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Comparative analysis of the impact of new inspection regime on port state control inspection

Comparative Analysis of the Impact of New Inspection Regime on Port State Control Inspection

Zhisen Yang, Zaili Yang, Ângelo Palos Teixeira

Abstract

As an administrative measure to ensure maritime safety, Port State Control inspections are implemented and regarded as an important line of defence in coping with potential maritime accidents. To reinforce its role, a New Inspection Regime (NIR) was developed and put into practice by Paris MoU in 2011. It is widely recognised that the implementation of NIR has transformed and modernized the PSC inspection system in the Paris MoU region, as well as stimulated the quality of shipping. In this paper, the influence of the implementation of NIR on the PSC inspection system and vessel quality is revealed for the first time. Based on inspection data and records collected from the Paris MoU online database, a comparative analysis between the 'Pre-NIR' (time before the implementation of NIR) and 'Post-NIR' (time after the implementation of NIR) periods is conducted from two perspectives. A macroscopic approach is first adopted to characterise the overall changes in inspection results and inspected vessels' quality through a statistical analysis of extrinsic Key Performance Indicators (KPIs) such as detention rate and deficiency rate. Then, a microscopic analysis is conducted to assess the influence of the NIR on intrinsic attributes of the vessels and of the inspection results based on Bayesian Network models derived from Pre and Post-NIR periods. The findings of this research systematically reveal the aspects from which the NIR improves the PSC inspection system, vessel quality and maritime safety. It will generate significant impact on and contribution to the promotion and stimulation of the adoption of NIR in more ports and regions to improve safety at sea in the whole world.

Key words: Port State Control, New Inspection Regime, Bayesian network, maritime safety

1. INTRODUCTION

Port state control (PSC) is an internationally agreed regime for the inspection of foreign-registered ships in port other than those of the flag state to verify that the condition of a vessel and its equipment complies with the requirements of international regulations. The original intention is to prevent shipping accidents and other risks from occurring in their legal waters.

In recent years, it is regarded as an important line of defence in dealing with sub-standard vessels.

To improve the PSC inspection system, the much-anticipated NIR was finally launched on January 1st, 2011, after many years of preparation. It was viewed as the most significant change that transforms and modernises the PSC system in recent years according to the Paris MoU annual report. Compared to the old system that was based on the agreement from 30 years ago, NIR introduced a radical change. The change was necessary to bring the Paris MoU in line again with global maritime developments, introduction of new IMO instruments and a better-balanced method of targeting and inspection of ships. The main objective during the development has been to reward quality shipping and to intensify control and sanctions on ships with poor performance.

The new regime introduces a major departure from the "25% inspection commitment" and 6-month inspection intervals, which overburdened the shipping industry and PSC authorities with inspections. When the criteria are met, quality ships will be rewarded with a "low risk ship" status and the inspection interval may increase up to 36 months. Even "standard risk ships" benefit from the new system extending inspection intervals to up to 12 months. New to the system is that companies are now also monitored for performance, based on the inspection history of their ships. Paris MoU establishes a shipping company performance formula that takes into account detention and deficiency records of the vessels under the company's management over a period of 36 months. Based on the deficiency and detention rates, the performance of International Shipping Management (ISM) companies is classified into groups of four grades: high, medium, low and very low. A list of 'ISM managers' of poor performance has been developed, consisting of the ISM companies who have shown an unwillingness or inability to comply with the international conventions on maritime safety and/or on the protection of marine environment.

To balance the system, more resources will be directed to ships with poor safety records, the "high risk ships". These ships are subject to mandatory expanded inspections every 6 months when they call at a Paris MoU port. A complex system of risk calculations, targeting and recording of inspections is supported by the new database "THETIS", hosted and managed by the European Maritime Safety Agency (EMSA) in Lisbon. Results of inspections, currently detained and banned ships are now displayed directly from THETIS on the Paris MoU web site.

It should be understood that substandard ships would no longer be tolerated in the region and with the new refusal of access measures in place, repeated offenders will be “banned” from Paris MoU ports. This has happened to a substantial number of vessels already, some of which have been recycled in the meantime. Others choose to find new areas to operate, endangering the lives of the seafarers on board and constituting a risk to the environment.

As a risk-based targeting mechanism, NIR rewards quality shipping with a reduced inspection burden and concentrates efforts on high-risk vessels. Making use of not only the performance of the flag State and of the Recognized Organization (RO), but also the performance of the ISM Company for calculating the ship risk profile, the NIR is expected to be a comprehensive regime ensuring the maritime safety and preventing illegal actions of ship owners. However, as a so-called ‘most significant change in Paris MoU history’, there is few research focusing on the influence brought by the implementation of NIR, making it unclear whether the introduction of NIR has generated any significant influence on both inspection system and maritime safety. Therefore, quantifying the influence of NIR consists of a gap that needs to be addressed in this field.

This study aims at conducting a comparative analysis based on a statistical method and dynamic BN models to provide a comprehensive understanding of the impact of the NIR on the Paris PSC inspection system, vessel quality and maritime safety. Based on the annual reports of the Paris MoU in recent decades, the extrinsic Key Performance Indicators (KPIs) in PSC inspections are selected to aid the analysis from a macroscopic perspective. Additionally, two Bayesian Network (BN) risk models developed through over 100,000 primary historical inspection records in the past decade provide a novel way to clarify the influence of intrinsic parameters microscopically. Through analysing the change of these parameters related to inspection results and vessel quality, the actual positive influence of NIR on improving inspection system robustness, vessel quality and maritime safety is finally revealed for rationalising PSC policy making in other regions.

The main contributions of this paper include: 1) since NIR went into effect in 2011, its influence is for the first time, clarified through a scientific research. 2) BN models are utilised as an effective approach to quantify the variations of some intrinsic parameters which is not possible to analyse by a traditional way. 3) the managerial insights about the influence brought by the NIR are obtained to guide its wide-scope implementation, macroscopically and microscopically. For instance, the detention rate after the implementation of NIR is lower and more stable compared to the period before NIR; the burden of ship owners is reduced; the cost and resources of port authorities spent on inspections are also reduced; and Paris MoU enables

to reward vessels with high or medium performance level shipping companies. 4) the research work conducted highlights the significance of NIR in a comprehensive and scientific way, which is helpful for the promotion and popularization of NIR around the world, as well as provides Paris MoU with advices on the aspects that need further improvement in the future.

The remainder of this paper is organised as follows. Section 2 reviews the current literature on the PSC system, and on the implementation and influence of NIR. Section 3 presents the change brought by NIR from a macroscopic perspective. It is followed by a microscopic comparative analysis based on two BN models of different periods in section 4. Finally, Section 5 concludes this study with reference to its scientific and practical contributions, limitations and future research agenda.

2. LITERATURE REVIEW

Since PSC inspections play an increasingly important role in maritime safety, more and more research works have been conducted from both qualitative and quantitative perspectives, as evidenced by the increasing number of the relevant papers in recent decades. Various approaches have been developed and applied to analyse PSC inspections, demonstrating the diversity and high demand of this research field.

Kasoulides (1993) stressed how flag state enforcement has diminished in the face of the proliferation of open registries and why coastal states have reacted by asserting their rights through the resultant regime of PSC at the regional level. Similarly, Bell (1993) analysed the nature of flag and port state control in the UK. A comparison between two inspection forms indicated that the effectiveness of PSC needs to be improved not only in the UK, but also in Europe, and even throughout the world. Based on the view from practice, Kiehne (1996) focused on the sanctions available to PSC authorities in respect of the foreign ships being inspected, ranging from instructions to rectify deficiencies (i.e., with immediate effect before departure, within two weeks, or at the next port of call) to outright detention. The sanctions that port authorities have should help eliminate the operation of substandard vessels in the ports of Europe. In 2001, Özçayır (2001) reviewed the practice of PSC in different jurisdictions and pointed out the issues existing in the practice of European PSC, such as the pivotal role of the ISM Code and the function of classification societies. Chiu et al. (2008) investigated the implementation of the PSC system in Taiwan and further discussed some in-depth issues about the system including the difficulties of the implementation and the inadequacies of the system.

Similar research works have been conducted by Chang (2001), Chiu & Chiou (2005) and Chiou (2006).

Payoyo (1994) assessed the PSC regime by analysing inspection statistics generated by the Paris MoU from 1982 to 1992. Although substandard vessels still posed a threat to maritime safety, the inspection regime achieved several significant accomplishments such as the collection of baseline data on substandard ships in the region, increased effectiveness in the enforcement of international standards, and closer regional cooperation resulting in the more efficient employment of maritime safety enforcement resources. This conclusion was in line with the work conducted by Mejia (2005). As one of the first contributions on the assessment of the effectiveness of PSC, Owen (1996) described the practice of PSC in the Paris MoU in detail and discussed the limitations inherent in the PSC regime connected with the fact that the port state has no direct influence over the design and construction of vessels that are being inspected. One year later, Hare (1997) showed how the proliferation of regional MoUs has significantly diminished the potential for substandard ships in international shipping. In 2000, McDorman (2000) examined the contribution of regional PSC agreements and harmonized inspection procedures, and then pointed out that the playing field among different ports has been improved.

When entering the 21st century, the studies related to PSC were restricted to not only qualitative analysis, but also quantitative analysis. However, the application of quantitative risk approaches to PSC was limited to risk diagnosis, waiting for new solutions on real time risk prediction to be explored.

Shen & Chen (2003) and Yang (2004) both proposed risk assessment PSC systems, which had been proved to have better performance than traditional PSC inspection mechanisms. Knowing that intense maritime traffic may cause significant navigational challenges in the Istanbul Strait, Kara (2016) applied a weighted point method to assess the risk level of each vessel experiencing the PSC inspection under Black Sea MoU. However, the weighting and scoring methods adopted in these studies are in large part based on subjective expert judgements, which causes the concern of subjective bias on the results obtained.

Avoiding subjectivity in weighting has been extensively studied in this research field. Xu et al. (2007) presented a risk assessment system based on support vector machine to estimate the risk of candidate vessels according to historical data before conducting on-board inspections. Evaluations showed that the proposed system could improve the accuracy of risk assessment. Furthermore, Gao et al. (2008) combined support vector machine and K-nearest neighbour

approaches to develop a new risk assessment model capable of coping with noisy data. Consequently, this method significantly improved the accuracy of the results. Although showing attractiveness, such methods still reveal problems in their practical applications in tackling dynamic risk prediction (e.g. ship detention probability) in different environments. This problem hinders the practical contribution of risk assessment approaches in PSC inspections. To solve this issue, Yang et al. (2018) pioneered the development of a BN framework to create a detention rate prediction tool for port authorities. The advantages of BN over other approaches in dynamic prediction is that it provides important insights to seek the optimal inspection policies under different environments in NIR. However, Yang et al. (2018) only addressed risk analysis and have not conducted further studies on how the dynamic risk results can lead to the optimization of inspection policy making of port authorities in PSC.

Cariou et al (2008) used 4,080 observations collected from the Swedish maritime administration database from 1996 to 2001 to build Poisson models to test the effectiveness of PSC. The estimation showed that some vessels' characteristics (e.g. vessel age, vessel type, vessel flag) have significant influence on the number of deficiencies detected during PSC and length of time between two successive PSC inspections. Subsequently, the analysis also pointed out that following a PSC inspection, the reported deficiencies during the next inspection are reduced by 63%, demonstrating the effectiveness of PSC in controlling vessel safety.

Based on 183,819 PSC inspection records, Knapp & Franses (2007) applied binary logistic regression to measure the effect of inspections on the probability of casualties, especially for very serious cases. Meanwhile, the model determined the magnitude of improvable areas for substandard vessels. Later in the same year, they did a further econometric analysis about the influence on the detention probability of different risk factors, and the results revealed that only vessel types and PSC regimes were influential elements. Knapp & Franses (2007) incorporated quantitative risk analysis to ship inspection to improve its effectiveness. The study disclosed that the age of the vessel, ship type, and flag of registry appear to be significant predictors.

In 2014, Li et al. (2014) built a bi-matrix game between the port authorities and ship operators in PSC inspection to decide on the optimal inspection policy aiming at saving the costs on inspection whilst keeping deterrence pressure on potential wrongdoers. Through a numerical case study, it is shown that the optimal inspection rate obtained from the model can yield a significant saving, as well as prevent potential violations by ship operators.

In general, the research on PSC inspections has developed towards a diverse and popular academic research field. More approaches, either qualitative or quantitative, have been applied to a broader range of topics, showing that PSC inspection is still exposed to some challenges, attracting growing attention.

However, when searching the literature from various sources (e.g. Web of Science, Google Scholar), there is only little research focusing on the implementation of NIR in PSC inspection or the analysis of the influence brought by NIR on PSC inspection system and maritime safety (e.g. Rodríguez & Piniella, 2012; Piniella et al., 2014). In other words, the relevant PSC studies involving NIR have yet been explored in full. Since the Paris MoU propagated that the introduction of NIR is the most important change in PSC history, it is beneficial to assess the influence brought by NIR to provide experimental evidence on the rational implementation of NIR. As a supplement to this research field, this study will focus on completing this research gap based on a mixed comparative analysis method. Furthermore, to the authors' best knowledge, no relevant studies had ever been undertaken to investigate how the valuable influence of NIR can facilitate the policy transfer from Paris MoU to other regions in the world.

3. MACROSCOPIC COMPARATIVE ANALYSIS

The process of conducting macroscopic comparative analysis consists of three essential steps: 1) collecting the relevant data from Paris MoU; 2) determining the KPIs analysed for this research; 3) analysing the difference between the Pre and Post-NIR periods. Specifically, the facts and figures of overall inspection situations from 2005 to 2016 in Paris MoU are summarized from its annual reports, laying a solid foundation of the subsequent analysis. Accordingly, the KPIs identified from the annual reports and used for analysis are number of inspections, number of inspected vessels, number of deficiencies, number of detainable deficiencies, number of detentions, and refusal access of vessels. Each KPI corresponds to an important aspect estimating the overall quality and safety condition of inspected vessels, as well as reflecting the efficiency of the inspection system under the NIR. The analysis of these KPIs are conducted from two perspectives: one is the general analysis of the whole inspection system, while the other is the detailed analysis of different vessel types. It is essential to understanding the changes from these aspects for clarifying the macroscopic influence introduced by NIR on the PSC inspection system.

3.1 General analysis

3.1.1 Facts and Figures

To start the analysis, the facts and statistics of PSC inspections conducted within Paris MoU region are presented in a chronological order from 2005 to 2018, which are derived from the Paris MoU online inspection database (www.parismou.org). A careful analysis of the original data indicates that particular indicators can be selected as KPIs because they are the most important indicators representing the PSC inspection system, as stated in Paris MoU official statements. These KPIs include the number of inspections, the individual vessels inspected, the number of deficiencies, the detainable deficiencies, the number of detentions, and the number of access refusals. Since the implementation of NIR, most ports in Paris MoU have raised their inspection policies to adapt to the NIR, bringing the transformation of the whole system. Hence, it is not difficult to understand that the analysis on the changes of these KPIs provides a means for characterising the influence of the implementation of NIR on the PSC Inspection system.

Table 1 lists these KPI values derived from the Paris MoU annual reports in 2005-2018. Due to the unavailability of data, the detainable deficiencies in 2005 and 2006 are not provided.

Table 1 Facts of PSC inspection from 2015 to 2016

Year	Inspections	Individual vessels	Deficiencies	Detainable deficiencies	Detentions	Refusal of access to ships
2018	17952	15301	40368	3171	566	24
2017	17923	15356	41125	3883	693	32
2016	17845	15237	42131	3896	687	21
2015	17878	15255	41820	3541	611	11
2014	18477	15386	46224	3155	623	21
2013	17687	14108	49074	3231	668	29
2012	18308	14646	49261	2882	669	14
2011	19058	15268	50738	3080	688	20
2010	24058	14762	64698	3866	790	6
2009	24186	14753	71911	5451	1059	13
2008	24647	15237	83751	6280	1220	19
2007	22877	14182	74713	6434	1250	14
2006	21566	13417	66142	-	1174	14
2005	21302	13024	62434	-	994	28

(Source: Paris MoU)

One thing to notice is that the cut-off date for inspection data to be included in the Annual Report is Feb 19th each year. Changes to inspection data after this date have as a rule not been taken into account. Due to PSCC50 decision, the Annual Report data will, from now on, include the current annual year and all amended data in previous years back to 3 calendar years.

Some explanations of these KPIs:

1) Deficiencies: one or more deficiencies identified by the PSC inspector during an inspection, written in the PSC inspection report;

2) Detainable deficiencies: A deficiency that is serious enough that it should be rectified before departure and reviewed by the port state control officer (PSCO) before the ship may continue its voyage (the list of detainable deficiencies can be found on the Paris MoU website);

3) Detention: the judgment of PSCO to keep the vessel in port until the deficiencies are rectified based on the inspected deficiencies;

4) Refusal access (Banning): A ban is a measure imposed on an individual ship. It means the vessel will be no longer allowed to access the ports within Paris MoU.

It is worth noting that some of the statistics in Table 1, such as the number of deficiencies and the number of inspections, may not be suitable to use for analysis directly. The NIR entered into force on the 1st of January 2011. Consequently, the targeted ships for inspection have changed; inspection and deficiency data from 2011 onwards should not be compared to the ones from 2010 and before directly. In other words, the decline in the number of deficiencies and inspections does not mean the improvement of PSC inspection system. Hence, in order to make the research conclusions rational, actions are taken to generate the new parameters used in the present analysis (shown below Table 2), which are normalised by the number of inspections or vessels, as shown in Table 2. Each new parameter is given a code Ki (i =1~6).

Table 2 Results of inspection-related rates in 2005-2018

Year	K1: Deficiency per inspection	K2: Average inspections per vessel per year	K3: Detainable deficiencies per inspection	K4: Detainable deficiency rate (%)	K5: Detention rate (%)	K6: Refusal rate (%)
2018	2.249	1.173	0.177	7.855	3.15	0.134
2017	2.295	1.167	0.217	9.442	3.87	0.179
2016	2.361	1.171	0.218	9.247	3.85	0.118
2015	2.339	1.172	0.198	8.467	3.42	0.062
2014	2.502	1.201	0.171	6.825	3.37	0.114
2013	2.775	1.254	0.183	6.584	3.78	0.164
2012	2.691	1.250	0.157	5.850	3.65	0.076
2011	2.662	1.248	0.162	6.070	3.61	0.105
2010	2.689	1.630	0.161	5.975	3.28	0.025
2009	2.973	1.639	0.225	7.580	4.38	0.054
2008	3.398	1.618	0.255	7.498	4.95	0.077
2007	3.266	1.613	0.281	8.612	5.46	0.061
2006	3.067	1.607	/	/	5.44	0.065
2005	2.931	1.636	/	/	4.67	0.131

(Source: Author)

1) deficiency per inspection = number of deficiencies/number of inspections

2) average inspections per vessel per year = number of inspections/numbers of individual vessels

3) detainable deficiencies per inspection = number of detainable deficiencies/number of inspections

4) detainable deficiency rate = number of detainable deficiencies/number of deficiencies

5) detention rate = number of detentions/number of inspections

6) refusal rate = number of refusal access/number of inspections

3.1.2 Change in K5 (Detention rate)

As the most important and typical indicator, detention rate is the barometer used to test the effect and influence of the implemented policies related to PSC, and NIR is not an exception. Figure 1 illustrates the trend of the detention rate from 2005 to 2018, covering both the 'Pre-NIR' and 'Post-NIR' periods, for the convenience of the comparative analysis.

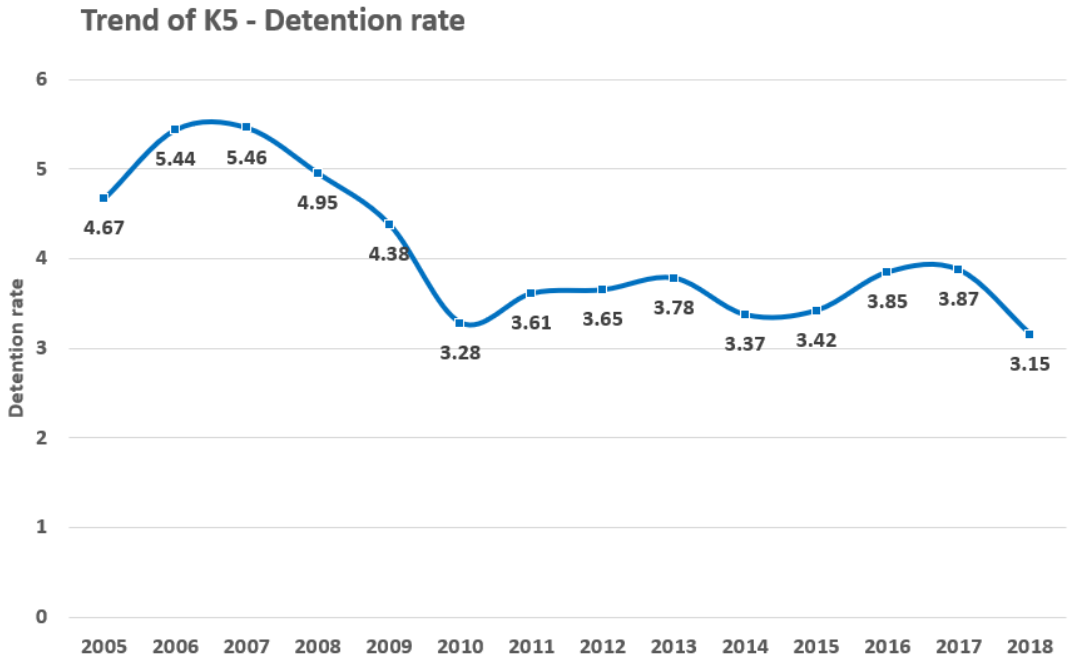

Figure 1 Variation of Paris MoU PSC detention rate from 2005 to 2018

The conclusions derived from such an analysis prove that the implementation of NIR is significant in terms of improving the PSC inspection system. The following observations can be drawn from the detention rate variation:

1) Overall, the detention rate after 2011 is lower and more stable compared to the period before NIR.

Although in 2010, the detention rate declined sharply and reached the second lowest point in the past decade, the overall detention rate before and after the implementation NIR is widely different. The average detention rate from 2005 to 2010 is 6487/138636=4.68%, while the one in the period of 2011-2018 is 3.59%, which corresponds to a decrease of 23.34% (i.e. (4.68%-3.59%)/4.68%) after the implementation of NIR. It is obvious that the introduction of NIR significantly improved the operation of the PSC inspection system and stimulated the ship owners to invest more on the maintenance of the quality of their vessels.

Meanwhile, the fluctuation magnitude of the detention rate after 2011 is less than 0.5%, much lower than the rate of 2.2% in 2005-2010, indicating the PSC inspection system is currently running healthy and stable.

2) In 2010, the last year before the implementation of NIR, the detention rate dropped to 3.28%, the second lowest point until now.

Although it had not been put into practice at this time, the new regime was put forward in 2009 and was formally adopted this year in the 43rd session of the PSC Committee in Dublin. It is likely that some shipowners understanding the introduction of the NIR in 2011, have proactively moved their substandard ships to other trading areas (Paris MoU annual report 2010). Therefore, it is not surprising to see that many indicators in this year dropped to a relatively low level, not only detention, but also other KPIs analysed below.

3) After the implementation of NIR, the detention rate initially exhibits an increasing trend, and then the trend has been reversed temporally in 2014 and 2015; after two years (2016, 2017) growth, 2018 witnessed a huge drop of detention rate reaching the lowest point in the past decade.

In general, the trend of detention rate consists of four stages: growth stage (2011-2013), decline stage (2014-2015), growth stage (2016-2017), decline stage (2018-now).

Growth stage 2011-2013: the initial phase after the implementation of NIR witnessed a slight increase of detention rate. This can be explained since the focus of NIR targeting is on vessels with a higher priority. It takes time for both the ship owners and port authorities to get used to the radical changes on the inspection system. Therefore, it is inevitable that the corresponding detention rate increased in the period.

Decline stage 2014-2015: After an initially increasing detention rate, the trend has been reversed in 2014. This is mainly because after three years efforts, a large number of sub-standard vessels have been banned from the region after multiple detentions during this period. Many of them have been recycled after having lost their trading area. Some have been moved to other areas in the world where NIR was yet introduced.

Growth stage 2016-2017: the detention rate reached its highest value in this period. Two reasons contribute to this phenomenon: first, ship owners and shipping companies explored the weak part of Paris MoU inspection system, which is the southern part of the Paris MoU region. They made deliberate choices to operate substandard ships in the area because the risk of being detained and rectifying deficiencies outweigh the costs of running a “bonafide operation”;

second, under the rising economic pressures, ship owners may choose to cut corners in areas where this is possible, in order to reduce the operating costs of their ships and to remain competitive. Although Paris MoU adopted multiple measures to get through these difficulties, the detention rate still reached a peak point.

Decline stage (2018-now): last year the economic environment had a huge turnaround, serving as the major contributor to the huge decline of detention rate. Additionally, the Paris MoU Committee adopted more measures and took decisions to further improve the NIR, for example, the cooperation with other regional agreements was hugely strengthened to restrict the sub-standard vessels around the world. As a result, the detention rate reached the all-time low point in the past decades.

4) It is believed that the detention rate will continue to drop in the future, or at least maintain the same level as 2018.

The conclusion could be reached from the following aspects: First, after several years of improvement and effort (i.e. training in cooperation with EMSA, Concentrated Inspection Campaigns), a fairly completed form of NIR has been developed in these two years, according to the reports and statements of Paris MoU. Second, the gradually increasing punishment on substandard vessels within the Paris MoU region improves the overall inspected vessel quality to some extent. Third, the huge decline in 2018 is a positive signal that sub-standard vessels are getting harder and harder to survive within the Paris MoU region. Additionally, the analysis of detention rate, in various forms including exponential form, logarithmic form, or polynomial form, indicates the detention rate keeps a declining momentum in general since the implementation of NIR.

Overall, the analysis of the detention rate shows that vessel quality has been improved because of the implementation of NIR. Besides, it also stimulates ship owners to pay more attention on their vessel maintenance and port authorities to intensify their monitoring on the inspected vessels and, therefore, it is expected that the detention rate will be stable, if not continuing to drop, in the future.

3.1.3 Change in K1 (deficiencies per inspection), K3 (detainable deficiencies per inspection), and K4 (detainable deficiency rate)

Figure 2 presents a combination chart of the K1 (deficiencies per inspection), K3 (detainable deficiencies per inspection), and K4 (detainable deficiency rate) from 2005 to 2018. K1 and K3 are presented in column chart on principle coordinate, while K4 are shown in line chart on the secondary coordinate.

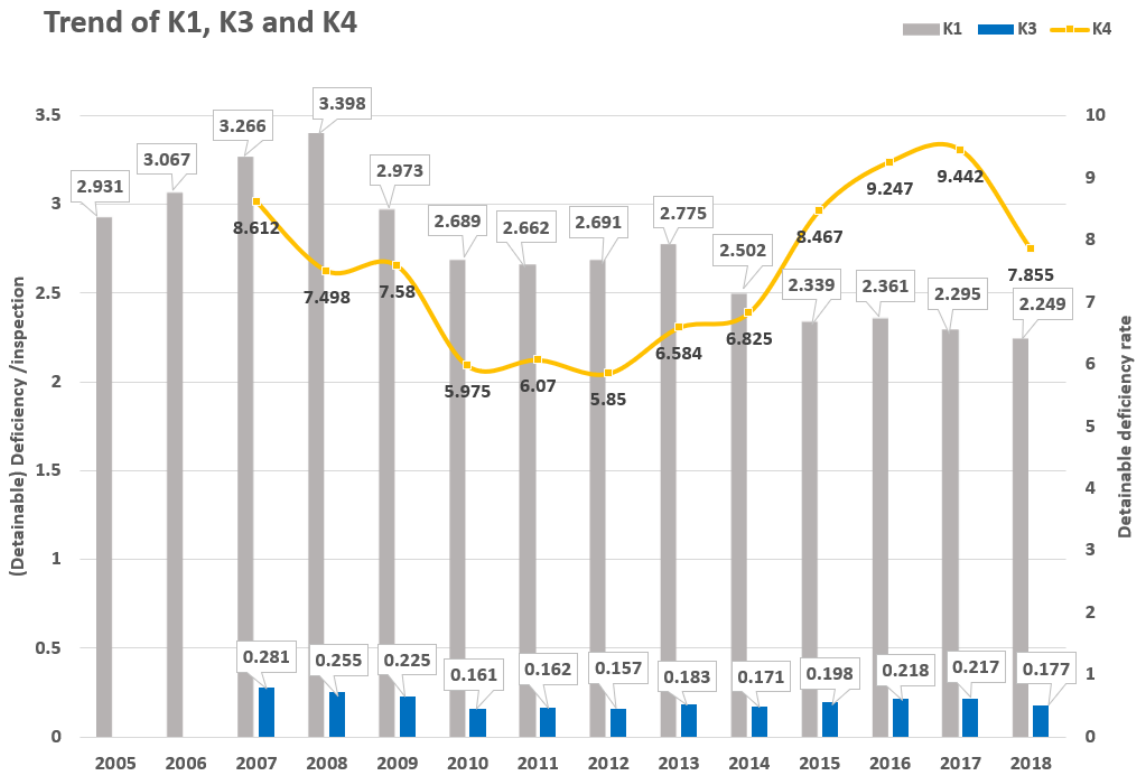

Figure 2 Variations of K1, K3 and K4 from 2005 to 2018

(Source: Author)

Through analysing the trends of the three parameters presented in the figure, several findings related to the influence of NIR on the PSC inspection system are revealed. Additionally, these changes will further affect vessel quality and maritime safety.

1) Generally, the introduction of NIR reduced the value of K1.

Although the number of inspections and deficiencies decreased simultaneously, it is obvious that the trend of K1 is descending since the implementation of NIR from Figure 2. Admittedly, the trends of K1 experienced certain fluctuations (i.e. Year 2013), however, it is normal rebound phenomenon brought by every new policy and does not hinder the overall descending trends.

It is worth noting that year 2010 is special compared to other years before the implementation of NIR. K1 was at a relatively low-level equivalenting to the years at 'Post-NIR' period. The reason is similar to that explained above in the detention rate part.

2) After the implementation of NIR, K4 decreased in 2012, and then it showed an increasing trend from 2013 to 2017. In 2018, it dropped significantly. The same goes to K3.

K3, the detainable deficiencies per inspection, is the inspected deficiencies per inspection; K4, the detainable deficiency rate, is the proportion of detainable deficiencies in the inspected deficiencies. Unlike the trend of K1, K3 and K4 maintained rising trends until 2018, when there were significant decreases for both indicators, a relative minus of more than 18%.

The reasons for this phenomenon are complicated. Through a careful reading of relevant reports published by Paris MoU, the reasons are summarized from a bidirectional perspective. On the one hand, ship owners need time to adapt to the new policy; on the other hand, Paris MoU improves the NIR from many aspects continuously. After several years of stabilising detainable deficiencies through various ways, i.e. PSC training and seminars, expert and specialized training, cooperation with EMSA, Concentrated Inspection Campaigns (CIC), year 2018 finally witnessed a huge drop of both indicators.

3.1.4 Change in K2 (Average inspection per vessel per year)

Although not considered in statements and annual reports of Paris MoU, K2, the average inspection per vessel per year should not be ignored when analysing the influence of NIR. It reflects the burden Paris MoU places on ship owners every year. Excessive PSC inspections may harm the competitiveness of the ports and increase the burden of ship owners, leading ship owners to leave for other destinations that may have a more relaxed inspection policy (Li et al., 2014). Therefore, the change in this indicator plays an important role in influencing ship owners' actions.

Figure 3 illustrates the trend of K2 in the research period. It is obvious to see some positive influence that NIR has generated on the ship owners and PSC inspection system.

1) K2 dropped sharply when NIR was implemented, and maintained a general downward trend since 2011.

K2 is the only parameter whose value is significantly and continuously reduced after the implementation in NIR. From figure 3, K2 was 1.63 in 2010, and has reduced approx. 40% to a level of 1.248 in 2011. This is because K2 is closely associated with the inspection policy.

Specifically, the NIR shifts from a national commitment, where each member state of the Paris MoU inspected 25% of the individual ships calling at their ports, to a regional commitment aiming to inspect all ships visiting the ports and anchorages in the Paris MoU region. Consequently, since January 1st 2001, the annual inspection target for each member State is based on ship movement data rather than individual ship calls. In addition, the original 6-month inspection intervals are replaced by the new criteria, which is set according to the vessel quality.

Quality ships will be rewarded with a “low risk ship” status and the inspection interval may be up to 36 months. Even “standard risk ships” benefit from the new system extending inspection intervals up to 12 months. On the contrary, more resources will be directed to those ships with poor safety records to balance the system, the “high risk ships”. These ships are subject to mandatory expanded inspections every 6 months when they call at a Paris MoU port. Such radical changes significantly reduced the burden of the disciplined ship owners, shipping industry and PSC authorities with inspections. For example, for a standard vessel, it has to face two inspections per year before, but now it only needs to experience one inspection per year if it maintains standard. The vessel owner could save one inspection’s expenditure, including the vessel maintenance cost, time cost waiting at ports, potential delay, and so on. PSC authorities also save lots of resources due to the reduced number of inspections. The same goes to those low risk vessels. However, for high risk vessels, things will be even worse than before. The inspection interval maintains the same, but the punishment has been stiffened. Accordingly, the new criteria will facilitate more ship owners to improve their vessel quality. Hence, it is not surprised to understand the sharp decline in K2 under this virtuous circle.

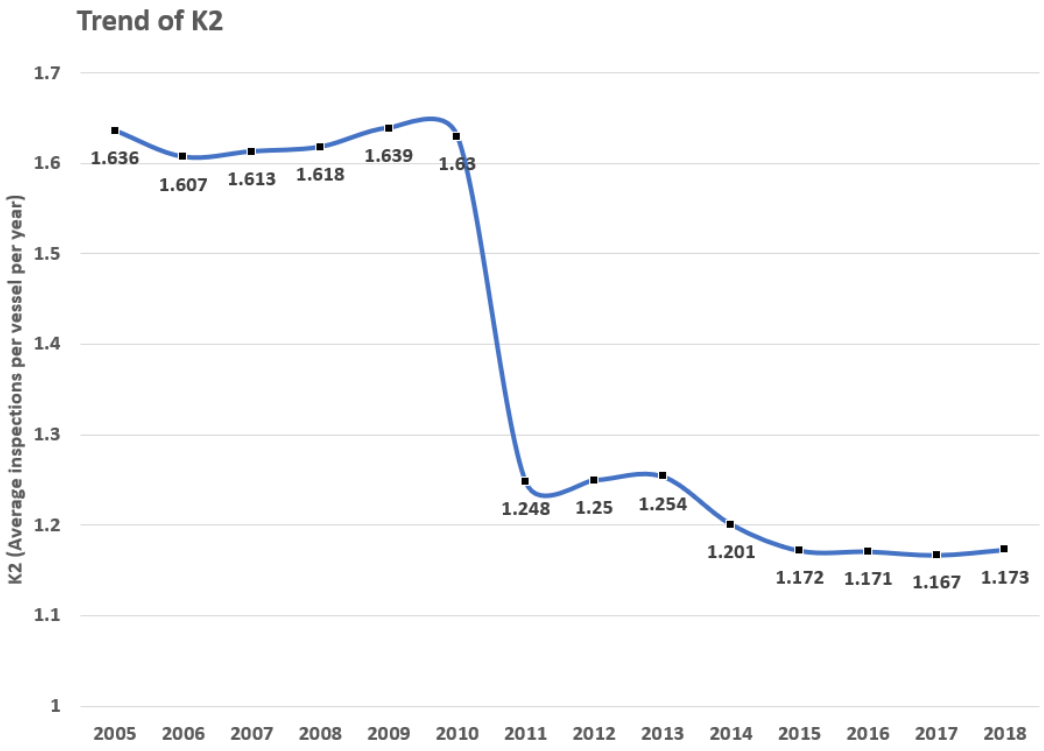

Figure 3 Trend of average number of inspections per vessel per year

(Source: Author)

2) The reduced burden of ship owners, and the reduced cost and resources for port authorities to spend in inspections.

In fact, the decline of K2 reflects a win-win situation for both ship owners and Paris MoU. In fact, the decline of K2 reflects a win-win situation for both ship owners and Paris MoU. This could be explained from two perspectives. On the one hand, the huge decline of K2 indicates that the introduction of NIR rewards ship owners for their qualified vessels with less inspection and maintenance burdens, which reduces their expenditures on PSC inspections and makes it possible for them to invest more resources on their business; On the other hand, less inspections conducted on vessels also benefit the ports within the Paris MoU region. The cost and resources port authorities spent on inspection are reduced, which helps them invest more resources on mechanism improvement, inspector training and other areas related to PSC inspection system. From the above explanation, it is observed that the decline of K2 is beneficial for both ship owners and port authorities, forming a 'win-win' situation. Such a win-win situation is an important contribution brought by the NIR.

3.1.5 Change in K6 (Refusal rate)

As the most severe means of punishment, refusal of access (banning) is set to punish the vessels offending rules consecutively in a certain period or jumping the detention. These vessels will be refused to access any ports in the region of Paris MoU unless the banning is lifted.

Figure 4 shows the trends of both refusal access and K6 from 2005 to 2018, and it shows that the implementation of NIR intensifies the focus on banning.

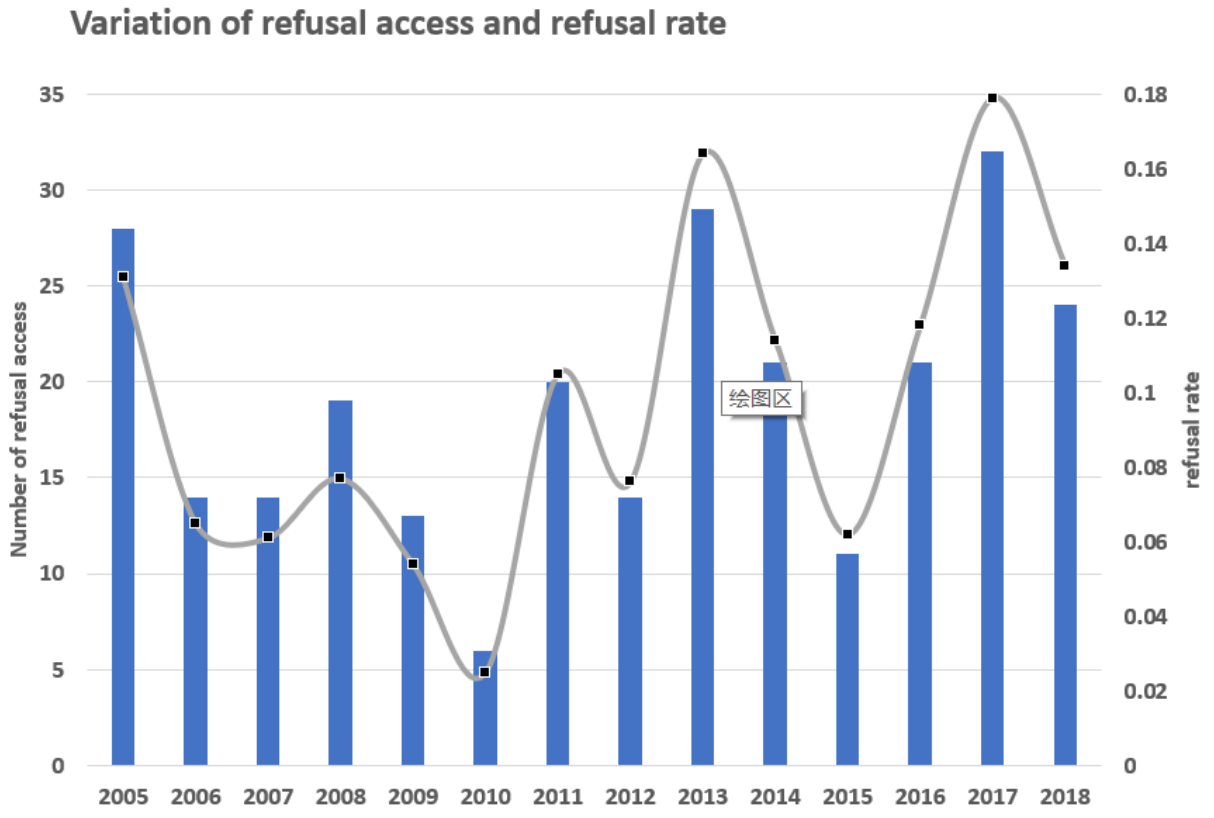

Figure 4 Variation of refusal access and K6

(Source: Author)

With the new refusal of access measures, more situations lead to banning now, for example, repeated offenders; second, refusal of access or underperforming ships will be applicable on all ships following multiple detentions, regardless of the position of their flag State on the Memoranda performance list. Accordingly, the implementation of NIR strengths the monitoring and punishment on these incorrigible sub-standard vessels.

1) The change of number of refusal access and refusal rate maintains synchronization.

This interesting phenomenon is due to the fact that the inspections conducted every year basically remain unchanged, and at the same time, K6 represents the refusal of access/number of inspections, the refusal rate changes synchronously as refusal of access.

As to the fluctuation of refusal of access, it is probably because in some years a number of vessels remain banned from previous years, or some vessels have been banned a second time and have a longer banning period (more than 12 months). Therefore, at some years, like 2013, 2017, the number of refusal access goes up drastically.

3.2 Influence of NIR on different vessel types

In section 3.1, the derived statistics reveals that every year over 10,000 individual vessels are inspected at the ports within the region of the Paris MoU, consisting of bulk carrier, chemical tanker and combination carrier, etc. Normally speaking, different vessel types have different inspection performance due to their strategies to cope with PSC inspections. Understanding the performance change of different vessel types after the implementation of NIR becomes crucial , because 1) It will present the degree of adaptation of different vessel types; 2) the results will intuitively show the overall quality of inspected vessels.

Due to the fact that more than 20 vessel types are inspected at ports, it is difficult to analyse all of them. Two criteria are utilized to determine the selected vessel types for the analysis to ensure the representativeness of the findings:

1) Vessel types should have more than 1,000 inspections every year;

2) Vessel types are continuously considered in annual reports of Paris MoU.

As a result, the following vessel types are selected, including general cargo vessel, container, bulk carrier, chemical tanker and oil tanker.

3.2.1 The percentage of inspections with deficiencies

Among the completed inspections, some inspections record one or more deficiencies, others refer to the vessels without faults. Although having deficiencies does not mean the inspected vessels are offenders, the percentage of inspections with deficiencies (PID) is still an important indicator to measure the quality of inspected vessels. A higher value of this indicator is a signal to port authorities that the overall quality of this vessel type is at a low level and some measures should be taken to stimulate ship owners to improve their ships. Figure 5 presents this KPI for different vessel types from 2005 to 2018.

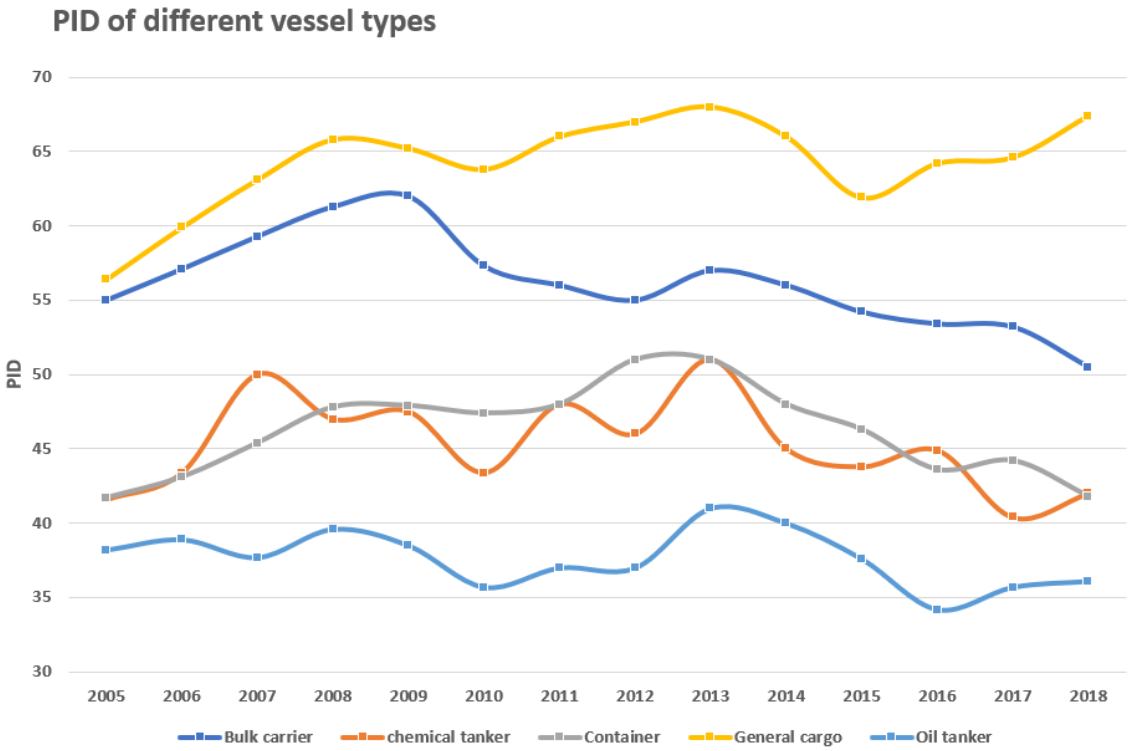

Figure 5 Percentage of inspections with deficiencies of different vessel types in 2005-2018

(Source: Author)

1) In general, bulk carriers and oil tankers have a downward trend after the implementation of NIR, especially bulk carriers. Other vessel types basically maintain the same level as 'Pre-NIR' period with a slight volatility.

Paris MoU annual reports do not take the PID of whole inspection system into account. Nevertheless, from figure 5, it is not difficult to conclude that the PID of whole PSC system will increase slightly at the beginning of NIR implementation, since most vessel types present an upward trend. This is probably because more deficiency categories are considered under NIR, and ship owners are still in an adaptive process. However, in recent years (2016-2018),

the PID level of most vessel types (except dry cargo) began to drop, indicating that the overall condition is becoming better.

2) In 2013, the PID of all vessel types reached the peak value at the same time.

In 2013, not only the PID but also many other KPIs mentioned above had increased to a peak/very high value. It is evident that the entry of Maritime Labour Convention (MLC) in Paris MoU contributes to this. Since the adoption of the MLC in February 2006, it took a further 7 years for it to enter into force. As a significant contribution in securing decent working and living conditions on board ships, many vessels are detected not complying with the rules of this area, according to the annual report 2013 of Paris MoU. Therefore, it is not surprising to find an increment of this indicator.

3) After 2013, PID values began to drop, revealing more efforts made by ship owners, ports and Paris MoU to improve vessel quality.

After the adaptive process, ship owners better understood the requirements under the new rules of Paris MoU, hence the overall quality of inspected vessels improved.

3.2.2 Detention rate

As mentioned above, detention rate is the most important indicator in PSC inspections. Figure 6 shows the trends of the detention rates of different vessel types, as well as the average detention rate K5. Through the analysis of these trends, the change of the vessel quality of different vessel types is further clarified.

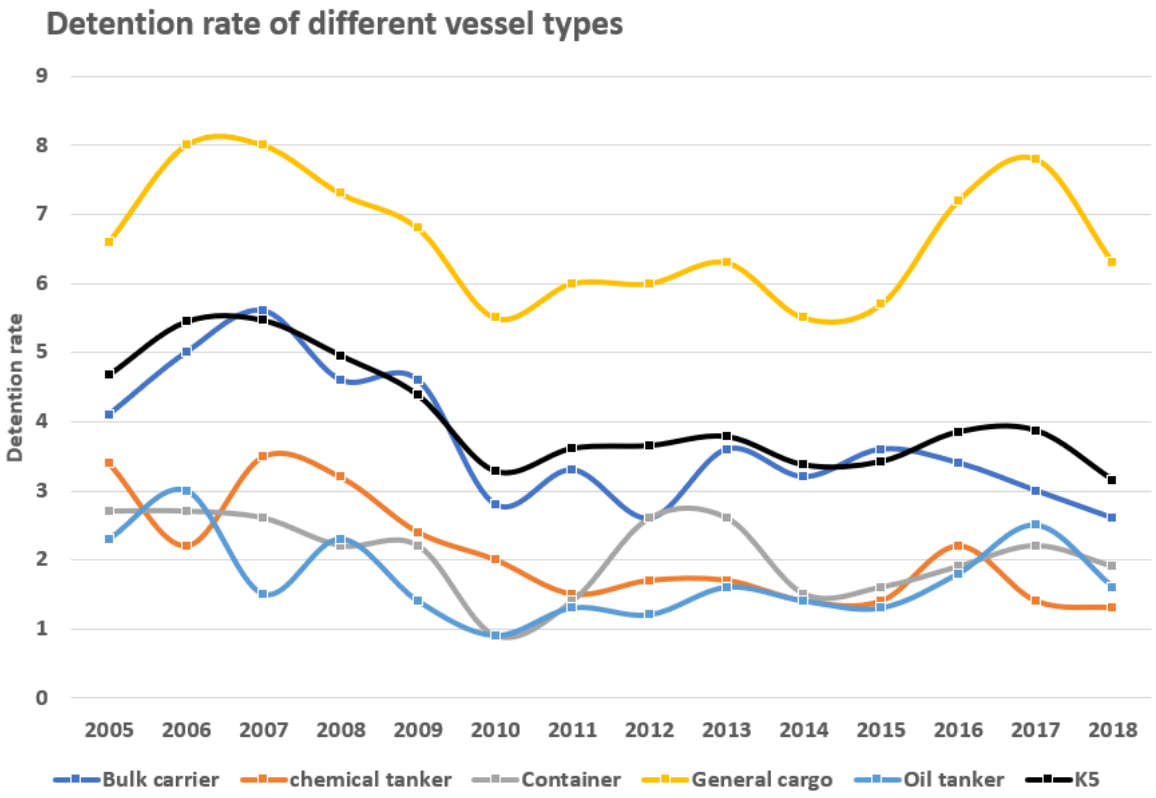

Figure 6 Detention rates of different vessel types from 2005 to 2018

(Source: Author)

1) In general, the detention rate of all these vessel types dropped after the implementation of NIR.

This promising finding indicates that the NIR provides a comprehensive inspection system by which the quality of all vessel types is improved, leading to a safer maritime environment for transport, business and many other uses in all circumstances.

2) Among these vessel types, bulk carrier presents the most similar trajectory to K5 (detention rate).

Unlike other vessel types, the detention rate of bulk carriers has a similar trajectory over time to K5. Additionally, the detention rate value of bulk carrier is not so far different from the value of K5, as shown in Figure 6.

3) General cargo vessel is the most dangerous and risky vessel type, before and after the implementation of NIR.

In the past decades, the detention rate of general cargo vessels is in the range from 6% to 8%, twice higher than the average detention rate (K5). Although the implementation of NIR slightly reduced the value of the indicator, it still maintains at a high level.

4) Containerships, chemical tankers and oil tankers have lower detention rates and better inspection performance.

5) After 2011, the detention rates of different vessel types are becoming more stable compared to 'Pre-NIR' period, except general cargo vessels.

The slight fluctuation of detention rates after the NIR implementation cannot hide the truth that the detention rates of most vessel types are stabilizing in recent years, resulting in the consistent value of K5 as mentioned above. General cargo vessels experienced a huge growth in 2016 and 2017, probably because it suffered a higher impact of financial pressure at this time.

Besides these above explained NIR impact, another finding is that the change of bulk carriers is in many aspects similar to the behaviour of the whole system. For example, the detention rate and PID change simultaneously. Therefore, bulk carriers are selected as the target vessel type for the following microscopic comparative analysis.

4. MICROSCOPIC COMPARATIVE ANALYSIS

Besides the macroscopic comparative analysis on extrinsic KPIs related to inspections and vessels, a microscopic comparative analysis is also conducted in this study to further assess the influence of NIR on some intrinsic underlying factors such as risk factors related to inspection results and vessel characteristics. The changes of these factors are not available from existing resources, i.e. Paris MoU annual reports or publications. Hence, new risk models developed in different periods are developed and used to figure out the impact of these underlying factors.

Specifically, a BN-based PSC risk model is adopted in this study. It is utilized to develop risk assessment models of inspection results (detention or not) based on historical data. According to previous risk-based PSC inspection studies, BN shows its superiority (e.g. bi-directional analysis) over other risk assessment approaches. According to previous risk-based PSC inspection studies, BN shows its superiority (e.g. bi-directional analysis) over other risk assessment approaches. A BN is a probabilistic graphical model that represents a set of random variables and their conditional dependencies in a directed acyclic graph. The graph consists of

several nodes representing variables, as well as links representing the probabilistic causal dependence among the variables (Li et al., 2014). Each variable has a finite set of mutually exclusive states. It is useful to analyse the causal relationships among variables, as well as serve as a prediction tool when new evidence enters. Normally, the process of developing a BN model consists of four stages: data acquisition, BN structure learning, BN monitoring and analysis, and model validation (Yang et al., 2018). Its increasing applications in maritime (incl. port) risk assessment in recent years (e.g. Alyami et al., 2014; John et al., 2016; Yang et al., 2018a; Wan et al., 2019) provide useful insights and experimental evidence on how it can be applied in risk studies in general and risk based PSC in specific.

As a powerful risk assessment approach, it has the ability to model the inspection results (detention rate) in terms of the risk factors detected from historical inspection records. When the information about a specific inspection is collected, ship owners or port authorities can use the BN model to calculate the detention rate of the vessel in a proactive manner. Compared to other risk assessment models, BNs combine the visualization with mathematical knowledge, enabling the analysis of the relationships between different risk factors. Additionally, to improve the accuracy and rationality of BN models, a data-driven learning approach called Tree Augmented Naïve (TAN) learning is applied for model development, resulting in objective and reasonable models (Yang et al., 2018b, 2018c).

Data used for model construction and development is derived from the Paris MoU online inspection database. As aforementioned, bulk carrier is selected as the illustrative ship type for BN modelling. Risk factors are identified from the inspection reports. From the authors' previous relevant findings, 'vessel group' and 'inspection group' are two dummy variables representing the overall risk level of a vessel and the overall risk level of the inspection, respectively. They are used to reduce the calculation work of conditional probability tables (CPTs).

The resulting models for the 'Pre-NIR' period from 2005 to 2009 and for the 'Post-NIR' period from 2014 to 2018 are shown in Figures 7 and 8, respectively. Detailed information on the development of BN models could be found in Yang et al. (2018b, 2018c). These BN models are used in the present study to analyse the changes brought by the introduction of NIR.

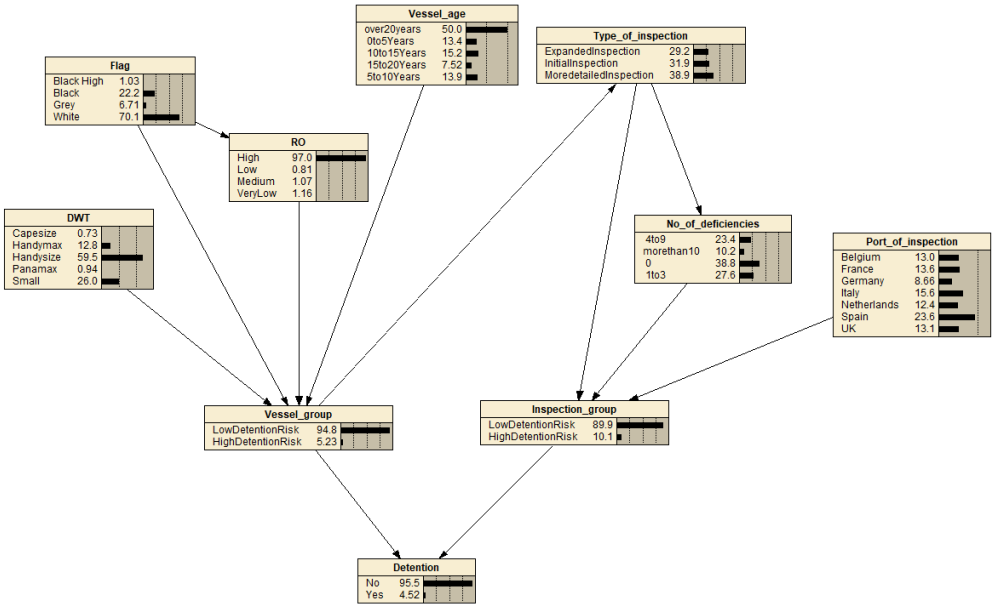

Figure 7 'Pre-NIR' BN model

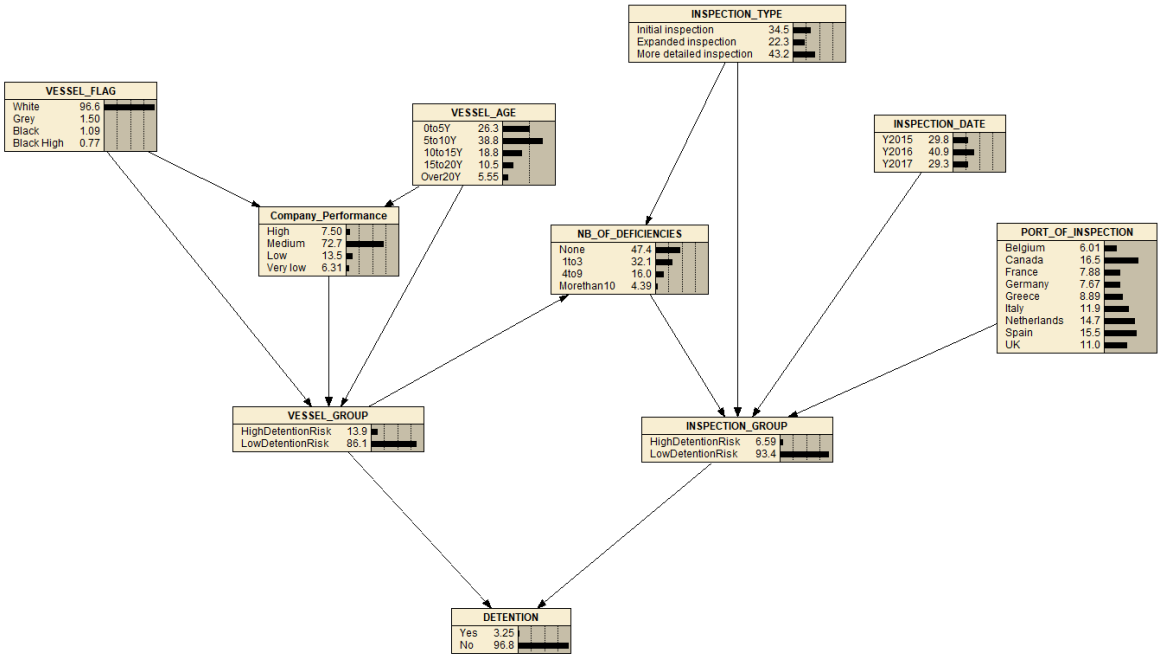

Figure 8 'Post-NIR' BN model

The comparative analysis is conducted from the following aspects, including 1) the influence degree of risk factors on detention; 2) Prior probability change; 3) Company performance impact; 4) Change of risk level of different factor groups. Each aspect represents one important intrinsic parameter/factor influenced by NIR. Through the comparison of these aspects in the two BNs, the influences of NIR on the maritime safety and PSC inspection system are assessed from a microscopic perspective.

4.1 Sensitivity to detention -The influence degree of risk factors under different periods

As a powerful risk assessment tool, BNs are able to provide the influence degree of different risk factors on inspection results. For Paris MoU and its subordinate ports, this is an important information enabling them to improve PSC inspection system and fight against sub-standard vessels. For example, authorities could allocate more resources on high-level influential risk factors or formulate relevant policies to restrict the occurrence of them as well. Therefore, clarifying the change in this aspect will contribute to the understanding of the influence brought by NIR.

The influence degree of risk factors can be presented through mutual information. Mutual information is an effective way to measure the mutual dependence of different variables. It is the value used to calculate the strengths of the relationships between the target node (i.e. detention) and influencing nodes (i.e. vessel age, vessel flag). The larger the value of mutual information is, the stronger relationship exists between two variables. Tables 3 and 4 present the results of mutual information calculated with respect to both periods (pre and post).

Table 3 Mutual information with detention (Pre-NIR)

Node	Mutual Information	Percentage	Variance of Beliefs[1]
Detention		100	
Inspection group	0.09654	36.4	0.0108729
Number of deficiencies	0.09386	35.3	0.0105047
Type of inspection	0.01464	5.51	0.0008056
Vessel group	0.00140	0.527	0.0001046
RO	0.00025	0.0933	0.0000171
Vessel flag	0.00025	0.0929	0.0000161
DWT	0.00009	0.0331	0.0000053
Vessel age	0.00003	0.0131	0.0000021
Port of inspection	0	0.0007	0.0000001

(Source: Author)

Table 4 Mutual information with detention (Post-NIR)

Node	Mutual Information	Percent	Variance of Beliefs
Detention	0.20672	100	0.0314319
Inspection group	0.06135	29.7	0.0061904
Number of deficiencies	0.04891	23.7	0.0050644

[1] Belief: Here belief means posterior probability of the variable.

Variance of belief: The expected change squared of the beliefs of the node, taken over all of its states, due to a finding of 'detention'.

Vessel group	0.03622	17.5	0.0024699
Company performance	0.02659	12.9	0.0016154
Vessel age	0.00638	3.09	0.0003219
Type of inspection	0.00579	2.8	0.0002493
Port of inspection	0.00110	0.531	0.0000505
Vessel flag	0.00036	0.174	0.0000208
Inspection date	0.00008	0.0369	0.0000033

(Source: Author)

Several findings can be drawn on the influence of NIR from the comparative analysis of the results referring to the two time periods:

1) Since NIR was implemented, many former insignificant risk factors have closer and stronger influence on inspection results now, indicating a more balanced PSC inspection system.

This change is reflected in the percentage of mutual information (PMI). Before the implementation of NIR, 'the inspection group' and 'number of deficiencies' had dominant influence on the inspection results, while impacts of other factors were basically insignificant. This is abnormal and irrational for the inspection system. Things changed after 2011, as one can see from Table 4. Although 'inspection group' and 'number of deficiencies' are still the most influential ones, other factors like "vessel group" and "company performance" play an important role as well.

Additionally, in the 'Pre-NIR' model, the differences of the PMI values between the first two factors and other factors are huge (35.3% for 'number of deficiencies', 5.5% for 'type of inspection', and other factors lower than 1%). In contrast, these differences become narrow considerably in the 'Post-NIR' model (29.7%, 23.7%, 17.5%, 12.9% in order), indicating that the PSC inspection system is more balanced now.

In other words, the implementation of NIR provides a healthier and more reasonable inspection system. Within this new system, influence of risk factors is balanced and each risk factor has a rational participant in the PSC decision-making process.

2) Vessel-related risk factors become one of the focal points of Paris MoU under the new regime.

The biggest change comes from 'vessel group', or vessel-related risk factors, evidenced by the huge growth from 0.527% to 17.5%. This indicates that the influence of vessel quality on inspection results is growing more and more. Port authorities take corresponding measures to pay more attention on vessel-related factors in PSC inspections, resulting in greater pressure

on ship owners. The opportunistic attempts of ship owners do not work in the new regime, and they have to invest more resources on vessel maintenance to meet the requirements of Paris MoU. The PMI increase of 'vessel age' and 'vessel flag' also supplements this finding.

3) The newly added factor "company performance" indeed generates some positive impacts, justifying its introduction.

The detailed analysis on this factor is presented separately in section 4.3 due to its length for an integrated presentation of this section (i.e. Section 4.1).

4) The influence of inspection-related factors is weakened under NIR, except "port of inspection".

Since more efforts and resources are invested into reinforcement of vessel-related factors, it is not strange to find that the influence of inspection-related factors becomes weaker. The increase of "port of inspection" is somehow unexpected, probably because more strict inspection policies are adopted by these ports.

4.2 Prior probability change

As prior probabilities are obtained directly from observed data, their changes after the implementation of NIR embody the influence of NIR on the choice and actions of ship owners directly These prior probabilities represent many vessel characteristics and inspection details. The proposed BN models consist of several root variables, however, only those involved in both models are selected for the comparative analysis. Table 5 shows the prior probabilities of the common root variables before and after the implementation of NIR, including vessel age, vessel flag, inspection type, and port of inspection.

Table 5 Comparison of prior probability before and after NIR

Vessel flag							
	Black	Black	Grey	White			
Pre-NIR	0.0103	0.2218	0.0671	0.7008			
Post-NIR	0.0077	0.0109	0.0150	0.9664			
Vessel age							
	0 to5 Years	5 to10Years	10to15Years	15to20Years	Over20Years		
Pre-NIR	0.1340	0.1392	0.1519	0.0752	0.4998		
Post-NIR	0.2633	0.3884	0.1876	0.1051	0.0556		
Port of inspection							
	Belgium	France	Germany	Italy	Netherlands	Spain	UK
Pre-NIR	0.1297	0.1360	0.0866	0.1564	0.1243	0.2356	0.1315
Post-NIR	0.0806	0.1057	0.1027	0.1593	0.1975	0.2072	0.1470

Inspection type							
	Initial	More	Expanded				
Pre-NIR	0.2814	0.3668	0.3518				
Post-NIR	0.3447	0.4319	0.2234				

(Source: Author)

1) The flag performance of inspected vessels improves considerably, reflected by the fact that almost all the inspected vessels have a white flag.

After 2011, more and more ship owners select flag states that are listed on the white list of the Paris MoU (from 0.7008 to 0.9664). On the contrary, the percentage of selecting black list flag states declined sharply from 0.2218 to 0.0109. The other two states of 'vessel flag' have shown a slightly drop as well.

2) Young vessels replace the position of old vessels and become the majority of all inspected vessels.

Currently, most of the inspected vessels are young vessels under 10 years old, corresponding to over 60% of the total number. This figure was only around 27% before the implementation of NIR. Meanwhile, the percentage of vessels over 20 years old drops significantly from 49.98% to 5.56% accordingly.

This change reflects a positive signal that old vessels have gradually been eliminated by ship owners. This is because under the new inspection system, old vessels are riskier and more dangerous, and associate with a higher probability to be caught in accidents. To avoid possible loss, many ship owners gradually replace their old vessels with young ones, according to annual reports and statements of Paris MoU. The reduction of involving old vessels in the Paris MoU region is of great significance for ensuring the regional maritime safety.

3) There is not much change in the port of inspection before and after the introduction of NIR.

4) More-detailed inspections is the preferred inspection type of port authorities, while the rate of expanded inspections reduces approximately 40%.

The stricter NIR stimulates ship owners to improve their vessel quality, which can be reflected by the change on inspection type. The reduction in expanded inspections shows that fewer vessels need to take a full check of the overall condition, which reflects the improvement of overall vessel quality. However, more-detailed inspection is still the most frequent inspection type, indicating that there is still room for improvement.

In general, the changes of these parameters, no matter vessel characteristics or inspection details, indicates that more and more vessels are improving their quality under NIR. Younger vessels, safer flag states, and less expanded inspections are all signs of a gradual improvement of the vessel quality and inspection system as a whole.

4.3 Company performance impact

As a newly added factor in the PSC inspection system, company performance plays an important role when calculating the Ship Risk Profile (SRP) of the vessels. Its appearance means ship owners need to choose their shipping management companies more carefully. Actually, company performance is viewed as one of the most significant improvements and changes of the inspection system stated by many PSCOs and members of the Paris MoU. The analysis of degree of importance above also proves that company performance has a great impact on inspection results, making it one of the most influential risk factors currently.

In this section, the influence of company performance is further clarified. Table 6 presents the variation in percentage of the detention rate when company performance is presented at different states.

Table 6 Effect of **company performance** on detention rate

	High	**Medium**	**Low**	**Very low**	**Detention rate**	**Changes rate**
General case	7.5%	72.7%	13.5%	6.3%	3.3%	
High CP vessel	100%	0	0	0	1.5%	-54.2%
Medium CP vessel	0	100%	0	0	1.3%	-59.4%
Low CP vessel	0	0	100%	0	9.2%	+182.2%
Very low CP vessel	0	0	0	100%	14.9%	+358.5%

('-'means a reduction of detention rate, '+' means an increase of detention rate.)

From Table 6, several findings related to the company performance are highlighted.

1) Poor and very poor company performance *is no longer tolerable in Paris MoU, and corresponding vessels are much likely to be detained under NIR.*

As seen in Table 6, if the shipping company of a vessel is classified as "low performance", the detention rate increases by 182.2%. The impact is even higher when very low performance is concerned, with a detention rate increase by 358.5%. The huge changes in these scenarios clearly demonstrate the punishment intensity on substandard shipping companies of Paris MoU under NIR.

2) Accordingly, Paris MoU will reward the vessels from the shipping companies of high or medium performance levels. However, the results show that high company performance *does not necessarily have more benefits than medium* company performance.

It is not difficult to reach this conclusion from Table 6. It means that the current PSC inspection regime has room for improvement towards a new scheme, which can reflect the rational in reality that a company of high-level performance mirrors a lower detention rate than the one of medium level performance.

3) The involvement of shipping company is an effective way to stimulate ship owners to ensure their vessel quality.

Before the implementation of NIR, shipping companies are just third-party managers who, for a negotiated fee and with no shareholding ties with their clients, undertake the responsibility of managing vessels in which they have no financial stake (Mitroussi, 2003). They accepted ships from and managed them on behalf of ship owners without much concern on their technical soundness given that they had no responsibility on vessels' failures of passing PSC inspections. Consequently, the random selection of ship owners, the poor operation and management of shipping companies led to vessel quality concerns. The NIR fixed this problem. The introduction of shipping companies in PSC inspection system on one hand forces ship owners to choose the shipping companies of high performance level to avoid potential punishment, while it on the other hand stimulates ship owners to improve their vessel quality with the help of shipping companies as shipping companies do not want to accept sub-standard vessels now. Such change has positive influence on improving the overall vessels quality.

4.4 Change of risk level of different factor groups

Although 'vessel group' and 'inspection group' are two dummy variables in the BN models of Figures 7 and 8, they still have real meanings representing the overall risk level of vessel-related factors and inspection-related factors. As discussed in section 4.1, vessel-related risk factors become one of the focal points of Paris MoU and therefore it is necessary to figure out the extent to which the vessel-related factors affect the detention rates. The same applies to the effect of inspection-related risk factors. The results reveal the changes of new PSC inspection system, and whether it is an improvement over the previous system.

Table 7 Change on 'vessel group' and 'inspection group'

Inspection group (IG)	**Pre-NIR**	**Post-NIR**	**Vessel group (VG)**	**Pre-NIR**	**Post-NIR**
General case	4.52%	3.25%	General case	4.52%	3.25%
IG = High	35.7%	32.9%	VG = High	8.87%	15.60%

Changes rate	+689.8%	+912.3%	**Changes rate**	+96.20%	+380%
IG = Low	1.03%	1.16%	VG = Low	4.28%	1.26%
Changes rate	-77.2%	-64.3%	**Changes rate**	-5.3%	-61.2%

('-'means a reduction of detention rate, '+' means an increase of detention rate.)

Table 7 illustrates the detention rate and its variation in percentage under different scenarios. Some valuable insights are derived from Table 7.

1) Vessel-related risk factors are no longer tolerable under NIR.

Before NIR was implemented in 2011, a higher level of vessel-related risk factors increases the probability of detention to a limited extent. The 96.2% detention rate was still in the tolerance range of ship owners. More importantly, a vessel with low vessel-related risk factors is almost rewarded nothing by port authorities (only a decrease of 5.3%), which limits the ship owners' motivation for improvement.

However, things are entirely different under the new inspection system. High vessel-related risk vessels suffer a nearly 400% detention rate increase. Additionally, the reward for the qualified vessels worth the effort they put into (a decrease of over 60%). Because of the attitude change of vessel-related risks in the new system, ship owners are more motivated to take proactive corrective measures.

2) Although the detention rate under high inspection-related risks slightly decreases, the punishment on those unqualified vessels in this aspect intensifies.

Not only the vessel-related risks, but also the inspection-related risks are paid more attention under NIR. The decrease of the detention rate under high inspection-related risks situation is because of the improvement of the overall inspection condition and vessel quality. Nevertheless, the punishment inflicted on those unqualified vessels is more severe, reflected by the 912% increase on detention rate.

3) The changes on the inspection and vessel risks demonstrate that port authorities are vigilant to all potential risks and will no longer tolerate any types of risk.

No more risks will be tolerated under NIR. The cognitive change for Paris MoU is characterized in the way it treats risks. From the single dominating inspection risks to the incorporation of both inspection risks and vessel risks, the PSC inspection system is becoming more robust and healthier. As stated by the Paris MoU secretary, since the implementation of NIR, the results in reality prove that the work has remarkable effect on vessel quality improvement.

5. Implication summary and research agenda for further improvement

Through the above two-step comparative analysis, the impact of many important parameters under new PSC inspection system are revealed. From both macroscopic and microscopic perspectives, the impact indicates that the implementation of NIR indeed brings significant benefits on the PSC inspection system, vessel quality and maritime safety. To present the results of the analysis more clearly, a classification scheme of the revealed impacts introduced by NIR is applied in this section.

Table 8 classifies the impacts from three aspects: 1) the changes related to the inspection system, 2) the changes related to vessel quality, and 3) other changes not belonging to the first two groups. Additionally, in each aspect, the changes are further clarified according to their influence type, positive or negative, intuitively illustrated in Table 8. Finally, it provides experimental evidence to support the Paris MoU official statement that the implementation of NIR is a significant action taken towards the improved PSC inspection practice.

Table 8 Classification of the influences introduced by NIR

	Positive influences	Negative influences
Vessel quality	The detention rate after the implementation of NIR is lower and more stable compared to the period before NIR.	After the implementation of NIR, the detention rate initially exhibits an increasing trend and then experiences another growth in 2016-2017
	The detention rate of most vessel types dropped and maintained stable as well.	After the implementation of NIR, K3 (detainable deficiencies per inspection) and K4 (detainable deficiency rate) presented an increasing trend from 2013 to 2017
	Detention rate dropped in 2014-2015 and 2017-2018.	In 2013, the PID of all vessel types reached the peak value at the same time.
	2018 witnessed a huge drop of detention rate, reaching the lowest point in the past decade.	
	The introduction of NIR reduced the value of K1 (deficiencies per inspection).	
	K2 dropped sharply when NIR was implemented, and maintained a general downward trend since 2011.	
	It is believed that the detention rate, K1 (deficiencies per inspection), K3 (detainable deficiencies per inspection) and K4 (detainable deficiency rate) will continue to drop in the future, or at least maintain the same level as 2018.	
	The PID of bulk carrier and oil tanker have a downward trend after the implementation of NIR, especially bulk carrier. Other vessel types basically maintain the same level as 'Pre-NIR' period with a slight volatility.	
	After 2013, PID (percentage of inspections with deficiencies) values began to drop, revealing more efforts are made by ship owners, ports and Paris MoU to improve vessel quality.	
	The flag performance of inspected vessels improves considerably, reflected through the fact that almost all the inspected vessels have a white flag.	
	Young vessels replace the position of old vessels and become the majority part of inspected vessels.	
	The burden of ship owners reduced	
	The cost and resources of port authorities spent on inspections reduced	There is not much change in the port of inspection before and after the introduction of NIR.

Inspection system	Since NIR was implemented, many former insignificant risk factors have closer and stronger influence on inspection results now, indicating a more balanced PSC inspection system.	High company performance vessels do not have more benefits than medium company performance vessels from port authorities.
	Vessel-related risks become one of the focal points of Paris MoU under new regime, and are no longer tolerable under NIR	
	The influence of inspection-related factors is weakened under NIR, except port of inspection.	
	Although the detention rate under high inspection-related risks slightly decreases, the punishment on those unqualified vessels in this aspect intensifies.	
	The newly added factor, company performance, indeed influences the inspection results to some extent, supporting its introduction.	
	The involvement of shipping company is an effective way to stimulate ship owners to ensure their vessel quality.	
	Paris MoU will reward vessels with high or medium performance level shipping companies.	
	Poor and very poor company performance are no longer tolerable in Paris MoU, and corresponding vessels are much likely to be detained under NIR.	
	More-detailed inspections are the preferred inspection type of port authorities, while the rate of expanded inspections reduces approximately 40%.	
	The changes on the inspection and vessel risks demonstrate that port authorities are vigilant to all potential risks and will no longer tolerate any types of risk.	
Other	In 2010, the last year before the implementation of NIR, the detention rate dropped to 3.28%, the second lowest value until now.	
	Among all vessel types, bulk carriers have a trend similar to K5 (detention rate).	
	General cargo vessels are the most dangerous and risky vessel type, no matter before or after the implementation of NIR.	
	Container vessel, chemical tanker and oil tanker have lower detention rate and better inspection performance.	

From Table 8, it is obvious that most of the influences brought by NIR are positive, on inspection system or vessel quality. They provide important insights for both port authorities and ship owners to adjust and adapt their behaviours to the new inspection regime proposed by Paris MoU. Consequently, a more adequate PSC inspection system and an environment with higher vessel quality are being achieved, effectively ensuring maritime safety. The results of the present paper prove the capability and achievements of NIR.

However, the 3.25% detention rate indicates that sub-standard ships are still a reality of today's shipping. Equally concerning is there are still a few flags and recognized organizations around that are willing to act as a "legal shelter" to substandard ships by providing them with a registry and certificates. This needs to be continuously tackled by informing the Paris together with other MoUs (e.g. Tokyo) and the IMO their identities.

Although there has been a very close and effective co-operation between Paris and Tokyo MoUs, sub-standard vessels will always find a new trading area. It is therefore imperative that other regions enhance their PSC activities, train PSCOs and implement more stringent enforcement measures. Some progress has already been reported in the area of training where exchange programs and training activities have been implemented with the assistance of the IMO. Closer collaboration between regional agreements will be the only effective way to put a stop to sub-standard ships on a global scale.

The company performance list proposed by Paris MoU has already regularized many companies' behaviour, but the impact and effectiveness are still be verified, probably needing more efforts to be put forward. Nowadays, there are still shipping companies that have made a deliberate choice to operate substandard ships for the obviously reason of seeking for higher profits. The southern part of the Paris MoU region is a showcase as their preferred area of operation. It shows that in that particular area, the risk of being detained and rectifying deficiencies probably still outweigh the costs of running a "bonafide operation". The seafarers on these ships may have to live under often horrendous working and living conditions. Filthy living quarters, unsanitary conditions and rotting food are a few examples. Sometimes crew are waiting for months to get paid or they are not allowed their leave on time. They are unacceptable and should and will be enforced rigorously, as demonstrated by the fact that more and more substandard ships if this feature are published at the Paris MoU website in "caught in the net".

6. CONCLUSIONS

In 2011, the long-awaited NIR was launched after 30 years of the introduction of the old inspection system. It is not surprising that the new system is highly rated by many, and even regarded as the most radical change in the Paris MoU history. However, few studies have been conducted to investigate the influence of NIR and provide experimental evidence to support it from a scientific perspective.

In this paper, a comparative analysis is conduced to assess the influence brought by NIR on PSC inspection system and vessel quality from both microscopic and macroscopic perspectives. The important KPIs related to PSC inspections are derived and assessed from the Paris MoU annual reports in the period 2005-2018, including deficiency per inspection, average inspections per vessel per year, detainable deficiencies per inspection, detainable deficiency rate, detention rate and refusal rate. A trend analysis of these KPIs clearly shows the changes after the implementation of NIR representing the positive macroscopic influences of NIR. Additionally, two BNs developed based on inspection data of bulk carriers in 2005-2009 and 2014-2018 from the Paris MoU are used to enable detailed impact analysis of the implications of the NIR. It is noteworthy that through the comparison between 'Pre-NIR' and 'Post-NIR' BN models from several aspects, the microscopic influences of NIR are revealed with many quantified measures.

The influences are classified into two main categories: vessel quality related and inspection system related. In both categories, the results obtained reveal that most of the influences brought by NIR are positive, i.e. the values of detention rates decrease and become more stable, the burden on ship owners drops, the inspected vessels are younger and the inspection costs to port authorities become lower. All these influences indicate that the NIR provides a radical and significant evolution of the PSC inspection system, improving the control of substandard vessels, stimulating ship owners to maintain their vessels at a high-quality level, and finally ensuring maritime safety.

From the drawn managerial insights, it is evident that apart from the positive influences NIR is exposed to some further improvement requirements, calling for future research agenda. For instance, first the detention rate experiences strong fluctuations after the implementation of NIR, the same applies to some other KPIs. Secondly, high company performance vessels do not gain corresponding benefits for ship owners under the current scheme. Thirdly new regimes that can facilitate the cooperation through regional agreements, and effective company performance monitoring are highly demanded.

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