Riyadh MoU, the Caribbean MoU, the Mediterranean MoU, and Acuerdo de Vina del Mar with a specific annual inspection rate; (2) the USCG, which is responsible for foreign ships and the flag State for US vessels; and (3) the New Inspection Regime (NIR) initially implemented by the Paris MoU in 2011 and adopted by the Tokyo MoU in 2014, the Black Sea MoU in 2016, and the Indian Ocean region in 2018.

In the MoUs that rely on risk-based targeting systems, port States pay more attention to ship type, flag State performance, ship age, historical records of detention and deficiencies, and company performance. For example, the Caribbean MoU has a 15% annual inspection rate per country within 3 years and proposes that port States focus on the following types of ships for inspection: "(1) passenger ships, roll-on/roll-off ships, bulk carriers, ships of traditional build, and ships below 500 tons gross tonnage; (2) ships that may present a special hazard—for instance, oil tankers, gas carriers, chemical tankers and ships carrying harmful substances in packaged form; (3) ships flying the flag of a State appearing in the three-year rolling average table of above-average detentions in the annual report of the Memorandum; and (4) ships that have had several recent deficiencies. Aside from the aforementioned, the MoU suggests that port States utilize the targeting matrix to select ships for inspection and avoid inspecting ships that have been inspected by others within the previous 6 months unless clear grounds exist" [3].

Under the USCG, the Port State Control Officers (PSCOs) will carry out a nearly 100% annual inspection rate per vessel. In accordance with the targeting matrix, Priority I Vessels, Priority II Vessels, and Non-Priority Vessels will be confirmed. A ship classified as a Priority I Vessel may be restricted until the PSCOs inspect it; a ship classified as a Priority II Vessel may only be restricted if the PSCOs confirm that the ship poses risks to maritime safety or the environment; a ship classified as a Non-Priority Vessel may be selected and inspected at random. In addition, to encourage ships to meet the requirements of relevant conventions, the USCG introduced the Quality Shipping for the 21st Century Program (QUALSHIP 21) and the E-Zero (meaning zero environmental deficiencies or violations) program as incentives such as a frequency reduction in PSC.

For MoUs implementing the NIR, inspection regimes depend on both periodic inspections based on the ship risk profile (SRP) and additional inspections caused by overriding or unexpected factors. For example, the inspection regimes of the Tokyo MoU cover two factors. First, ships are assigned with SRPs based on the NIR to help port States determine inspection priorities and intervals. Periodic inspections are implemented at intervals that depend on the SRP. If a ship is evaluated as a high-risk ship (HRS), it may be inspected within 2–4 months of the preceding inspection and must be inspected when the time window has closed. For ships evaluated as standard-risk ship (SRS) and low-risk ship (LRS), they may be inspected within 5–8 and 9–18 months, respectively, of the preceding inspection and must be inspected when the time window has closed. Second, overriding or unexpected factors might trigger inspections between periodic inspections regardless of the NIR. For example, when overriding factors such as ships carrying dangerous or polluting goods may pose a threat to the safety of the ships, their crews, or the marine environment, PSCOs need to undertake additional inspections [4].

In summary, the three inspection regimes differ when it comes to ship selection for PSC. Considering the popularity of the NIR, the need to assess its standardized procedures and further examine the effectiveness of detention decisions made under it is urgent.

The remainder of this study is organized as follows. Section 2 reviews the literature on the ship selection systems of PSC regimes and the inspection procedures of PSC. Section 3 introduces the binary logistic regression methodology. Section 4 presents the empirical analysis results of the risk of detention based on 125,259 cases of inspection records from the Tokyo MoU and uses a decision tree to analyze the NIR's decision rules. Finally, Section 5 presents our conclusion and discussion about the NIR.

2. Literature review

2.1. Research on the confirmation of the target factors of PSC inspection regimes

For ship selection systems, researchers tend to discuss the determinants of detention in current ship selection systems and how to improve these for PSC inspections. For the determinants of detention, researchers analyze inspection histories to confirm whether target factors such as ship age, ship type, flag State, and classification society were significant to a detention. For example, by analyzing 18,000 inspections from the early 1990s, the Australian Maritime Safety Authority (AMSA) confirms that ship age has been the most important target factor and finds considerable variation among different recognized organizations and classification societies in the total number of deficiencies based on inspection histories for 2002 and 2003 [5]. Cariou et al. [6,7] collect 4080 inspections by the Swedish Maritime Administration from 1996 to 2001 to analyze the effectiveness of PSC and confirm the determinants of the number of deficiencies inspected during PSC. The results show that ship age, ship type, and flag State are significant predictors, and repeated PSC inspections could make ship owners reduce deficiencies during subsequent inspections. Subsequently, Cariou et al. [8] analyze 26,515 inspections under the Indian Ocean MoU from 2002 to 2006 and propose that the main influential factors of detention are ship age, recognized organization, and place of inspection. Meanwhile, Li and Zheng [9] collect PSC inspections of the Paris MoU, the Tokyo MoU, and USCG from 1994 to 2005. They analyze the inspection effectiveness of the three different target systems, highlighting the importance of ship type, ship age, classification society, flag State, and vessel history (e.g., detention and casualty numbers). Knapp and Philip [10] find that target factors such as ship age, gross tonnage, flag State, and classification society do not vary significantly across the various regimes for the probability of detention based on 183,819 inspections under the five MoUs (Paris MoU, Caribbean MoU, Acuerdo de Vina del Mar MoU, Indian Ocean MoU, and USCG) and AMSA from 1999 to 2004. Fan et al. [11] conclude that ship age is an important factor for PSC inspections; more significantly, they find that PSC intended to inspect ships flying the flags of countries other than those of shipowners. Moreover, several researchers investigating methods to improve the current target systems apply historical inspection records to verify the necessity of considering other target factors. For example, substandard ships with many deficiencies or detentions can change their flag States and classification societies to improve their SRP. Thus, some researchers suggest that changing flag States and classification societies should be included in target systems when PSC makes inspection decisions [12,13]. Aside from changes of flag States and classification societies, Heij et al. [14] combine ship arrival, inspection, and casualty databases and propose that casualty risk warrants consideration when selecting which vessels to inspect. In addition, some researchers propose improving the mathematical model of risk-based ship selection systems and introduce generalized additive modeling to realize optimization automatically to solve problems such as the negative Matthew Effects caused by historical factors [15].

In the case of the NIR, selection criteria can be divided into two priority categories: Priority I criteria apply when ships must be inspected because either their time windows have closed or an overriding factor exists; meanwhile, Priority II criteria apply when ships may be inspected because although they are within their time windows, the port State believes unexpected factors justify inspections. Some researchers show that inspection reports from different PSCOs with different professional backgrounds affect deficiencies and detentions, thereby making ships with poor condition experience longer intervals between inspections. They then suggest joint decision-making by multidisciplinary teams [16, 17]. Wu et al. [18] evaluate the effectiveness of fire drills for emergencies related to International Safety and Management (ISM) deficiencies to develop certain valuable suggestions for key stakeholders to cope with the NIR, which pays more attention to ISM deficiencies than others. Emecen Kara [19] stresses the importance of the performance of flag States in PSC inspections based on the Black–Grey–White lists of the Black Sea MoU from 2004 to 2014 and predicts that the NIR with a logical target system will improve maritime safety, particularly navigation safety. The Black–Grey–White lists mark the performance of flag States in terms of inspection records over 3-year periods; for example, according to the 2017 annual report of the Tokyo MoU, flag States whose ships were involved in 30 or more port State inspections over the 3-year period are listed in the White–Grey–Black lists, whereas flag States involved in 30–49 port State inspections with no detentions are listed at the top of the White list [19]. Moreover, Chen et al. [20] identify key deficiencies that cause ship detentions based on the annual reports of the Tokyo MoU from 2008 to 2017.

In summary, we can conclude that the current determinants of detentions in various ship selection systems—including ship age, ship size, ship type, flag State, classification society or recognized organization, place of inspection, and vessel history—are efficient for identifying and eliminating substandard ships. With the introduction of the NIR, specific targets such as ship age, ship type, performance of flag State, and recognized organization have been proposed. However, the NIR does not investigate certain important factors such as ship size. In addition, the risks of detentions may differ because ships are inspected in different port States. Hence, the latest inspection database must be used to analyze the determinants and risks of ship detentions.

2.2. Steps for ship inspection of PSC

In the NIR, each MoU has subtle differences in both SRP and time windows. Given that the Tokyo MoU produces the most inspection data every year, we use it as an example to describe the following ship selection and inspection steps.

- Step 1: Confirm a ship's risk type based on the NIR (see Table 1).
  - When the sum of weighting points is equal to or greater than 4, the ship is regarded as HRS.
  - When the sum of weighting points equals 0, the ship is regarded as LRS.
  - When the sum of weighting points is between 0 and 4, the ship is regarded as SRS.

  Step 2: Check the time window based on the ship's risk type.
  - HRS: 2–4 months.
  - SRS: 5–8 months.
  - LRS: 9–18 months.

  Step 3: Check priority.
  - Priority I: Time window closed or overriding factor.
  - Priority II: Time window open or unexpected factor.
  - Non-Priority: Time window yet to open and no overriding or unexpected factors

  Step 4: Confirm whether or not to inspect a ship. If yes, begin step 5; if not, end the process.

  Step 5: Implement an inspection based on the IMO (Res.1119, 2.2.5).
  - An initial inspection.
  - A more detailed inspection.
  - Detention.

  Step 6: Record the inspection result that will be considered in step 1.
  - Reporting authority, name of ship, flag State, ship type, call sign, IMO number, gross tonnage, deadweight (where applicable), date keel laid, date of inspection, place of inspection, date of release from detention, IMO company number, details of ship certificates, information on last intermediate or annual survey, deficiencies, supporting documentation, and decision on ship detention.

Table 1 shows the SRP of the Tokyo MoU and contains the target factors. The following points warrant emphasis. When the sum of weighting points is equal to or greater than 4, equal to 0, and between 0 and 4, a ship is designated as HRS, LRS, and SRS, respectively. Moreover, these ships should be inspected between 2 and 4 months (HRS), between 9 and 18 months (LRS), and between 5 and 8 months (SRS) from the previous inspection. Based on these criteria, the SRP decides the time window. If the target factors in the NIR are not

Table 1
Ship risk profile of the Tokyo MoU.

Parameters		Profile			
		High-risk ship (Sum of weighting points ≥ 4)		Standard-risk ship (Sum of weighting points = 0–4)	Low-risk Ship (Sum of weighting points = 0)
		Criteria	Weighting points	Criteria	Criteria
Type of ship		Chemical tanker, gas carrier, oil tanker, bulk carrier, passenger ship, container ship	2	Neither LRS nor HRS	–
Age of ship		All types > 12y	1		–
Flag	BGW-list	Black	1		White
	IMO Audit	–	–		Yes
Recognized organization (RO)	RO of Tokyo MoU	–	–		Yes
	Performance	Low Very low	1		High
Company performance		Low Very low No inspection Within the previous 36 months	2		High
Deficiencies	No. of deficiencies recorded in each inspection within the previous 36 months	How many inspections were there which recorded over 5 deficiencies?	No. of inspections which recorded over 5 deficiencies		All inspections have five or fewer deficiencies (at least one inspection within the previous 36 months)
Detentions	No. of detention within the previous 36 months	3 or more detentions	1		No detention

Source: http://www.tokyo-mou.org

appropriate, the conditions of a ship cannot be reflected accurately. This could lead poorly performing ships to go long periods without being inspected and ships that are performing well to experience shorter periods between inspections. Inadequate target factors not only reduce the efficiency of PSC but also enable substandard ships to escape inspections. Therefore, there is an urgent need to assess the NIR to examine the effectiveness of detention decisions and to determine the policy implications of optimizing the NIR's target factors.

3. Methodology

Logistic regression is used widely to deal with situations where observed outcomes for dependent variables are categorical. Binary logistic regression can be applied based on the types and orders of categorical outputs. Binary logistic regression models are widely applied in maritime transportation to solve flag choices, port preferences and choices, vessel management choices, seafarer employment choices, and ship safety [21]. For example, Bergantino and Marlow [22] use a binary logistic regression with flag State choices as the dependent variable and label "national flag" 1 and "non-national flag" 0 to determine the probability of shipowners' flag decisions based on a set of variables. Meanwhile, Tongzon and Sawant [23] apply a binary logistic regression where the dependent variable is shipping line choices coded as 1 for "choose" and 0 for "not choose" to identify the key factors that influence the port choices of shipping lines. To identify the extent of outsourcing in shipping and the key factors that affect the likelihood of outsourcing, Cariou and Wolff [12] use a binary logistic regression in which the dependent variable is vessel management choices coded as 1 for "the same company" and 0 for "others." Moreover, to evaluate the probability of utility of alternatives, Ding and Liang [24] apply a binary logistic regression in which the dependent variable is seafarer employment choices coded as 1 for "national seafarers" and 0 for "non-national seafarers." Other researchers use binary logistic regression models where the dependent variable is ship safety and labeled with 1 for "casualty"/"accident" and 0 for "no casualty"/"no accident" to confirm the conditional probability of ship involvement in maritime casualties [25–28].

In this study, we assess the determinants and risks of ship detention. The detention described as the dependent variable y equals either 0 or 1. The independent variables are marked x_i, which include ship age, ship type, deadweight, flag State performance, classification society performance, port State, and number of deficiencies. The results of binary logistic regression predict the probability of detentions and the ratios of the occurrence of detentions based on the values of the independent variables x_i. The conditional probability of occurrence is described as $P(y=1|x_i)$ and can be formulated as follows:

$$P(y=1|x_i)=\frac{1}{1+e^{-(\beta_0+\sum_{i=1}^{n}\beta_i x_i)}}=\frac{e^{\beta_0+\sum_{i=1}^{n}\beta_i x_i}}{1+e^{\beta_0+\sum_{i=1}^{n}\beta_i x_i}} \tag{1}$$

The probability of a detention not occurring $P(y=0|x_i)$ can be written as.

$$P(y=0|x_i)=\frac{1}{1+e^{\beta_0+\sum_{i=1}^{n}\beta_i x_i}} \tag{2}$$

$\frac{P(y=1|x_i)}{P(y=0|x_i)}$ is defined as the odds used to predict the ratio of occurrence depending on the values of the independent variables x_i. To develop a linear logistic regression model, the logarithm of the odds, called log-odds, is formulated as follows:

$$\ln\left(\frac{P(y=1|x_i)}{P(y=0|x_i)}\right)=\beta_0+\sum_{i=1}^{n}\beta_i x_i \tag{3}$$

As the intercept, β_0 refers to the value of $\ln\left(\frac{P(y=1|x_i)}{P(y=0|x_i)}\right)$ when all $x_i=0$. The log-odds will be explained by n variables of x_i and the parameters β_i and β_0.

4. Empirical analysis

4.1. Data description

The protocol of the PSC is tied directly to maritime safety and the environment; thus, we aim to understand how the efficiency of PSC is improved to maintain maritime safety and prevent environmental pollution. The Tokyo MoU that introduced the NIR in 2014 serves as a good example. In total, 125,259 inspection records with detailed ship information were collected between January 1, 2015, and December 31, 2017. To capture ships' basic information and inspection records, we need to enter "inspection search" into the PSC database (http://www.tokyo-mou.org/inspections_detentions/psc_database.php). Then, we enter "ship search" into the PSC database based on its IMO number to obtain detailed information about each inspected ship. As a result of this heavy workload, we collect big data using Python. In the Tokyo MoU, the NIR lists the inspection requirements for the ships' characteristics and historical inspection records. The NIR prioritizes inspections according to ship type (chemical tanker, gas carrier, oil tanker, bulk carrier, passenger ship, or container ship), ship age (>12 years), performance of flag State (black), and performance of recognized organization (medium). Aside from the above variables, we include deadweight, port State, and number of deficiencies to capture the physical information and current practices. Table 1 shows the distributions of inspections.

From the results shown in Table 2, we can conclude that 69.5% of inspected ships have deficiencies and 2.5% of inspected ships are detained. Deficiency means that a ship's condition was unable to meet the standard of the required conventions. Defective item inspections by the Tokyo MoU covered 17 major items and 565 minor items, mainly related to certification and documentation, structural conditions, water/weathertight conditions, emergency systems, radio communications, cargo operations including equipment, fire safety, lifesaving appliances, alarms, dangerous goods, propulsion and auxiliary machinery, ISM, working and living conditions, safety of navigation, pollution prevention, labor conditions (conditions of employment), and others [29]. According to annual reports, the most frequent detainable deficiencies for 2015–2017 were lifesaving appliances, ISM, fire safety, emergency systems, water/weathertight conditions, and MARPOL Annex I, II, and IV.

The Tokyo MoU includes 20 PSC member authorities. China conducted the most inspections under the Tokyo MoU at 22.2%, followed by Japan at 16.9%, and Australia at 15%. Performances of flag States and recognized organizations play critical roles in PSC. Those indicators show inspection historical records over the preceding three calendar years. The performances of flag States are grouped into white, grey, and black. Most inspected ships flew a flag on the white list; only 8.5% of inspected ships flew a flag on the black list. Meanwhile, the performances of recognized organizations are grouped into medium and high performance. In this study, we use classification society to represent recognized organizations, and 92.1% of the classification societies are in the high-performance group. Among the 24 ship types, the PSC focused on six types of ships that constitute 68.9% of all ships. The inspected percentage of ships that were >12 years old is 37.8%. We divide the constant variable deadweight into five categorical variables; the greatest percentage of deadweight is 1000–10,000 t (32.6%).

4.2. Empirical results

Detention is an intervention taken by the PSC when it deems a ship's condition not appropriate to sail forward under relevant international conventions. According to the inspection procedures, the PSC conducts an initial inspection including checking certificates, documents, and the ship's overall condition. If concerns about a substandard ship arise,

Table 2
Frequency table.

Variables	Classification	Frequency	Percent	Cumulative Percentage
Ship Age	0 (0–5 years)	21129	16.9	16.9
	1 (6–12 years)	56784	45.3	62.2
	2 (13–20 years)	26111	20.8	83.0
	3 (21–30 years)	17471	13.9	97.0
	4 (>30 years)	3764	3.0	100
Deadweight	0 (<1000 t)	1614	1.3	1.3
	1 (1000–10,000 t)	40890	32.6	33.9
	2 (10,000–50,000 t)	36518	29.2	63.1
	3 (50,000–100,000 t)	30896	24.7	87.8
	4 (>100,000 t)	15341	12.2	100
Ship Type	Bulk carrier	46466	37.1	37.1
	General cargo/ multipurpose	27988	22.3	59.4
	Container Ship	20164	16.1	75.5
	Chemical tanker	8203	6.5	82.1
	Oil tanker	7671	6.1	88.2
	Vehicle carrier	3234	2.6	90.8
	Gas carrier	2815	2.2	93.0
	Refrigerated cargo	2677	2.1	95.2
	Woodchip carrier	1015	0.8	96.0
	Passenger ship	973	0.8	96.8
	Tugboat	721	0.6	97.3
	Other special activities	577	0.5	97.8
	Offshore supply	533	0.4	98.2
	Ro-Ro cargo	430	0.3	98.6
	Ro-Ro passenger ship	386	0.3	98.9
	Livestock carrier	350	0.3	99.2
	Special-purpose ship	337	0.3	99.4
	Heavy load	262	0.2	99.6
	NLS tanker	254	0.2	99.8
	Combination carrier	156	0.1	100
	High-speed passenger craft	23	0.0	100
	Fish factory	11	0.0	100
	MODU and FPSO	9	0.0	100
	Commercial yacht	4	0.0	100
Recognized Organization	0 (High)	115367	92.1	92.1
	1 (Unknown)	5393	4.3	96.4
	2 (Medium)	4499	3.6	100
Flag State	0 (White)	107352	85.7	85.7
	1 (Grey/unknown)	7276	5.8	91.5
	2 (Black)	10631	8.5	100
Port State	Australia	18751	15.0	15.0
	Canada	1600	1.3	16.2
	Chile	3904	3.1	19.4
	China	27865	22.2	41.6
	Hong Kong	2480	2.0	43.6
	Indonesia	6660	5.3	48.9
	Japan	21160	16.9	65.8
	Korea	7983	6.4	72.2
	Malaysia	4316	3.4	75.6
	Marshall Islands	80	0.1	75.7
	New Zealand	819	0.7	76.3
	Philippines	9226	7.4	83.7
	Papua New Guinea	618	0.5	84.2
	Russian Federation	6168	4.9	89.1
	Singapore	4097	3.3	92.4
	Thailand	2172	1.7	94.1
	Vietnam	5922	4.7	98.9
	Peru	1354	1.1	99.9
	Vanuatu	5	0.0	99.9
	Fiji	79	0.1	100
No. of Deficiencies	0 (0)	38187	30.5	30.5
	1 (1–5)	66627	53.2	83.7
	2 (6–10)	14234	11.4	95.0
	3 (11–20)	5199	4.2	99.2
	4 (21–30)	742	0.6	99.8
	5 (>30)	270	0.2	100
Detention	0 (No)	122136	97.5	97.5
	1 (Yes)	3123	2.5	100

Resolution A. 1119 (30) requires that the PSC carry out a more detailed inspection and potentially detain the ship [30]. The purpose of detention is to eliminate ships that are hazardous to safety and the environment. Therefore, it is vital to improve the targeting system used to select substandard ships. For the targeting system of the Tokyo MoU (Table 1), we present the following hypotheses.

Hypothesis 1. • *Ships more than 12 years old are more likely to be substandard.*

According to the SRP of the Tokyo MoU, if a ship is more than 12 years old, 1 point will be added to its evaluation score. As Table 1 shows, when the sum of weighting points is greater than 4, the ship is classified as HRS and is more likely to be substandard.

Hypothesis 2. • *Ship type has a significant effect on ship condition (standard or substandard).*

According to the SRP of the Tokyo MoU, if a ship is a chemical tanker, gas carrier, oil tanker, bulk carrier, passenger ship, or container ship, 2 points will be added to its evaluation score. This means that the Tokyo MoU regards ship type as exerting a significant effect on ship conditions.

Hypothesis 3. *Ships whose flag State shows higher performance are more likely to be standard.*

As shown in Table 1, if a ship's flag State is on the Tokyo MoU black list, 1 point will be added to its evaluation score. This means that the Tokyo MoU regards ships from lower-performing (higher-performing) flag States as more likely to be substandard (standard).

Hypothesis 4. Ships whose recognized organization shows higher performance are more likely to be standard.

Similarly, if a ship's recognized organization shows low/very low performance, 1 point will be added into its evaluation score. This means that the Tokyo MoU regards ships from lower-performing (higher-performing) recognized organizations as more likely to be substandard (standard).

Hypothesis 5. Ship size has no significant effect on ship condition (standard or substandard).

As shown in Table 1, the Tokyo MoU does not emphasize ship size such as deadweight. We therefore presume that a ship's size has no significant effect on its condition.

Hypothesis 6. *Ships with over five recorded deficiencies are more likely to be substandard.*

As shown in Table 1, ships that undergo inspections that reveal over five deficiencies will be significantly considered. We therefore presume that ships with over five recorded deficiencies are likely to be substandard.

Hypothesis 7. *There are no discrepancies in the administration of PSC by port States in the Tokyo MoU.*

As shown in Table 1, there is no special information regarding port States. Meanwhile, port States in the Tokyo MoU follow the same NIR. Therefore, we assume that no discrepancies occur in their administration of PSC.

To test the above hypotheses and the determinants and risks of ship detention, we apply the binary logistic regression using SPSS 23.0. In this model, the dependent variable described as y is equal to 0 (no detention) or 1 (detention). Independent variables identified and classified as ordinal include ship age, performance of flag States and recognized organizations, deadweight, and number of deficiencies, whereas those classified as unordered include ship type and port State; all these variables are considered factors in detention decisions. In our model, we select ship age (0–5 year), flag State (white), and recognized organization (high) as reference categories because ships with such characteristics are more likely to be standard. Likewise, we select port State (Australia), deadweight (<1000 t) [31], ship type (bulk carrier), and deficiency (>30) as reference categories because ships with such characteristics are more likely to be substandard. We administered the Omnibus tests of model coefficients to explore the significant differences between blocks of independent variables or their coefficients and the Hosmer–Lemeshow test to explore the goodness of fit for logistic regression models [32]. The results of these two tests reveal that our models are good fits to explain the relationships between the independent and dependent variables.

As the results in Table 3 indicate, ship age, ship type, deadweight, flag State, port State, and number of deficiencies are significantly associated with the probability of detention, whereas the performance of recognized organization is not associated with the probability of detention. We can thus conclude that hypotheses 2 and 3 are valid, whereas hypotheses 4 and 5 are invalid. Hypotheses 1, 6, and 7 are examined further.

Hypothesis 1. *Ships more than 12 years old are more likely to be substandard.*

The relationship between ship age and the probability of detention is significant. The risks of detention for ships aged between 6 and 12 years, between 13 and 20 years, and older than 30 years are 1.228, 1.187, and 1.254 times higher, respectively, than those of ships aged less than 6 years. We can thus conclude that the risk of detention for ships aged between 13 and 20 years is lower than that of ships aged between 6 and 12 years. In other words, according to the empirical results, ships older than 6 years are more likely to be substandard. Therefore, Hypothesis 1 is valid but insufficient.

Hypotheses 6 and 7 can be proved and further explained based on decision-making rules using the C4.5 decision tree algorithm, which is a machine-learning algorithm for classification as introduced in Ref. [33]. This algorithm has been widely used in decision-making analysis, including in both transportation and marine sciences [34,35]. In this study, we apply it to identify the most significant variables and relationships between two or more variables, and further, to predict target variables. This could supplement the binary logistic regression, especially when it comes to revealing multiple factors involved in decision-making rules. Due to the lower probability of detention in practice, only about 2% of observations in the original dataset are labeled as detained, which could cause difficulties in decision tree learning. To overcome this problem, we randomly select the same number of non-detained samples to generate a dataset with ratio 1 of two labels. Using this dataset, we apply fivefold cross-validation to train the decision tree as shown in Fig. 1.

As Fig. 1 shows, the decision tree contains 10 leaf nodes and 9 non-leaf nodes. By following the branch from root node to leaf node, we can determine the decision rule. For example, if an observation satisfies branch b2, we can determine that the non-detention probability of this ship is 85% ((688 − 103)/688). For a specific leaf node, we can determine its hidden rules based on its corresponding branch.

Hypothesis 6. *Ships with over five recorded deficiencies are more likely to be substandard.*

The relationship between the number of deficiencies and the probability of detention is significant. The risks of detention for ships with between 1 and 5, between 6 and 10, and between 11 and 20 deficiencies are 0.021, 0.176, and 0.593 times lower, respectively, than that of ships with more than 30 deficiencies. We can thus conclude that an increase in the number of deficiencies leads to an increase in accident probabilities. Furthermore, the decision tree shows that from the root node to the leaf nodes, the variable *number of deficiencies* plays the most significant role in classification. Ships with five or more deficiencies have a high probability of being detained.

Hypothesis 7. *There are no discrepancies in the administration of PSC by port States in the Tokyo MoU.*

The analysis shows that the inspection place is significantly related to

Table 3
Empirical results on all independent variables and detention.

Independent variables	B	Sig.	Exp(B)	Independent variables	B	Sig.	Exp(B)
Ship Age		0.039*		**Deadweight**		0.003*	
1 (6–12 years)	0.206	0.008*	1.228	1 (1000–10,000)	−0.418	0.005*	0.658
2 (13–20 years)	0.171	0.040*	1.187	2 (10,000–50,000)	−0.246	0.126	0.782
3 (21–30 years)	0.105	0.240	1.110	3 (50,000–100,000)	−0.308	0.069	0.735
4 (>30 years)	0.226	0.042*	1.254	4 (>100,000)	−0.410	0.020*	0.664
Flag State		0.000*		**Recognized Organization**		0.342	
1 (Grey/unknown)	0.412	0.000*	1.510	1 (Unknown)	0.111	0.158	1.117
2 (Black)	0.367	0.000*	1.444	2 (Medium)	0.072	0.342	1.074
Ship Type		0.001*		**Port State**		0.000*	
Woodchip carrier	−0.113	0.671	0.893	Marshall Islands	−1.303	0.039*	0.272
Tugboat	−0.501	0.090	0.606	New Zealand	−1.090	0.000*	0.336
Other special activities	0.142	0.543	1.153	Philippines	−3.517	0.000*	0.030
Offshore supply	0.119	0.700	1.127	Papua New Guinea	−1.277	0.000*	0.279
Ro-Ro cargo	0.534	0.053	1.706	Russian Federation	−2.200	0.000*	0.111
Ro-Ro passenger ship	−2.068	0.000*	0.126	Singapore	−1.263	0.000*	0.283
Livestock carrier	−0.090	0.774	0.914	Thailand	−3.157	0.000*	0.043
Special-purpose ship	0.513	0.124	1.671	Vietnam	−2.222	0.000*	0.108
Heavy load	0.030	0.947	1.030	Peru	−1.771	0.000*	0.170
NLS tanker	0.615	0.135	1.849	Vanuatu	−0.902	1.000	0.406
Container ship	−0.131	0.073	0.877	Canada	−1.152	0.000*	0.316
Combination carrier	−0.559	0.585	0.572	Fiji	−0.376	0.636	0.686
High-speed passenger craft	0.810	0.450	2.247	Chile	−0.897	0.000*	0.408
Fish factory	−18.516	0.999	0.000	China	−0.453	0.000*	0.636
MODU and FPSO	−0.358	0.753	0.699	Hong Kong	−0.917	0.000*	0.400
Commercial yacht	−0.308	1.000	0.735	Indonesia	−0.088	0.434	0.916
Chemical tanker	−0.319	0.009*	0.727	Japan	−1.425	0.000*	0.241
Oil tanker	0.138	0.170	1.148	Korea	−0.383	0.000*	0.682
Gas carrier	0.241	0.171	1.272	Malaysia	−1.518	0.000*	0.219
Passenger ship	−0.770	0.017*	0.463	**No. of Deficiencies**		0.000*	
General cargo/multipurpose	0.027	0.715	1.028	0 (0)	−20.188	0.918	0.000
Vehicle carrier	−0.020	0.918	0.980	1 (1–5)	−3.883	0.000*	0.021
Refrigerated cargo	0.072	0.589	1.074	2 (6–10)	−1.737	0.000*	0.176
Constant	0.088	0.711	1.092	3 (11–20)	−0.523	0.000*	0.593
				4 (21–30)	−0.033	0.845	0.968

Note: B is a partial regression coefficient; S.E. denotes the standard error; Sig. represents the P value of a corresponding value; Exp(B) denotes the odds rate of a corresponding value; * indicates statistical significance at the 5% level.

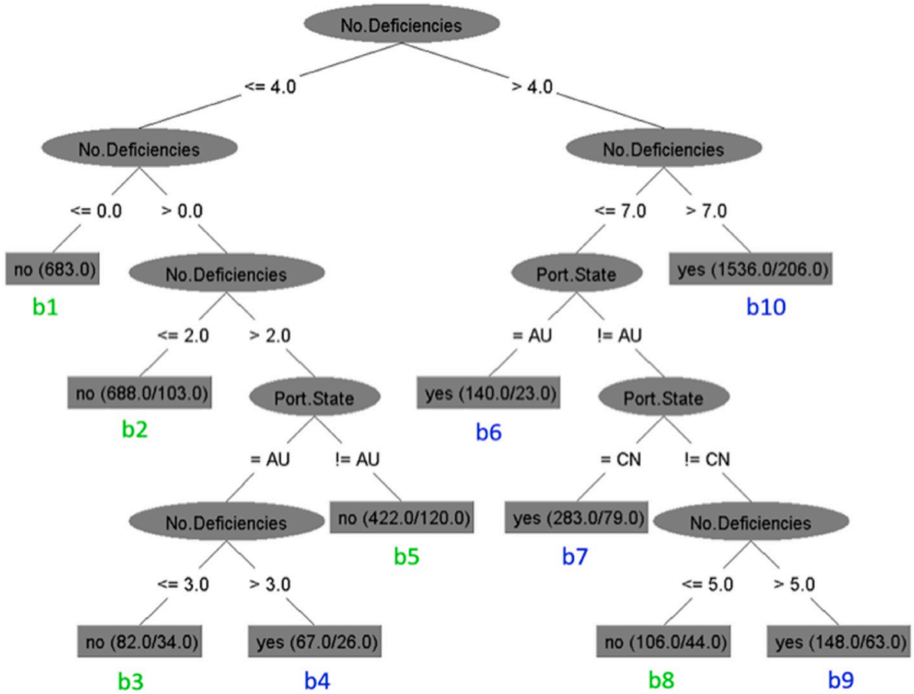

Fig. 1. A decision tree showing the decision-making rules of detention, where the rectangular and ellipse represent the leaf and non-leaf nodes (root node in the top), respectively. The path from top non-leaf node to leaf node is called a branch (bi, i = 1, 2, …, 10)). The number in the leaf node, for example, 688/103 in the leaf node of b2, represents the total number/wrongly assigned number of observations in the training dataset by following the rule of this branch.

the probability of detention. This means that discrepancies occur in the administration of PSC by port States in the Tokyo MoU. More specifically, the detention risk for ships inspected in Australia is higher than in other port States. Moreover, we can rank the detention risks for port States depending on Table 3, especially Sig. and Exp(B) representing the P-value and odds rate of a corresponding value, respectively. Australia ranks first, followed by Korea, China, Chile, Hong Kong, New Zealand, Canada, Singapore, Papua New Guinea, Japan, Malaysia, Peru, Russian Federation, Vietnam, and the Philippines. Furthermore, on the left branches of the root node, we notice that if the number of deficiencies is equal to 4 and the port State is Australia, the ship is more likely to be detained in b4. Otherwise, if the number of deficiencies is between 5 and 7 and the port State is Australia or China, then the ship is more likely to be detained, as suggested by b6 and b7. In sum, Hypothesis 7 is invalid because there are indeed discrepancies between different port States' administration of PSC.

5. Discussion and conclusion

In this study, using 125,259 inspections within the Tokyo MoU from January 1, 2015, to December 31, 2017, we analyze the determinants of the risk of ship detention by applying both a binary logistic regression and a decision tree to evaluate the effectiveness of the NIR.

The completed empirical exercise enables us to make sense of the NIR and better understand why certain processes and indicators are in place. The NIR target factors including ship age, ship type, performance of flag State, and number of deficiencies significantly impact detention and must be closely monitored. Importantly, compared with ships aged between 13 and 20 years, ships aged between 6 and 12 years seem more likely to be substandard. Meanwhile, ships with five or more recorded deficiencies have a high probability of being detained.

Moreover, ship inspections conducted by different members in the Tokyo MoU result in different detention risks. In other words, both the binary logistic regression and decision tree demonstrate that discrepancies exist in the administration of the PSC by port States in the Tokyo MoU. Specifically, based on the binary logistic regression, Australia ranks first in detention risk, followed by Korea, China, Chile, Hong Kong, New Zealand, Canada, Singapore, Papua New Guinea, Japan, Malaysia, Peru, Russian Federation, Vietnam, and the Philippines. Similarly, based on the decision tree, ships are more likely to be detained when the PSC is administered by Australia. These discrepancies among members are likely caused by the following: (1) discrepancies in manpower, financial resources, and technology; (2) unequal participation of members in the same MoU [36]; and (3) team composition and the backgrounds and numbers of PSCOs [13,37,38]. If the discrepancies among members of the Tokyo MoU still exist, varying risks across countries may occur for risk mitigation; however, this is bad for shipowners because they may not fully understand what to look forward to. Therefore, Tokyo MoU should adopt effective measures to reduce discrepancies among members, for example, Australia offered to provide assistance for PSC training to member countries of the Association of Southeast Asian Nation [39].

CRediT authorship contribution statement

Yi Xiao: Formal analysis, Writing - original draft. **Grace Wang:** Writing - review & editing, Supervision. **Kun-Chin Lin:** Funding acquisition, Writing - review & editing. **Guanqiu Qi:** Funding acquisition, Writing - review & editing. **Kevin X. Li:** Conceptualization, Writing - review & editing, Supervision, Funding acquisition.

Acknowledgments

This study is supported in part by the Korea Foundation (RG94770) and Zhejiang University Education Foundation Global Partnership Fund.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2020.103857.

References

[1] IMO, Resolution A. 787(19)-Procedures for Port State Control (accessed 29 November 2018), http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Assembly/Documents/A.787(19).pdf, 1995.
[2] C. Soldatou, Port State Control Inspections. R.N. 3493 (accessed 29 November 2018), https://maredu.gunet.gr/modules/document/file.php/MAK265/Dissertations%20in%20English/Port%20State%20control%20inspections.pdf, 2017.
[3] Caribbean MoU, Caribbean Memorandum of Understanding on Port State Control (accessed 7 January 2018), http://www.caribbeanmou.org/sites/default/files/Approved_MOU_Rev_7_Jan_2018.pdf, 2018.
[4] Tokyo MoU, Memorandum of Understanding on Port State Control in the Asia-Pacific Region (accessed 30 December 2018), http://www.tokyo-mou.org/doc/Memorandum%20rev18.pdf, 2018.
[5] Australian Maritime Safety Authority (AMSA), Ship Inspection Decision Support System (SIDSS) and Related Strategies (accessed 06 October 2019), http://www.finance.gov.au/archive/comcover/docs/2004AMSA.rtf, 2004.
[6] P. Cariou, M.Q. Mejia Jr., F.C. Wolff, On the effectiveness of port State control inspections, Transport. Res. E Logist. Transport. Rev. 44 (3) (2008) 491–503, https://doi.org/10.1016/j.tre.2006.11.005.
[7] P. Cariou, M.Q. Mejia Jr., F.C. Wolff, An econometric analysis of deficiencies noted in port State control inspections, Marit. Pol. Manag. 34 (3) (2007) 243–258, https://doi.org/10.1080/03088830701343047.
[8] P. Cariou, M.Q. Mejia, F.C. Wolff, Evidence on target factors used for port State control inspections, Mar. Pol. 33 (5) (2009) 847–859, https://doi.org/10.1016/j.marpol.2009.03.004.
[9] K.X. Li, H. Zheng, Enforcement of law by the port state control (PSC), Marit. Pol. Manag. 35 (1) (2008) 61–71, https://doi.org/10.1080/03088830701848912.
[10] S. Knapp, P.H. Franses, A global view on port State control: econometric analysis of the differences across port State control regimes, Marit. Pol. Manag. 34 (5) (2007) 453–482, https://doi.org/10.1080/03088830701585217.
[11] L. Fan, M. Luo, J. Yin, Flag choice and Port State Control inspections—empirical evidence using a simultaneous model, Transport Pol. 35 (2014) 350–357, https://doi.org/10.1016/j.tranpol.2014.04.008.
[12] P. Cariou, F.-C. Wolff, Do Port State Control inspections influence flag-and class-hopping phenomena in shipping? J. Transport Econ. Pol. 45 (2) (2011) 155–177. https://hal.archives-ouvertes.fr/hal-00455155.
[13] S. Knapp, P.H. Franses, Econometric analysis on the effect of port State control inspections on the probability of casualty: can targeting of substandard ships for inspections be improved? Mar. Pol. 31 (4) (2007) 550–563, https://doi.org/10.1016/j.marpol.2006.11.004.
[14] C. Heij, G.E. Bijwaard, S. Knapp, Ship inspection strategies: effects on maritime safety and environmental protection, Transport. Res. Transport Environ. 16 (1) (2011) 42–48, https://doi.org/10.1016/j.trd.2010.07.006.
[15] Z. Chi, S. Jun, Automatically optimized and self-evolutional ship targeting system for port State control. Systems Man and Cybernetics (SMC). IEEE International Conference on 2010, IEEE, 2010, pp. 791–795, https://doi.org/10.1109/ICSMC.2010.5641853.
[16] F.J. Ravira, F. Piniella, Evaluating the impact of PSC inspectors' professional profile: a case study of the Spanish Maritime Administration, WMU Journal of Maritime Affairs 15 (2) (2016) 221–236, https://doi.org/10.1007/s13437-015-0096-y.
[17] A. Graziano, J.U. Schröder-Hinrichs, A.I. Ölcer, After 40 years of regional and coordinated ship safety inspections: destination reached or new point of departure? Ocean. Eng. 143 (2017) 217–226, https://doi.org/10.1016/j.oceaneng.2017.06.050.
[18] J. Wu, Y. Jin, J. Fu, Effectiveness evaluation on fire drills for emergency and PSC inspections on board, TransNav, Int. J. on Marine Navigation and Safety of Sea Transportation 8 (2014) 229–236, https://doi.org/10.12716/1001.08.02.08.
[19] E.G. Emecen Kara, Risk assessment in the istanbul strait using Black Sea MoU port state control inspections, Sustainability 8 (4) (2016) 390, https://doi.org/10.3390/su8040390.
[20] J. Chen, S. Zhang, L. Xu, Z. Wan, Y. Fei, T. Zheng, Identification of key factors of ship detention under Port State Control, Mar. Pol. 102 (2019) 21–27, https://doi.org/10.1016/j.marpol.2018.12.020.
[21] W. Shi, K.X. Li, Themes and Tools of Maritime Transport Research during 2000–2014, Marit. Pol. Manag. 44 (2) (2017) 151–169, https://doi.org/10.1080/03088839.2016.1274833.
[22] A. Bergantino, P. Marlow, Factors influencing the choice of flag: empirical evidence, Marit. Pol. Manag. 25 (2) (1998) 157–174, https://doi.org/10.1080/03088839800000026.
[23] J.L. Tongzon, L. Sawant, Port choice in a competitive environment: from the shipping lines' perspective, Appl. Econ. 39 (4) (2007) 477–492, https://doi.org/10.1080/00036840500438871.
[24] J.F. Ding, G.S. Liang, The choices of employing seafarers for the national shipowners in Taiwan: an empirical study 32, Maritime Policy & Management, 2005, pp. 123–137, https://doi.org/10.1080/09523980500062643, 2.
[25] S. Knapp, P.H. Franses, Econometric analysis to differentiate effects of various ship safety inspections, Mar. Pol. 32 (4) (2008) 653–662, https://doi.org/10.1016/j.marpol.2007.11.006.
[26] K.X. Li, J. Yin, H.S. Bang, Z. Yang, J. Wang, Bayesian network with quantitative input for maritime risk analysis, Transportmetrica: Transport. Sci. 10 (2) (2014) 89–118, https://doi.org/10.1080/18128602.2012.675527.
[27] K.X. Li, J. Yin, L. Fan, Ship safety index, Transport. Res. Pol. Pract. 66 (2014) 75–87, https://doi.org/10.1016/j.tra.2014.04.016.
[28] J. Weng, D. Yang, Investigation of shipping accident injury severity and mortality, Accid. Anal. Prev. 76 (2015) 92–101, https://doi.org/10.1016/j.aap.2015.01.002.
[29] Tokyo MoU, List of Tokyo MoU Deficiency Codes (accessed 12 January, 2019), http://www.tokyo-mou.org/publications/tokyo_mou_deficiency_codes.php, 2012.
[30] IMO, Procedures for port State control, Resolution A 1119 (30) (2017) (accessed 20 December 2018), http://www.classnk.or.jp/hp/pdf/activities/statutory/ism/imo/imo_a1119-30.pdf.
[31] M. Jin, W. Shi, K.F. Yuen, Y. Xiao, K.X. Li, Oil tanker risks on the marine environment: an empirical study and policy implications, Mar. Pol. 108 (2019) 103655, https://doi.org/10.1016/j.marpol.2019.103655.
[32] A. Field, Discovering Statistics Using SPSS, third ed., SAGE, 2009.
[33] J.R. Quinlan, C4. 5: Programs for Machine Learning, Elsevier, 2014.
[34] X. Du, Z. Feng, A new data-driven design methodology for mechanical systems with high dimensional design variables, Adv. Eng. Software 117 (2018) 18–28, https://doi.org/10.1016/j.advengsoft.2017.12.006.
[35] J. Smith, A. Metaxas, A decision tree that can address connectivity in the design of Marine Protected Area Networks (MPAn), Mar. Pol. 88 (2018) 269–278, https://doi.org/10.1016/j.marpol.2017.11.034.
[36] D. Anderson, The effect of port state control on substandard shipping, Maritime Studies 125 (2002) 20–25, https://doi.org/10.1080/07266472.2002.10878678.
[37] A. Graziano, P. Cariou, F.C. Wolff, M.Q. Mejia Jr., J.U. Schröder-Hinrichs, Port state control inspections in the European Union: do inspector's number and background matter? Mar. Pol. 88 (2018) 230–241.
[38] F.J. Ravira, F. Piniella, Evaluating the impact of PSC inspectors' professional profile: a case study of the Spanish Maritime Administration, WMU J. Marit. Aff. (2016) 1–16, https://doi.org/10.1007/s13437-015-0096-y.
[39] Tokyo MoU, Annual report on port state control in the Asia-pacific region (accessed 19 June 2019), http://www.tokyo-mou.org/doc/Memorandum%20rev18.pdf, 2018.