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Is port state control influenced by the COVID-19? Evidence from inspection data

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ARTICLE INFO

Keywords:
Port state control (PSC) COVID-19 Maritime transport Deficiency code Ship detention

ABSTRACT

Maritime transport plays a key role in global trade. The safeguard of maritime transport is the Port State Control (PSC) inspection implemented all over the world. The outbreak of the Coronavirus disease (COVID-19) in 2020 presents new and unprecedented impacts on global supply chains and the ports as well as the entire shipping industry. Various measures were adopted by the countries and regions to halt the spread of the pandemic, mainly by reducing face-to-face interactions. As PSC inspections involve getting onboard vessels and in-person communications between the inspectors and the crew, its procedure and results are highly likely to be influenced by the COVID-19. This study aims to explore whether, how, and why the global and regional PSC inspection statuses are influenced by the pandemic through analyzing real inspection data. Specifically, three general indicators, namely inspection number, average deficiency number per inspection, and detention rate, are considered. Moreover, a detailed and comprehensive analysis of the inspection data at the Hong Kong port is conducted, including the number of inspections conducted, the average deficiency number and detention rate, the types of inspections conducted and ships inspected, the detailed deficiency and detention conditions, the relationship between the local pandemic situation and the PSC inspection status, and regression analysis on the influencing factors on inspection outcome. It is found that the COVID-19 pandemic indeed has an impact on PSC. Meanwhile, pragmatic and flexible measures are adopted by the port states, and the PSC has always been acting as a ‘safety net’ to guarantee maritime safety, promote the marine environment, and protect the seafarers’ rights even under the difficult times during the COVID-19 pandemic.

1. Introduction

Maritime transportation is the support of the global supply chain. It is reported that more than 80% of global trade volume is carried by vessels (UNCTAD, 2019; Qi et al., 2021; Wang et al., 2021). Ship flag, which is deemed as its nationality, is responsible to ensure that the ship complies with relevant international conventions and regulations. Nevertheless, it is believed that flag states cannot fulfill its obligations well as ships might visit their flag state ports only occasionally and irregularly (Carriou et al., 2007; Li and Zheng, 2008; Heij et al., 2011; Fan et al., 2014; Yan et al., 2021a). The situation can be worse in the flag of convenience, where easier vessel registration is allowed and thus lead to looser safety standards (Wang et al., 2019; Wang and Wu, 2021).

As a back-up of the flag state, the port state control (PSC) was proposed and rapidly developed all over the world as supported by the International Maritime Organization (IMO). PSC is an inspection of foreign ships visiting domestic ports to conform that their overall conditions and facilities are in compliance with international regulations and they are operated according to the related international rules (IMO, 2021). Many important conventions proposed by the IMO and the International Labour Organization (ILO) are covered by the PSC and are also the inspection target termed as ‘deficiency code’. A deficiency is a condition violating the regulations or conventions found onboard a ship by the inspectors who are also called PSC officers (PSCOs). If any serious/fatal deficiency is found onboard a ship by a PSCO, he/she can take a mandatory intervention action named detention to ensure that the hazard is addressed before the ship is allowed to leave the port (Yan et al., 2021c). After launching in 1982, nine regional agreements on PSC, which are called Memorandum of Understandings or MoUs, have been signed globally: Paris MoU, Tokyo MoU, Acuerdo de Viña del Mar, Paris MoU, Tokyo MoU, Acuerdo de Viña del Mar.

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https://doi.org/10.1016/j.tranpol.2022.04.002
Received 4 July 2021; Received in revised form 30 January 2022; Accepted 2 April 2022
Available online 19 April 2022
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Caribbean MoU, Abuja MoU, Black Sea MoU, Mediterranean MoU, Indian Ocean MoU, and Riyadh MoU. The United States Coast Guard maintains the tenth PSC regime.

A general PSC inspection procedure is as follows. After getting onboard a ship, the PSCO(s) would arbitrarily walk and look around the ship to access its overall condition. Then, documents and certificates are checked by the PSCO(s) to ensure that they are all onboard and correctly endorsed while also up to date. If little wrong is found onboard, an inspection might be concluded fairly rapidly. On the contrary, clear grounds regarding either the ship or its master or crewmembers could lead to a more detailed inspection, which is an in-depth inspection of the ship’s various conditions such as construction, Manning, equipment, and living and working situation. After an inspection, the results are recorded in the corresponding MoU’s database (Yan et al., 2020).

The outbreak of the Coronavirus disease (COVID-19) at the beginning of 2020 has an evident impact on the maritime industry due to the multi-nationality of the crew, the international nature of the shipping industry, and the lockdown of borders all over the world, making surveys, crew changes, and regular inspections difficult to be carried out as usual (Akyurek and Bolat, 2020). Especially, most of the special measures adopted during this difficult time are for the prevention of spread and escalation of the COVID-19. As PSC involves in-person attendance of PSCOs to foreign vessels and the two-way communication between onboard and onshore staff, it is inevitably influenced by the COVID-19 pandemic from various perspectives. Actually, in a video meeting organized by the IMO on April 8, 2020, the 10 PSC regimes all participated, a flexible measure, i.e., the so-called “pragmatic, practical and flexible” approach was agreed upon. This approach is mainly related to the adoption of flexible while harmonized actions to address the issues of certificate exemptions, waivers, and extensions of seafarers and ships and seafarers’ extended periods of service on board (IMO, 2020). Interim guidance relating to COVID-19 circumstances is further developed by individual MoUs, which is attached in the Circular Letter published by the IMO (2020). For example, it is clearly stated by the Tokyo MoU that pragmatic relaxation and case-by-case approaches should be adopted by member authorities regarding “extending periods of service onboard of seafarers, delaying periods for surveys, inspections and audits, etc.” (MoU, 2020).

Within this context, the main objective of this study is to explore whether the global and regional PSC inspections are influenced by the COVID-19 pandemic; and if yes, in which aspects and to what extent the PSC is influenced. To be more specific, we search and compare PSC data from different MoUs and ports around the world from 2017 to 2020. Furthermore, we select the port of Hong Kong as an example to explore the influence of the COVID-19 on the regional PSC inspection status by comparing the PSC condition between 2015 and 2019 and that in 2020 considering a wider range of indicators. Our key novelties and contributions are listed as follows.

a) To the best of the authors’ knowledge, this is the first study that compare PSC inspection statuses before and after the COVID-19 pandemic on a monthly basis in various MoUs and typical ports around the world based on a large amount of data. The potential reasons for the differences among the MoUs and ports are also discussed considering the pandemic situation and prevention measures in individual regions and countries.

b) This is also the first study that analyzes and explains the PSC inspection status at a port level (with the Hong Kong port as an example) from the perspectives of inspection status and inspection outcome (deficiency and detention) while considering local pandemic intensity. Especially, comprehensive description, comparison, and explanation of the changes in ship deficiency and detention conditions before and after the outbreak of COVID-19 are conducted. Furthermore, regression analysis is used to disentangle various influencing factors on PSC inspection results during the pandemic.

c) Based on the above analysis, policy and managerial insights are generated, which are beneficial to marine departments for policy making and strategy adjustment and to ship owners and managers for vessel maintenance and management.

2. Literature review

As PSC is one of the most significant marine policy, much attention has been put on the research of PSC. Those studies can be generally classified into three main categories: studies on PSC efficiency improvement, studies on PSC’s impacts, and studies on the overall evaluation of PSC (Yan and Wang, 2019). As this study aims to evaluate the influence of the COVID-19 pandemic on PSC inspection, we mainly review studies in the third category in this section.

2.1. Improving maritime safety by PSC

Enhancing maritime safety is one of the main purposes of PSC inspection. Therefore, there are some studies aiming at evaluating the effectiveness of PSC on the reduction of maritime accidents. Knapp and Franses (2008) conducted a prior study on measuring and interpreting the quality of an inspection, which could be either PSC inspection or vetting inspection, towards the probability of a very serious, serious, or less serious casualty. Results of binary regression models suggested that PSC inspections could decrease the probability of casualty in some areas over the world. Rodríguez and Piniella (2012) also concluded that the New Inspection Regime (NIR) in PSC could contribute to the reduction of maritime accidents. Yang et al., 2020 conducted a comparative analysis between the pre-NIR and post-NIR based on macroscopic approach and microscopic analysis to assess the NIR’s influence. Results showed that the NIR could improve the PSC inspection system, vessel quality, and maritime safety.

2.2. Discrepancies in PSC inspection

Much of the current literature on PSC overall evaluation and analysis pays particular attention to explore the causes leading to the discrepancy and inconsistency in ship selection criteria and onboard inspection process within different PSC regimes, the member states of one MoU, and even the PSCOs at the same port (Yan et al., 2020; Yan et al., 2021b; Yan et al., 2021d). Knapp and Franses (2007) and Knapp and Van de Velden (2009) both showed that the treatment of vessels across the MoUs was inconsistent based on more than 180k inspection records in more than 50 individual port states over the world. Especially, most differences can be found in the deficiencies leading to detention across the regimes. In addition, the background of PSCOs could also influence the detention decision and deficiency codes. Emenee Kara et al. (2020) demonstrated differences among MoUs based on the performance of flag states using a hierarchical clustering method to analyze detention and deficiency rates. Different levels of discrepancy among MoUs were identified.

Regarding the differences among member states of the same MoU, Bateman (2012) showed that although PSC was effective in the developed areas, it worked much less effective in the developing areas within the Indian MoU due to piracy and armed robbery against ships, less highly-skilled PSCOs, and the limited resources provided by the IMO to assist the effectiveness of PSC regimes. For detailed reasons leading to such discrepancy, Ravira and Piniella (2016) proposed that the professional profile of PSCOs could influence the PSC inspection results in Spain. Based on 14 interviews with subject matter experts, Graziano et al. (2017) concluded that although PSC in Europe was efficient and reliable, discrepancies existed in the process and outcome of inspections as a result of differences at the inspector and member state level. After analyzing more than 32k inspections conducted within the Paris MoU, Graziano et al. (2018) showed that the PSCO team composition and the PSCOs’ backgrounds could significantly influence the deficiency number.
and detention. In addition, the types of deficiencies detected would also be influenced by the background of PSCOs. A similar pattern was also identified in the Black Sea MoU where the member states within the same MoU adopted their own inspection approaches, and thus differences in inspections among the ports within the same MoU existed (Sanlier, 2020).

2.3. Comments on improving PSC inspection

Comments and suggestions for improving PSC inspection, either for a certain region or in the general context, are also given in current studies on PSC evaluation and analysis. Several current studies suggest further harmonizing the PSC inspection process as well as the inspection database all over the world to improve the overall safety standard and to reduce the ‘port shop’ of vessels (Knapp and Franses, 2008; Knapp and Van de Velden, 2009; Graziano et al., 2018). Li and Zheng (2008) addressed the effectiveness of the method for ship selection for inspection and the PSC based on ship total loss data and PSC inspection records. The authors concluded that the PSC is effective in improving the overall safety level of maritime transport. The current status of PSC in Taiwan Province, China was analyzed by Liou et al. (2011) via expert-interviews, the Analytic Hierarchy Process (AHP) model, and the close-loop questionnaire survey, especially regarding the impartiality and objectivity of the port authorities. A countermeasure by establishing an independent government agency to improve the situation was proposed by the authors. Mansell (2009) examined various factors of the Tokyo MoU and identified challenges for its member authorities. Such issues and challenges included but were not limited to discrepancies in the capacity, contribution, quality, and performance among the ports as well as harmonization of the member states within the Tokyo MoU. In addition to proposing measures to harmonize PSC inspection, the dependency and interdependency among influencing factors are analyzed (Wang et al., 2021) and approaches to rationalizing detention decision (Yang et al., 2021) are proposed in existing literature to improve PSC inspection.

To the best of our knowledge, there is only one paper aiming to analyze the impact of the COVID-19 outbreak on the PSC inspection (Akyurek and Bolat, 2020). Specifically, the authors collected inspection records in Paris MoU from January 2015 to May 2020 and analyzed the data using Grey Relational Analysis (GRA). They found that the number of inspections decreased dramatically, and the deficiency and detention conditions changed mainly due to the COVID-19’s influence on the PSCOs. Meanwhile, the inspection and detention rate remained the same after the outbreak of the COVID-19. As the COVID-19 has a significant impact on the global supply chain and the maritime industry, there is also an urgent need to comprehensively analyze whether the global and regional PSC inspection statuses are influenced by the COVID-19, and if yes, how it is influenced. This study aims to achieve this objective by first analyzing the global general PSC inspection status in 2020, and then analyze the inspection conditions at the port of Hong Kong in detail from a comprehensive perspective ranging from the number of inspections conducted and the detailed deficiency codes detected.

3. Overview of PSC inspection status all over the world

In this section, we give an overview of the PSC inspection status all over the world before and after the outbreak of the COVID-19 in 2020. Especially, online public inspection data can be found for eight MoUs, namely Abuja MoU (2021), Black Sea MoU (2021), Caribbean MoU (2021), Indian Ocean MoU (2021), Mediterranean MoU (2021), Paris MoU (2021), Riyadh MoU (2021), and Tokyo MoU (2021). In other words, Acuerdo de Viña del Mar and the United States Coast Guard do not provide public historical inspection records. We collect inspection data from 2018 to 2019 for Indian MoU where inspection records in 2017 are not accessible and the inspection data from 2017 to 2019 for all the other MoUs with public inspection records. We consider three indicators to describe the status of PSC inspection in each MoU: the number of inspections conducted (denoted by NO_INS), the average number of deficiencies (i.e., the ratio of the total number of deficiencies identified and the total number of inspections; denoted by AVG_DEF), and the detention rate (i.e., the ratio of the number of inspections that lead to detention and the total number of inspections; denoted by DET_R). We first present monthly statistical inspection data for each MoU with available inspection information in Section 3.1, and then present monthly inspection status of ports in different MoUs in Section 3.2.

3.1. Monthly inspection status in MoUs around the world

To have a closer examination of the global PSC inspection status, we present the trend of NO_INS, AVG_DEF, and DET_R on a monthly basis in 2020 in Fig. 1. To further test whether there are significant differences in the changes of the numbers of inspections conducted, the average numbers of deficiencies, and the detention rates in PSC inspections in each MoU before and after the outbreak of the COVID-19, respectively, we conduct a statistical test. To reduce the influence of absolute values on the comparison results, we first calculate the rate of change between the average values of 2017 (or 2018) to 2019 and the values of 2020 for the three indicators on a monthly basis, respectively. Then, we figure out whether the difference between the rates of change and zero is significant. As the rates of change are continuous and the observations are independent of each other, we adopt one sample t-Test if the values follow normal distribution according to the Shapiro-Wilk test and one sample Wilcoxon signed rank test, otherwise. We set the significance level α = 0.05 in both the Shapiro-Wilk test and one sample t-Test/one sample Wilcoxon signed rank test. The null hypotheses of the statistical tests are presented in Table 1. The test results are presented in Table 2.

As presented in Fig. 1, NO_INS in January 2020 is similar to the average status of the same period from 2017 (or 2018) to 2019. It starts to decrease from February 2020 in all MoUs except for Black Sea MoU, whose value begins to decrease since March 2020. The downward trend lasts until April or May for all MoUs except for Riyadh MoU, where no inspection is carried out since May to the end of 2020. After reaching the bottom, the number of inspections conducted in other MoUs begins to increase. The main reason for the downward trend is the decrease in the physical on-board ship inspections conducted during the COVID-19, especially after the WHO declared the COVID-19 a pandemic on March 11, 2020. Meanwhile, to perform the duties of PSC during such special and difficult time, 10 PSC regimes had an online meeting on April 8, 2020 and reached an agreement upon conducting a “pragmatic, practical and flexible” approach in a standardized and harmonized way which was coordinated by the IMO (IMO, 2020). Since then, PSC regimes began to issue guidance to recover ship inspection during the COVID-19 pandemic, which led to a rise in the number of inspections conducted by most of the MoUs. The inspection status becomes much more stable since June 2020. Although the IMO and the PSC regimes took timely responses, the mean/median of the change of NO_INS is significantly different from zero in most MoUs as shown in Table 3.

After the outbreak of the COVID-19 in 2020, there are two typical patterns of AVG_DEF in 2020: one is that the monthly AVG_DEF in 2020 is smaller than that of the average level between 2017 and 2019, and the other is that the monthly AVG_DEF in both periods show similar patterns. Especially, the first pattern can be observed in Tokyo MoU, Abuja MoU, Black Sea MoU, and Mediterranean MoU, and the second pattern can be observed in Indian MoU and Paris MoU. Take the Tokyo MoU as an example, the divergent pattern of the monthly AVG_DEF in these two periods is caused by different inspection measures adopted by countries and regions where a considerable part of deficiencies are identified. A typical example is China, where 27,910 deficiencies are detected in 2019 (accounting for 38% of all deficiencies detected in Tokyo MoU), while only 2,363 deficiencies are detected in 2020 (accounting for 7% of all deficiencies detected in Tokyo MoU). This is mainly caused by the
conservative pandemic prevention policy of China to halt the spread of COVID-19 by strictly reducing the onboard and onshore interaction. As a possible consequence, even if an inspection is conducted, less areas and items would be covered to reduce the interactions and the risk of infection, and thus lead to less deficiencies detected. A significant decrease in the number of deficiencies detected from 2019 to 2020 can also be observed in other major countries and regions, such as Hong Kong (China), Japan, Malaysia, and Singapore (Tokyo MoU, 2020a; 2021). Meanwhile, for both MoUs belonging to the second pattern, more fluctuations in the AVG_DEF are shown in 2020 compared to the situation between 2017 and 2019. This is mainly caused by the ever-changing intensity of pandemic and the corresponding pandemic prevention policies.

Finally, for indicator DET_R, the test of significance (Table 3) shows that only in three MoUs (i.e., Tokyo, Caribbean, and Mediterranean), the detention rates of 2020 are significantly different from the average level before 2020. Regarding the variations in DET_R, only the Tokyo MoU shows a basically stable pattern in all months of 2020 except for October. While in all the other MoUs, it varies dramatically in different months. We analyze the potential reasons as follows. The adoption of flexible measures agreed by the MoUs is one potential reason for the fluctuations in DET_R during 2020 observed in many MoUs. Decisions on ship inspection as well as deficiency and detention recording would be more influenced by the pandemic situation, the conditions of the ship, its management company and recognized organization, and the PSCOs’ behaviors and attitude. Consequently, DET_R gets more varied in different months throughout 2020. Furthermore, for MoUs where NO_INS shows many fluctuations, the fluctuations in DET_R are highly
likely to be caused by the fluctuations in NO_INS as the number of detentions is very small in itself, and thus it is more likely to be influenced by NO_INS which is the denominator for calculating DET_R.

Meanwhile, the NO_INS is stable in some MoUs, but the DET_R fluctuates a lot during 2020, e.g., the Indian MoU. This is mainly because more than 80% of the detention actions were carried out by ports in Australia in 2020 (178 out of 218; IOMoU, 2021), and thus DET_R is heavily influenced by the inspection policy and action as well as the pandemic intensity in Australia. Especially, the two highest values for DET_R appear in May and October 2020, which are just after the first wave of the COVID-19 pandemic in Australia from March to April 2020, and at the end of the second wave from June to October 2020 (BBC, 2020a), respectively. As the inspection data of Australia are also included in the Tokyo MoU, the surge in detentions in October of Australia also increases the DET_R in Tokyo MoU. However, as some other regions and countries, such as China, Indonesia, Japan, Republic of Korea, and Russian Federation, each account for 10% of all inspections, the overall trend of DET_R is relatively stable in Tokyo MoU over 2020 (Tokyo MoU, 2021). It is also interesting to find that except for April, May, and December in 2020, the DET_R is actually stable in Paris MoU. The potential reason is that PSC inspection in Paris MoU is heavily influenced by the COVID-19 in March, which is also reflected by the extremely low numbers of inspections and deficiencies. When it came to April, Paris MoUs tries to bring PSC back to normal, and part of the detentions (and deficiencies) compensate for those in March. As the detention rate is relatively stable in Paris MoU over the years while the detention rate is too low in the first eleven months in 2020 (Tokyo MoU, 2021), December 2020 observes a surge in ship detentions to catch up
In sum, the outbreak of the COVID-19 has a significant influence on NO_INS and also some impacts on AVG_DEF and DET_R due to several direct and indirect reasons. We summarize the influences and the possible reasons as follows.

- **COVID-19** reduces the monthly NO_INS in 2020 as expected. In most of the MoUs, there is a sharp decrease followed by an increase in NO_INS. Especially, the increase is observed after the online meeting of the IMO and the 10 PSC regimes on April 8, 2020, where an agreement upon conducting a “pragmatic, practical and flexible” inspection approach to retain the effectiveness of PSC during the pandemic is reached.

- There are two typical patterns of the monthly AVG_DEF among the MoUs in 2020, one is smaller than the average level between 2017 and 2019, and the other is similar to the pattern between 2017 and 2019. The potential reasons are mainly related to the pandemic prevention and inspection regulations of the countries and regions where a considerable part of the deficiencies are identified.

- Except for Tokyo MoU, all the other MoUs witness fluctuations in DET_R in different months of 2020. Potential reasons include the flexible measures adopted, fluctuations in NO_INS, the degree of concentration of detentions detected among the member states, and the regulations of the MoUs.

**Fig. 1.** (continued).
3.2. Monthly inspection status of ports in different MoUs

The macroscopic analysis of MoUs around the world in Section 3.1 shows that the influence of COVID-19 on different MoUs might be different. To have a closer examination of the influence and differences, we further analyze microscopic analysis on ports belonging to different MoUs. We select one representative port from the top-3 MoUs with the largest number of inspections conducted in 2020, i.e., the Port of Shanghai (China) for Tokyo MoU, the Port of Rotterdam (The Netherlands) for Paris MoU, and the Port of Melbourne (Australia) for Indian MoU. NO_INS, AVG_DEF, and DET_R on a monthly basis of the three ports in 2019 and 2020 are shown in Fig. 2.

Distinct COVID-19 pandemic patterns are observed in the three countries of concern. In China, the pandemic outbreak at the beginning of 2020, where more than 10 thousand confirmed cases were recorded in
The monthly confirmed cases began to decrease since March, and the situation was relatively stable until the end of 2020. The trend is opposite in the Netherlands, where there were few confirmed cases in the first two months in 2020, and then an increase from January to March, followed by a decrease to June, and then a sharp upward trend from July to December, especially during October and December. The pattern in Australia is different from that in the Netherlands, where the minimum number of inspections appeared one month later than the peak of the two waves, respectively. Especially, as the second wave of infection was attributed to an outbreak at a Mel bourne quarantine hotel, Victoria underwent a second strict lockdown, reducing the number of inspections to zero in August and September. Meanwhile, it is also observed that there would be an obvious increase in the inspection number after each wave of infection.

Table 2
Test of significance of the change in inspection status all over the world.

| MoU-Indicator’s rate of change | P value for normality test | Normal distribution? | Test of significance selected | P value for the test of significance | Significant difference in mean (median) and zero? | Average difference between the mean (median) of the average of 2017 (or 2018) to 2019 and the mean (median) of 2020 |
|--------------------------------|---------------------------|----------------------|-------------------------------|-------------------------------|-----------------------------------------------|--------------------------------------------------------------------------------------------------|
| Tokyo MoU NO_INS              | 0.196                     | Yes                  | One sample t-test             | 0                             | Yes                                           | −39.38%                                                                                           |
| AVG_DEF                       | 0.730                     | Yes                  | One sample t-test             | 0                             | Yes                                           | −21.87%                                                                                           |
| DET_R                         | 0.014                     | No                   | One sample Wilcoxon test     | 0.034                         | Yes                                           | −14.00%                                                                                           |
| Abuja MoU NO_INS              | 0.548                     | Yes                  | One sample t-test             | 0.226                         | No                                            | −11.20%                                                                                           |
| AVG_DEF                       | 0.958                     | Yes                  | One sample t-test             | 0.004                         | Yes                                           | +98.86%                                                                                           |
| DET_R                         | 0.013                     | No                   | One sample Wilcoxon test     | 0.152                         | No                                            | −56.00%                                                                                           |
| Black Sea MoU NO_INS          | 0.384                     | Yes                  | One sample t-test             | 0.166                         | No                                            | +5.43%                                                                                            |
| AVG_DEF                       | 0.440                     | Yes                  | One sample t-test             | 0                             | Yes                                           | −32.91%                                                                                           |
| DET_R                         | 0.613                     | Yes                  | One sample t-test             | 0.087                         | No                                            | −11.84%                                                                                           |
| Caribbean MoU NO_INS          | 0.528                     | Yes                  | One sample t-test             | 0                             | Yes                                           | −69.91%                                                                                           |
| DET_R                         | 0                         | No                   | One sample Wilcoxon test     | 0.033                         | Yes                                           | −100%                                                                                             |
| Indian MoU NO_INS             | 0.016                     | No                   | One sample Wilcoxon test     | 0.006                         | Yes                                           | −13.00%                                                                                           |
| AVG_DEF                       | 0.361                     | Yes                  | One sample t-test             | 0.641                         | No                                            | −1.03%                                                                                            |
| DET_R                         | 0.032                     | No                   | One sample Wilcoxon test     | 0.239                         | No                                            | +4.00%                                                                                            |
| Mediterranean MoU NO_INS      | 0.232                     | Yes                  | One sample t-test             | 0                             | Yes                                           | −38.65%                                                                                           |
| AVG_DEF                       | 0.838                     | Yes                  | One sample t-test             | 0                             | Yes                                           | −11.96%                                                                                           |
| DET_R                         | 0.603                     | Yes                  | One sample t-test             | 0.001                         | Yes                                           | −44.48%                                                                                           |
| Paris MoU NO_INS              | 0.022                     | No                   | One sample Wilcoxon test     | 0.006                         | Yes                                           | −12.00%                                                                                           |
| AVG_DEF                       | 0.378                     | Yes                  | One sample t-test             | 0.065                         | No                                            | −5.30%                                                                                            |
| DET_R                         | 0.617                     | Yes                  | One sample t-test             | 0.082                         | No                                            | −13.66%                                                                                           |
| Riyadh MoU NO_INS             | 0                         | No                   | One sample Wilcoxon test     | 0.002                         | Yes                                           | −100.00%                                                                                          |
| DET_R                         | 0                         | No                   | One sample Wilcoxon test     | 0.621                         | No                                            | −100.00%                                                                                          |

The pandemic brings about reduction and fluctuation to AVG_DEF to all the three ports, which becomes the most evident in months with no PSC inspection. Especially, this indicator returns to normal after mid-2020 at the Port of Shanghai. It is lower than the situation in 2019 since June after reaching the bottom at the Port of Rotterdam. The trend...
of AVG_DEF at the Port of Melbourne in 2020 is similar to that in 2019, except for the period of the second wave from August to October. The fluctuation in DET_R at the Port of Shanghai is magnified by the pandemic in 2020. Specifically, the DET_R curve is serrated in 2019, showing that there are some fluctuations. Such fluctuation is amplified between 2015 and 2020 from Asia Pacific Computerized Information System (APCIS), which is a public database owned by the Tokyo MoU.

Apart from basic inspection indicators adopted in Section 3, we also consider other indicators including the inspection rate of individual ships, the types of inspections conducted, the risk profiles of ships inspected, detected deficiency codes in each inspection, deficiency codes leading to detention, and the relationship between the number of daily local confirmed cases of the COVID-19 in Hong Kong and the daily number of PSC inspections conducted. Detailed analysis is presented in the following subsections.

4. Inspection status at the port of Hong Kong

We search and download all PSC records at the port of Hong Kong between 2015 and 2020 from Asia Pacific Computerized Information System (APCIS), which is a public database owned by the Tokyo MoU. Apart from basic inspection indicators adopted in Section 3, we also consider other indicators including the inspection rate of individual ships, the types of inspections conducted, the risk profiles of ships inspected, detected deficiency codes in each inspection, deficiency codes leading to detention, and the relationship between the number of daily local confirmed cases of the COVID-19 in Hong Kong and the daily number of PSC inspections conducted. Detailed analysis is presented in the following subsections.

4.1. The number of inspections conducted and the inspection rate

The number of inspections conducted at the Hong Kong port on a
Fig. 2. Monthly inspection status of three representative ports in 2019 and 2020.

(a) Monthly inspection data of the Port of Shanghai  
(b) Monthly inspection data of the Port of Rotterdam  
(c) Monthly inspection data of the Port of Melbourne

Fig. 3. Monthly number of inspections conducted.
Note: the numbers on the right of each box from the top to the bottom refer to the values at first quartile, second quartile (i.e., median), and third quartile of the monthly number of inspections conducted in each year, respectively.
monthly basis from 2015 to 2020 is presented in Fig. 3. It is clearly shown that the medians of the monthly number of inspections conducted over the period of 2015 and 2019 are quite stable, ranging from 60.5 to 78. After the outbreak of the COVID-19 in January 2020, the median drastically reduces to 16, which is only about one quarter of the average level before the pandemic. Additionally, in 2020, the largest number of inspections on a monthly basis is carried out in January as 74, which is similar to the situation in the same period of previous years. It is also noted that there are three months (i.e., February, August, and December) with no inspections conducted and one month (i.e., April) with only two inspections conducted in 2020, which never happened before 2020.

An individual ship might be inspected more than once in a month as it can go through multiple initial inspections or both initial and follow-up inspections. To demonstrate the change of inspection rate of individual ships (denoted by inspection rate for short) at the Hong Kong port, we further calculate the ratio of the individual ships inspected and the number of foreign-flag vessels calling Hong Kong (Marine Department of HKSAR, 2021) on a quarterly basis. The inspection rate of each quarter from 2015 to 2020 is shown in Fig. 4. It can be seen that the quarterly inspection rates are relatively stable in 2015 and 2018 over the whole year. In 2016, 2017, and 2019, drastic change occurs in the fourth quarter, the fourth quarter, and the third quarter, respectively, while the inspection rates have some minor fluctuations in the remaining quarters. When it comes to 2020, there is a sharp decline in inspection rates in all quarters compared to the same period of previous years. The inspection rate even decreases to 1.33% in the third quarter. Similar to 2019, the curve of the inspection rates in 2020 shows a jagged shape.

To find out whether the monthly number of inspections conducted and the quarterly inspection rates before and after the outbreak of the COVID-19 are significantly different, we conduct statistical tests. We first calculate the rates of change for the two indicators, and then we examine whether the difference between the rates of change and zero is significant. The basic settings and procedures are the same as those used in Section 3.2. The null hypotheses of the statistical tests are the same as those presented in Table 1. The test results are given in Table 4. It indicates that on average, both of the changes in the inspection number on a monthly basis and the inspection rates on a quarterly basis are significant before and after the outbreak of the COVID-19. Especially, the number of inspections is reduced by 76% regarding the median and the inspection rate is reduced by 57% regarding the mean.

4.2. Types of inspections conducted and ships inspected

According to the requirements of IMO and Tokyo MoU, there are two types of PSC inspections in the Asia-Pacific region: initial inspection and follow-up inspection (either onsite or remote) (IMO, 2017; Tokyo MoU, 2020a). Initial inspection means an onboard visit to a ship to check the certificates and documents of the vessel and its crew and the ship’s overall condition. A more detailed inspection will be conducted during an initial inspection if there are clear grounds found. The follow-up inspection is an inspection by PSCO for verifying rectification of deficiency (or deficiencies) found at the previous initial inspection(s) of a ship. A follow-up inspection can be onsite or remote. The remote follow-up inspection was first tried in 2019 by Tokyo MoU to allow PSCOs to verify and close certain deficiencies in specific circumstances without physically visiting the vessel (Tokyo MoU, 2020a). The distribution of the percentage of each type of inspection conducted on a monthly basis from 2015 to 2019 and in 2020 are presented in Fig. 5. It shows that the distribution of each inspection type is relatively stable during 2015 and 2019. In addition, the ratio of initial inspection to onsite follow-up inspection ranges between 2.9 and 4.5 and is relatively unvarying. In contrast, in 2020, most of the inspections are carried out when the pandemic intensity is loose, i.e., in January, May, June, and October. When the intensity is tight, few or even no inspection is conducted, i.e., in February, August, and December. The ratio of initial inspection to onsite follow-up inspection becomes much more fluctuated, ranging from 2.7 to 14. It is also shown in Fig. 5 that remote follow-up inspections are carried out in May, June, September, and October, which is a type of flexible inspection measure adopted with the aim to verify that

![Fig. 4. Quarterly inspection rates of individual ships.](image-url)
The ships have rectified the deficiencies while minimizing interactions between the crew and the PSC officers.

The New Inspection Regime adopted by the Tokyo MoU since 2014 divides a foreign visiting ship into one of the three ship risk profiles: HRS (High Risk Ship), SRS (Standard Risk Ship), and LRS (Low Risk Ship). Different inspection time windows are attached to each SRP. The ship selection procedure adopted at the member states of Tokyo MoU is based on the time window and the SRP: A ship must be inspected if its last inspection time is longer than its time window; a ship can be inspected if its last inspection time is within its time window; otherwise, a ship should not be inspected only if overriding factors exist (Tokyo MoU, 2013). The types of ships inspected from 2015 to 2020 are illustrated in Fig. 6.

![Fig. 6. Distribution of inspection types from 2015 to 2020.](image)

Table 4: Test of significance of the change in inspection status in Hong Kong port.

| Indicator’s rate of change          | P value for normality test | Normal distribution? | Test of significance selected         | P value for the test of significance in mean (median) and zero? | Significant difference in mean (median) of the average of 2017 (or 2018) to 2019 and the mean (median) of 2020 |
|-------------------------------------|----------------------------|-----------------------|---------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Monthly inspection number at the Hong Kong port | 0.033                      | No                    | One sample Wilcoxon test              | 0.004                                                         | Yes                                                                                             | −76.00%                                                                                          |
| Quarterly inspection rate at the Hong Kong port | 0.681                      | Yes                   | One sample r-Test                     | 0.014                                                         | Yes                                                                                             | −56.99%                                                                                          |

Intuitively, the local COVID-19 pandemic status would influence the PSC inspection conditions at the port of Hong Kong as there will be special work arrangements (e.g., work from home or the reduction of the number of people on duty) for government employees according to the local pandemic situation (GovHK, 2020). For simplicity, we use the number of daily local confirmed cases reported by the Census and Statistics Department of Hong Kong (GovHK, 2021) as the local COVID-19 pandemic status.

![Fig. 5.](image)

4.3. Relationship between local pandemic status and PSC inspection

Intuitively, the local COVID-19 pandemic status would influence the PSC inspection conditions at the port of Hong Kong as there will be special work arrangements (e.g., work from home or the reduction of the number of people on duty) for government employees according to the local pandemic situation (GovHK, 2020). For simplicity, we use the number of daily local confirmed cases reported by the Census and Statistics Department of Hong Kong (GovHK, 2021) as the local COVID-19 pandemic status.
pandemic status. To have an overview of the relationship between the number of daily local confirmed cases and the daily number of PSC inspections conducted, we plot the two curves in the same figure as presented in Fig. 7.

It is clearly indicated in Fig. 7 that the first local confirmed case appeared on January 23, 2020 in Hong Kong. Over the whole year of 2020, there were three waves of the COVID-19: during March and April, during July and August, and during November and December. As expected, very few PSC inspections were conducted during the three waves. By contrast, when there were limited local confirmed cases,

Fig. 6. Distribution of the types of ships inspected.

Fig. 7. Curves of the daily number of local confirmed cases and the PSC inspection.
usually one to six PSC inspections would be conducted per day. Therefore, it seems that the number of local confirmed cases is the causality of the number of PSC inspections conducted. To test whether such causality relation is significant from a statistical point of view, the Granger causality test (Granger, 1969) is conducted. The basic idea of the Granger causality test is that if the time-series variable \( X \) is the Granger cause of the time-series variable \( Y \), then the future values of \( Y \) can be better predicted using historical values of both \( X \) and \( Y \) than it can by using the historical values of \( Y \) alone. Note that ‘causality’ here means a statistical ‘causality’ which is supported by distribution or probabilistic distinction of samples instead of a strict logic ‘causality’.

In our case, the variable \( X \) is the number of daily local confirmed cases of the COVID-19 and the variable \( Y \) is the daily number of PSC inspections conducted. We first centralize the distributions of the two variables by Eqs. (1) and (2) respectively:

\[
X'_{d} = X_{d} - \text{mean}(X), d = 1, ..., D, \quad (1)
\]
\[
Y'_{d} = Y_{d} - \text{mean}(Y), d = 1, ..., D, \quad (2)
\]

where \( D = 344 \) is the total number of days from January 23, 2020 to December 31, 2020 and \( d \) is the index of one day. Then, both variables are detrended by Eqs. (3) and (4) respectively:

\[
X'_{d} = X'_{d} - \text{br}(d, X'_{d}), d = 1, ..., D, \quad (3)
\]
\[
Y'_{d} = Y'_{d} - \text{br}(d, Y'_{d}), d = 1, ..., D, \quad (4)
\]

where \( \text{br}(d, X'_{d}) = \text{br}(d, Y'_{d}) \) is the predicted value of \( X'_{d} \) (\( Y'_{d} \)) by the linear regression model fitted by \( d = 1, ..., D \) and \( X'_{d} \) (\( Y'_{d} \)). Next, as the premise of the Granger causality test requires the distributions of both variables in a stationary condition, we perform Phillips–Perron test (Phillips and Perron, 1986) to test their stationarity with significance level \( \alpha = 0.05 \). The \( P \) values for \( X'_{d} \) and \( Y'_{d} \) are 0.000 and 0.014, respectively, indicating that both of them are stationary. Finally, the Granger causality test is conducted using statsmodels library in Python with different lag lengths from 1 to 4, where lag means the values of the number of days ahead used for the prediction of the value of the current day. The test results are shown in Table 5.

Table 5 illustrates that with lag length no more than 3, the number of daily local confirmed cases in the Granger causality of the daily number of PSC inspections conducted under significance level \( \alpha = 0.05 \) as indicated by different statistical tests consistently. The maximum lag length at 3 indicates that the response of port state authorities considering the local pandemic status is timely to protect the health of the people both onboard and onshore.

### 4.4. Deficiency and detention statuses at the Hong Kong port

According to deficiency code list published by the Tokyo MoU as of December 3, 2017 (Tokyo MoU, 2017), there are 17 types of deficiency codes which are the main inspection targets of a PSC inspection in the Asia-Pacific Region listed in Table 6. If any major deficiency (indicating the ship condition or its crew not corresponding substantially with the relevant conventions) is found, a detention action can be taken by the port state authority. Such deficiency leading to detention is called a detainable deficiency.

In this section, we aim to analyze the deficiency (including detainable deficiency) and detention conditions at the Hong Kong port from 2015 to 2020. We first present the general inspection, deficiency, and detention statuses on an annual basis from 2015 to 2020 in Table 7. It evidently shows that similar to the total number of inspections conducted over a year, the annual average number of deficiencies detected per inspection is significantly reduced in 2020 compared to the situations from 2015 to 2019. Moreover, there is a stable decreasing trend in the detention rate from 2015 to 2019, which evidently shows that the quality of vessels has been constantly improved and the number of substandard ships is gradually reduced. This also reflects that the inspections conducted by port states “can be extremely effective” by providing a “safety net to catch substandard ships” as reported by the IMO (IMO, 2021). Meanwhile, the reasons for the decrease in detention rate from 2019 to 2020 might be more complicated. In addition to the improvement of ship conditions, such trend is also highly likely to be caused by the influences of the COVID-19, which leads to different ship selection and inspection methods as onshore and onboard interactions and face-to-face interactions are reduced. Consequently, less items onboard could be inspected, and less time could be spent during an inspection, leading to less detention decisions.

It is also interesting to find that the percentage of inspections without deficiency identified reaches the highest value in 2020 during this six-year period which is over 20%. In contrast, only about 7.4% of all the inspections conducted in 2017 have no deficiencies identified. Overall, it can be seen that a more flexible inspection strategy is applied at the Hong Kong port during the special circumstance brought by the COVID-19: There is an obvious decrease in the total number of inspections conducted (even though the number of vessels calling the Hong Kong port also decreases) as well as the average number of deficiencies per inspection and the detention rate; and the percentage of inspections without deficiency detected increases considerably.

#### 4.4.1. Deficiency conditions at the Hong Kong port

The average number of deficiencies detected per inspection on a monthly basis is presented in Fig. 8. It indicates that there are some variations in the medians of the average deficiency number per inspection between 2015 and 2019, while the overall status is generally stable. After the outbreak of the COVID-19 in 2020, the average number of deficiencies per inspection heavily decreases. Specifically, except for the three months with no inspections conducted, the median of inspection rate is reduced to 2.79, which is almost halved compared to the largest median value between 2015 and 2019 (i.e., 5.415 in 2017).

| Table 6 |
| --- |
| List of deficiency codes required by Tokyo MoU (2021) |

| Code | Meaning |
| --- | --- |
| 01 | Certificates & documentation | Safety of navigation |
| 02 | Structural condition | Life saving appliances |
| 03 | Water/Weatherlight condition | Dangerous goods |
| 04 | Emergency system | Propulsion and auxiliary machinery |
| 05 | Radio communication | Pollution prevention |
| 06 | Cargo operations including equipment | International Safety Management (ISM) |
| 07 | Fire safety | Labour conditions |
| 08 | Alarms | Other |
| 09 | Working and living conditions |

Please note that although the format of Table 6 is a little bit different from the one in the original manuscript, the content is the same.

### 4.4.2. Detention conditions at the Hong Kong port

The detention rate from 2015 to 2019 is illustrated in Fig. 9. It shows that despite the trend of decreasing detention rate during the COVID-19 pandemic, the Hong Kong port still detains a substantial number of substandard ships. This also reflects that the inspections conducted by port states “can be extremely effective” by providing a “safety net to catch substandard ships” as reported by the IMO (IMO, 2021). Meanwhile, the reasons for the decrease in detention rate from 2019 to 2020 might be more complicated. In addition to the improvement of ship conditions, such trend is also highly likely to be caused by the influences of the COVID-19, which leads to different ship selection and inspection methods as onshore and onboard interactions and face-to-face interactions are reduced. Consequently, less items onboard could be inspected, and less time could be spent during an inspection, leading to less detention decisions.

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### 4.4.3. Inspections conducted by port states

The average number of inspections conducted by port states from 2015 to 2019 is illustrated in Fig. 10. It shows that despite the trend of increasing inspection rate during the COVID-19 pandemic, the Hong Kong port still has a substantial number of inspections conducted. This also reflects that the inspections conducted by port states “can be extremely effective” by providing a “safety net to catch substandard ships” as reported by the IMO (IMO, 2021). Meanwhile, the reasons for the increase in inspection rate from 2019 to 2020 might be more complicated. In addition to the improvement of ship conditions, such trend is also highly likely to be caused by the influences of the COVID-19, which leads to different ship selection and inspection methods as onshore and onboard interactions and face-to-face interactions are reduced. Consequently, less items onboard could be inspected, and less time could be spent during an inspection, leading to less inspection decisions.

It is also interesting to find that the percentage of inspections without deficiency identified reaches the highest value in 2020 during this six-year period which is over 20%. In contrast, only about 7.4% of all the inspections conducted in 2017 have no deficiencies identified. Overall, it can be seen that a more flexible inspection strategy is applied at the Hong Kong port during the special circumstance brought by the COVID-19: There is an obvious decrease in the total number of inspections conducted (even though the number of vessels calling the Hong Kong port also decreases) as well as the average number of deficiencies per inspection and the detention rate; and the percentage of inspections without deficiency detected increases considerably.
Fig. 9 shows that the top 10 deficiency codes among all the 17 types of deficiency codes constitute more than 88% of all the deficiencies identified on a yearly basis within the whole period from 2015 to 2020. Particularly, deficiency codes 07-Fire safety, 10-Safety of navigation, and 11-Life saving applications, which account for about half of all the detected deficiencies, are the top 3 deficiency codes identified each year between 2015 and 2019. Especially, deficiency code 07 is the most popular deficiency code in all the years except for 2017 when code 10 ranks top, while deficiency code 11 is the third most popular deficiency code over the five years. In 2020, codes 07 and 11 remain in the top 3, while code 03-Water/weathertight conditions, ranking between 4th and 7th during 2015 and 2019, becomes second on the list.

As the first inspection item during a typical PSC inspection, deficiency code 01-Certification & documentation ranks from 6th to 8th between 2015 and 2017 and in 2019, and 4th in 2018. It is not surprising to find that it drops out of the top 10 (in 11th place at 3.545%) in 2020 during the COVID-19 pandemic. This is because during this special period when regular surveys, certification, and crew change, etc. become extremely difficult, flexible measures are adopted by the Tokyo MoU on a case-by-case basis for periods up to a maximum of three months, such as the extensions of validity of the ship’s certificates and the periods of service on board as well as the delaying periods for personnel certification (Tokyo MoU, 2020b).

It is also noted in Fig. 9 that deficiency code 09-Working and living conditions which ranks 4th in 2015 and 2016, first drops to 5th in 2017 and 2018, and then further drops to 11th in 2019. This indicates that the general living and working environments of seafarers on board have been greatly improved, thanks to the efforts of the ILO, the IMO, and the regional organizations as well as the local governments. In addition, deficiency code 09 ranks 7th in 2020 among all the deficiency codes. Its rise in the ranking shows that during the COVID-19 pandemic when crew changes and repatriation of seafarers become particularly difficult and the mental wellbeing of seafarers is heavily influenced, port states put more efforts on guaranteeing seafarers’ decent living and working conditions to release their mental fatigue and stress (ILO, 2021).

Another deficiency code related to seafarers’ welfare, namely 18-Labour conditions, which emphases more on aspects of seafarers’ employment condition, daily life (e.g., accommodation, food, catering, and recreational facilities), medical care, and social security, has received more and more attention in PSC inspections over the years. To be more specific, only one deficiency under code 18 was identified in 2015, ranking last on the deficiency code list. In 2017, more than 40 deficiencies under code 18 were identified. During 2019, a total of 243 deficiencies under code 18 were identified at the Hong Kong port, which
ranks 5th on the code list. In 2020, it ranks 8th on the code list. It is also worth mentioning that in 2019 and 2020, more than half of the deficiencies under code 18 are under subcode 184-Labor conditions-Health protection, medical care, social security. After the adoption and entry into force of the Maritime Labour Convention (MLC) 2006 with regards to seafarers’ rights and welfare, whether ships are MLC 2006 compliant will be subject to inspections conducted by port states. In recent years, increasing attention paid by the port state authorities to deficiencies under code 18 indicates that additional efforts are paid to eliminate ill-treatment of seafarers by effectively guaranteeing their welfare, not only regarding basic factors like food, accommodation, clothing, medical, and sanitary facilities, but also related to their nutrition, hygiene in accommodation and food, and recreational facilities. Such efforts can also be seen in the amendments of MLC 2006 in 2014 by the ILO which entered into force in January 2017 (Exarchopoulos et al., 2018).

Another issue worth mentioning is the general upward trend in the rank of deficiency code 14-Pollution prevention from 10th in 2016 to 6th in 2020. Specifically, there are eight subcodes under code 14: 141-MARPOL Annex I (the prevention of pollution by oil), 142-MARPOL Annex II (the control of pollution by noxious liquid substances in bulk), 143-MARPOL Annex III (the prevention of pollution by harmful substances carried by sea in packaged form), 144-MARPOL Annex IV (the prevention of pollution by sewage from ships), 145-MARPOL Annex V (the prevention of pollution by garbage from ships), 146-MARPOL Annex VI (the prevention of air pollution from ships), 147-Antifouling, and 148-Ballast water. The detailed numbers of deficiencies can also be seen in the amendments of MLC 2006 in 2014 by the ILO which entered into force in January 2017 (Exarchopoulos et al., 2018).

Another issue worth mentioning is the general upward trend in the rank of deficiency code 14-Pollution prevention from 10th in 2016 to 6th in 2020. Specifically, there are eight subcodes under code 14: 141-MARPOL Annex I (the prevention of pollution by oil), 142-MARPOL Annex II (the control of pollution by noxious liquid substances in bulk), 143-MARPOL Annex III (the prevention of pollution by harmful substances carried by sea in packaged form), 144-MARPOL Annex IV (the prevention of pollution by sewage from ships), 145-MARPOL Annex V (the prevention of pollution by garbage from ships), 146-MARPOL Annex VI (the prevention of air pollution from ships), 147-Antifouling, and 148-Ballast water. The detailed numbers of deficiencies can also be seen in the amendments of MLC 2006 in 2014 by the ILO which entered into force in January 2017 (Exarchopoulos et al., 2018).

![Fig. 9. Deficiency code distributions in each year at the Hong Kong port.](image-url)
under the subcodes of code 14 in each year are shown in Table 8.

Table 8 shows that regarding the deficiencies under code 14, there is no deficiency under subcode 142 detected, and there are few deficiencies under subcodes 143 and 147 detected at the Hong Kong port over the years concerned. Meanwhile, subcode 144 has the most deficiencies with a total number of 475, followed by subcode 141 with 309 deficiencies and subcode 146 with 263 deficiencies. There are obvious variations in the total number of deficiencies under code 14 identified over the years, with the largest number of deficiencies identified in 2018. The most possible reason is the conduction of Concentrated Inspection Campaign (CIC) on MARPOL Annex VI (i.e., related to subcode 146) from September 1, 2018 to November 30, 2018 by the member authorities of Tokyo MoU, where a total of 111 deficiencies under subcode 146 were detected at the Hong Kong port. It is also noted that only 79 deficiencies under code 14 were identified in 2020 due to the influence of the COVID-19 pandemic. Although the global limit on sulphur in ships’ fuel oil is required to be reduced to 0.50% from January 1, 2020, it is slightly surprising to find that only 7 deficiencies under subcode 146 were identified in 2020 due to the influence of the COVID-19 pandemic. The global limit on sulphur in ships’ fuel oil is required to be reduced to 0.50% from January 1, 2020, it is slightly surprising to find that only 7 deficiencies under subcode 146 were identified in 2020 due to the influence of the COVID-19 pandemic.

Overall, deficiency code 03 ranks in the top 3 for the first time in 2020 over the period from 2015 to 2020. Because of the flexible and pragmatic inspection measures adopted by the member states of Tokyo MoU, especially those related to the inspection of certificates and documents of ships and crew, the rank of code 01 is the lowest in 2020 over this whole period concerned and ranks out of top 10 for the first time. Besides, the overall seafarers’ living and working conditions have been greatly improved over the years, and it gained much attention again during the special circumstances during the COVID-19 pandemic. Meanwhile, another deficiency code related to seafarers’ rights and welfares, i.e., code 18 is receiving increasing attention over recent years. There is no apparent trend in the ratio of deficiencies detected under each subcode of deficiency code 14 related to environmental protection under the subcodes of code 14 in each year are shown in Table 8.

Table 8 | The number of deficiencies under the subcodes of code 14.
| Year/Code | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total |
|-----------|------|------|------|------|------|------|-------|
| 141'      | 64(32.82%)* | 41(36.28%) | 53(21.72%) | 77(18.60%) | 44(19.30%) | 30(37.97%) | 309 |
| 142'      | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) | 0 |
| 143'      | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) | 0 |
| 144'      | 75(38.46%) | 34(30.09%) | 92(37.70%) | 170(41.06%) | 79(34.65%) | 25(31.65%) | 475 |
| 145'      | 41(21.03%) | 29(25.66%) | 45(18.44%) | 50(12.08%) | 20(3.77%) | 14(17.72%) | 199 |
| 146'      | 75(38.46%) | 97(20.41%) | 53(21.72%) | 111(26.81%) | 69(30.26%) | 7(18.60%) | 263 |
| 147'      | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) | 2 |
| 148'      | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) | 0(0) | 24 |
| total     | 195 | 113 | 244 | 414 | 228 | 79 | 1,273 |

Note*: the percentage in each bracket is the ratio of the deficiency number under each deficiency subcode and the total number of deficiencies under code 14 identified in the whole year.

Fig. 10. Detention rate.
Note: the numbers on the right of each box from the top to the bottom refer to the values at first quartile, second quartile (i.e., median), and third quartile of the monthly detention rate in each year, respectively.
issues, except that much fewer deficiencies under this code were detected in 2020.

4.4.2. Detention conditions at the Hong Kong port

The detention rate on a monthly basis (calculated by dividing the total number of detentions by the total number of inspections conducted over one month) from 2015 to 2020 is shown in Fig. 10. It shows that there is a general downward trend in the detention rate from 2015 to 2019 with the median decreasing from 0.0555 in 2015 to 0.0175 in 2019. Except for the three months without inspection conducted in 2020, more than half of the months with inspections conducted have no detention, and the highest detention rate occurs in July where a detention decision is reached in 6.3% of all the inspections.

Similar to the analysis of deficiency conditions, we also present the distribution of the top 10 detainable deficiencies at the Hong Kong port on a yearly basis from 2015 to 2020 shown in Fig. 11. Fig. 11 shows that deficiencies under the top 3 most popular detainable deficiency codes account for about half of all the detainable deficiencies in most of the years between 2015 and 2020. Meanwhile, deficiencies under the top 10 most popular detainable deficiency codes

![Fig. 11. Detainable deficiency code distributions in each year at the Hong Kong port.](image-url)
constitute more than 95% of all the detainable deficiencies, which is more concentrated than the whole distribution of the deficiency codes detected as discussed in Section 4.4.1. Among all the detainable deficiency codes, 07-Fire safety is the most common, which ranks top in 2015, 2019, and 2020. The second most popular detainable deficiency code is 15-ISM (ISM is the abbreviation for international safety management), which ranks 1st in 2016 and 2017. Code 02-Structural conditions is the most popular detainable deficiency in 2018. Other detainable deficiency codes ranking top 3 are 03-Water/weathertight conditions, 10-Safety of navigation, and 11-Life saving appliances. Compared to the top 3 deficiency codes detected, more types of deficiencies occur in the top 3 detainable deficiency codes, covering several aspects of maritime safety.

It is also interesting to find that code 12-Dangerous goods has never been the detainable deficiency code over the period between 2015 and 2020 at the Hong Kong port. In addition, codes 08-Alerts, 09-Working and living conditions, and 13-Propulsion and auxiliary machinery are rarely regarded as detainable deficiency codes within this period. Some particular trends are shown in other deficiency codes. For example, code 14-Pollution prevention ranks 9th in 2015 and 2016, then moves up to 5th in 2017 and reaches the highest position at 4th in 2018. It further moves back to the 9th position in 2020. There are certain variations in the rank of code 01-Certificate & documentation, which ranges between 4th and 7th from 2015 to 2019, and then falls to the 10th place due to the flexible and case-by-case inspection measures adopted by the Hong Kong port. It is also noted that six detainable deficiencies under code 09-Working and living conditions were detected in 2015, whereas there was no deficiency under this code that is regarded to be detainable in the following years until 2020. In contrast, for the other deficiency code related to seafarers’ rights namely 18-Workers’ conditions-accommodation, recreational facilities, food and catering, zero deficiency under this code was regarded as detainable between 2015 and 2018 except for 2017, where only one such deficiency was considered to be detainable. In 2019, three deficiencies under code 18 were considered as detainable deficiencies, and the number further grows to six in 2020. The upward rank of deficiency code 18 and the downward rank of deficiency code 09 are the same as those in the deficiency codes detected at the Hong Kong port over the period. Both trends show that the hardware facilities onboard of seafarers’ living and working conditions have been improved a lot. Meanwhile, wider aspects regarding the seafarers’ rights and welfare, especially those related to food, health, medical care, security, and recreational facilities are getting more attention.

To conclude, it is evident that the monthly number of inspections conducted, the quarterly inspection rate of individual ships, the average number of deficiencies detected per inspection, and the detention rate heavily decrease after the outbreak of the COVID-19 in 2020 compared to the normal status between 2015 and 2019 at the Hong Kong port due to restrictions of ship-shore interaction and the flexible inspection strategies adopted. During the pandemic, it is also noted that remote follow-up inspections are conducted, while more HRS and less LRS are inspected. In addition, the Granger causality test shows that the number of daily local confirmed cases is the Granger causality of the daily number of PSC inspections conducted in Hong Kong, with the maximum lag length as 3. Besides, interesting trends in deficiency codes and detainable deficiency codes between 2015 and 2020 are also identified through comprehensive analysis. In sum, it can be seen that the PSC authority of Hong Kong port adopts flexible and pragmatic inspection strategies during the difficult time due to the COVID-19 pandemic, with the aim to deal with the impact of the outbreak of COVID-19, retain the effectiveness of PSC inspection, and guarantee the health of onshore PSCOs and onboard crew members.

4.5. Factors influencing PSC outcome at the Hong Kong port

Although it is clearly shown in the previous subsections that the average number of deficiencies and the detention rate at the Hong Kong port decrease significantly during the pandemic of COVID-19, the influencing factors of such decrease can be complicated and entangled. In addition to the pandemic intensity, differences in the outcome might also be related to the changes in the composition of vessels calling in terms of ship type, flag/RO/company performances in the Tokyo MoU, SRP, and ship age, etc. Therefore, it is essential to disentangle the effects of the possible influencing factors. To achieve this, we first calculate the weekly statistics of the distributions of flag performance, RO performance, and company performance in Tokyo MoU, the distribution of vessel type, the distribution of SRP, and the average age of the vessels inspected in 2019 and 2020 at the Hong Kong port as well as the average number of confirmed cases in Hong Kong, and then the weekly difference between 2019 and 2020 is calculated. We choose AVG_INS and DET_R as the indicators of the inspection outcome, and their weekly differences between 2019 and 2020 are also calculated which show decreases in AVG_INS and DET_R. We have 53 records in the dataset in total. Linear regression analysis is then conducted using SPSS to test whether the influence of each of the factors considered is significant on the indicators with significance level α = 0.1. For category variables ship type, flag/RO/company performance, and ship SRP, one-hot encoding is used to discretize their values, and the number of variables after discretization equals the number of the values minus one. Variables after decoding are presented in Table 9.

For the regression analysis of AVG_DEF, variables with variance inflation factor (VIF) larger than 10 which indicates the existence of collinearity are excluded, including Ship_PSC_Bulk_carrier, Ship_Type_Container_ship, Ship_Type_Tanker, flag_White, RO_High, and ship age. The $R^2$ of the linear regression model is 0.582, and the F value of the ANOVA test is 5.198, showing that the regression model is statistically significant. Coefficients of the regression model are presented in Table 10.

Table 10 shows that four variables have significant effect on AVG_DEF, namely HK_daily_confirmed_case, RO_Medium, company_Low, and SRP_HRS. The result indicates that as the inspection resource becomes more stringent in 2020, more HRS and ships with worse RO and company performances are inspected. Moreover, the decrease in AVG_DEF from 2019 to 2020 is also significantly influenced by the number of COVID-19 confirmed cases in Hong Kong, and one confirmed case would decrease AVG_DEF by about 0.22.

For the regression analysis of DET_R, variables with VIF larger than 10 are the same as those in the regression analysis of AVG_DEF and they are excluded. The $R^2$ of the linear regression model is 0.609, and the F value of the ANOVA test is 2.255, showing that the regression model is statistically significant. Coefficients of the regression model are presented in Table 11.

Table 11 shows that three variables have significant effect on DET_R, namely Ship_Type_Passenger_ship, RO_Medium, and company_Low. The
5. Discussion

Based on the above results and analysis, several policy and managerial insights can be generated which are summarized as follows.

(a) As the scarce inspection resources at port authorities become more limited during the COVID-19 pandemic, more accurate high-risk ship selection methods that can be more efficient for ship selection should be developed to rationalize the assignment of the limited resources and thus to improve the overall inspection efficiency.

(b) According to the current onboard PSC inspection scheme, deficiency items related to documentation and certification are the first to check during an inspection, and whether to conduct more detailed inspection is highly dependent on their inspection results. To improve the overall inspection process, digitalized documentation and certification management system based on text mining and processing and/or blockchain technology can be developed. Ships for inspection can therefore be efficiently identified by checking the documents and certificates of the foreign visiting vessels and the seafarers, while the onboard inspection time can also be highly reduced, so as to reduce the epidemic spread risk.

(c) The above analysis clearly shows that the pandemic has made the inspection pattern different from usual times. One critical reason is the need of epidemic prevention and control by reducing face-to-face interactions between onboard and onshore members. Therefore, developing and adopting online virtual inspection system based on image recognition and virtual reality, which could be applied to both initial inspection and follow-up inspection, might be a viable way to bring the PSC inspection back to normal. The risk of infection can be eliminated by using such remote inspection method. Moreover, as more ships can be inspected in a timely manner, maritime safety and the marine environment can also be safeguarded.

(d) More standardized and unified flexible inspection measures should be implemented by individual MoUs, especially those related to ship selection and inspection outcomes. Appropriate measures under regular pandemic prevention and control should also be adjusted from time to time.

Several directions can be investigated in future research. For the analysis of the inspection status of individual MoUs, only three indicators on a monthly basis, i.e., INS_NO, AVG_DEF, and DET_R are examined in this study. More indicators can be analyzed in future research, such as the types of inspections conducted, the types of ships inspected, and the specific deficiencies and detainable deficiencies detected. Regional pandemic intensity and prevention measures can also be taken into account when evaluating the effectiveness and deficiencies of PSC in such difficult time to generate more effective policy insights. For the analysis of the inspection status at the Hong Kong port, more specific disease prevention and control measures and arrangements announced by the Government of the HKSAR, such as social distancing control, reducing gathering, and virus surveillance in the community should be considered. Special arrangements and strategies for PSC adopted by the Marine Department of HKSAR should also be considered to analyze the efficiency of local PSC inspection. In addition, more types of research methods, such as questionnaire, interview, and survey of different stakeholders such as PSC officers, crew members, ship owners and managers, and staff in shipping companies, can be applied to collect more empirical data. Such data can be used to capture a wider aspect of the influence of the pandemic on PSC inspection, derive perceptive policy insights, and generate measures to reduce the adverse impact of the disease on the shipping and port management.

6. Concluding remarks

This study aims to analyze how the outbreak of the COVID-19 pandemic influences the status of PSC inspection on a global level and a regional level. On a global level, we search the online public inspection data in eight MoUs all over the world and analyze their inspection status including the number of inspections conducted as well as the inspection results from 2017 to 2020. The main findings are summarized as follows.

(a) In 2020, the monthly total number of inspections conducted is significantly reduced in most MoUs since February or March and reaches the bottom in April or May. The number of inspections conducted on a monthly basis becomes much more stable since June.

(b) In 2020, the monthly average number of deficiencies is lower in some MoUs compared to the average level between 2017 and 2019, while others show a similar pattern before the outbreak of the COVID-19. Meanwhile, some fluctuations exist in the detention rates in 2020.

(c) The influence of COVID-19 pandemic on PSC in different MoUs and ports different, and such differences can be caused by
different pandemic intensities, pandemic prevention measures, and PSC inspection strategies.

On a regional level, we search for the inspection information in details at the port of Hong Kong from 2015 to 2020 including the number and types of inspections conducted, the types of ships inspected, the deficiency codes, and the detention conditions. The PSC inspection status in Hong Kong can be summarized as follows.

(a) The monthly number of inspections conducted and the monthly detention rate are generally stable from 2015 to 2019, and they are both significantly reduced in 2020. The quarterly inspection rate also significantly declines in 2020 compared to the same period before the outbreak of the COVID-19.

(b) Pragmatic and realistic inspection strategies are applied at the Hong Kong port during the pandemic: 1) Online follow-up inspection starts to be conducted in 2020 with the ratio at 3.43%; 2) More than half of the inspected ships are HRS while the percentage of LRS declines to 13.40%; 3) The total number of inspections conducted, the average number of deficiencies per inspection, and the detention rate all decrease; 4) The percentage of inspections without deficiency detected increases considerably.

(c) With the lag length no more than 3, the number of daily local confirmed cases of the COVID-19 is the Granger causality of the daily number of PSC inspections conducted.

(d) The general patterns of deficiency conditions during 2015–2020 and some special trends brought by the COVID-19 in 2020 are comprehensively analyzed.

(e) The significant influencing factors on the average number of deficiencies from 2019 to 2020 include local pandemic situation, ship flag and RO performances, and HRS ratio, while those on detention rate are related to passenger ship ratio and ship flag and RO performances.

In sum, the statistics of global PSC inspection status show that the port lockdown policy and the special inspection arrangements for PSC agreed on by the IMO and the MoUs over the world have considerable influences on the number of inspections conducted and the inspection results. Especially, the port of Hong Kong, as a global maritime center, adopts pragmatic measures to keep the effectiveness of PSC inspection while protecting the health of onboard crew and onshore officers. Despite the difficulties brought by the COVID-19 pandemic, PSC has always been acting as a ‘last safety net’ to safeguard the maritime transport.

CRediT authorship contribution statement

Ran Yan: Conceptualization, Data collection, Methodology, Formal analysis, Writing - original draft. Haoyu Mo: Methodology, Writing - review & editing. Xiaomeng Guo: Data collection, methodology, Formal analysis. Ying Yang: Conceptualization, Manuscript revision, Writing, Suggestions. Shuaian Wang: Conceptualization, Methodology, Validation, Resources, Supervision, Writing - review & editing.

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