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Ship Deficiency Data of Port State Control to Identify Hidden Risk of Target Ship

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Abstract: In the new inspection regime (NIR) of port state control (PSC), the criteria for being judged as a standard risk ship (SRS) is too broad. Some ships are classified as SRS even though they have a large number of ship deficiencies. This paper develops a selection system to identify the hidden risk of target ships in the SRS category using PSC inspection records. This system allows the target ship to be used to help reduce cases of flags being greylisted or blacklisted, which can cause huge shipping losses. This study analyzes ship deficiency data in the Tokyo memorandum of understanding (Tokyo MoU) database. It adopts the multiple criteria decision making (MCDM) model as a data processing technique to build a risk assessment scale. It uses fuzzy importance performance analysis (F-IPA) and technology for order preference by similarity to the ideal solution (TOPSIS) for its analysis. Subsequently, the weights of F-IPA and TOPSIS are adopted into the MCDM model. This article also consulted the Tokyo MoU database. It has been verified that the next time PSC inspection, the system hits 83.3% of the hidden risk ships in the SRS category. Thus, this system will help inspectors be more insightful for target ships.

Keywords: port state control; standard risk ship; hidden risk; inspection records; multiple criteria decision-making

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1. Introduction

The purpose of implementing port state control (PSC) is to effectively crack down on substandard ships and to reduce the occurrence of shipwrecks by carrying out ship inspections. It can be used to enhance the seaworthiness of the target ship, maintain the safety of water navigation and protect the marine ecological environment. By carrying out PSC inspection, coastal countries learn the deficiencies of the inspected ships and can then implement enforcement steps to impound them [1,2]. With the efforts of experts and scholars, the international maritime organization (IMO) has developed a series of minimum international norms and standards for use by inspection agencies and personnel as the basis for inspection standards [3–5].

However, the new inspection regime (NIR) in PSC only classifies inspected ships into three types: high risk ship (HRS), standard risk ship (SRS) and low risk ship (LRS). Of these, the SRS covers a wide range of ships in the NIR, so it is easy for errors to occur when assessing the risk levels of ships. The HRS, SRS and LRS in different memorandum of understandings (MoUs) are used to determine when the ship has to be inspected next time. However, according to the description in Tokyo MoU's NIR, the NIR has taken into account the impact of the ship's characteristics (e.g., ship flags, ship ages, ship types, etc.) on the ship's risk [6]. Scholars' research results support this statement [5,7]. At present, some ships are classified as SRS even though they have a large number of ship deficiencies. These ships have also adopted relatively loose inspection time regulations. This situation can easily lead to a navigation crisis during a ship's voyage, which may directly or indirectly cause harm. This study calls this situation a hidden risk. This study argues that it is necessary to learn the risk performance of the inspected ships from the PSC inspection records, and then use it to establish a system for selecting the hidden risk ships.

The main purpose of the research is to establish a selection system for identifying hidden risk target ships in the SRS category. This system based on the previous inspection results in the flag of the ships. This approach can eliminate ships with overestimated seaworthiness from the SRS. Seaworthiness is a concept that runs through maritime law. A carrier of goods by sea owes a duty to a shipper of cargo to ensure that their ship is seaworthy at the start of the voyage. In this study, "seaworthiness" represents the safety of the ship during its voyage. This study adopted a data processing technique to explore the inspection records in the port state control memorandum of understanding (PSC MoU) database, and used this technique to search for ship deficiency relevance. These data were then combined with multiple criteria decision making (MCDM) analysis modes. Next, it utilizes the results of analysis to design different weights and establish an evaluation scale, and this evaluation scale can be used as a basis for evaluating the hidden risk of a ship. When the target ship is evaluated, the situation of the ship can be understood according to the established evaluation scale. It can reduce the possibility of being greylisted or blacklisted. The black-grey-white lists are adopted by the flag of the ships to present the results of the annual PSC MoU implementation. If the flag of the incoming ship is classified as a blacklist, it is easy to delay voyage planning and cause additional costs for the companies [8,9].

With the unceasing increase in the amount of data, the data processing technique can enable more scientific and efficient screening of information and processing of the database [10]. This allows the data processing technique of potential regularities in ship detention deficiencies that have not yet been noticed [4,11,12]. In addition, when performing data analysis, it is not possible to directly analyze the 18 deficiency categories of ships, as classified by PSC. These 18 deficiency categories are related, and direct data analysis will produce a lot of errors [9,13,14]. Therefore, given that the deficiencies of ships may affect the analysis results, this study believes that MCDM is more appropriate. Subsequent research results by many researchers proved that the MCDM model applied to the research topic of PSC screening of inspected ships has significant effects [11–13]. Through the MCDM model, their research results have achieved good results in simulating the screening of inspected ships.

In this research we utilize two methods, namely, importance performance analysis (IPA) and the technique for order of preference by similarity to ideal solutions (TOPSIS) as means to build the evaluation scale. IPA in the research is to compare the situation of deficiency ships of the target flag with the inspection of ships of all other flags. TOPSIS can strengthen the performance of the deficiency categories of the target ship and increase the weight. This makes the evaluation scale that has been built more suitable for application to ships of the target flag. The deficiency data for this evaluation scale is obtained from the Tokyo memorandum of understanding (Tokyo MoU) database [15]. Therefore, regardless of the source of the data acquisition or the accuracy of the data, there is a stable and accurate data supply. This system can adjust a target ship within it for the flag by checking information about different ship registrations in the Tokyo MoU database. This selection system cannot directly analyze the target ship, otherwise it will not be able to obtain the effective weight of the ship's deficiency categories. Before adopting this selection system, it is necessary to analyze the flag of the target ships and global ships. This allows us to know what categories of ship deficiency are frequently detected by PSCO during the execution of PSC on the flag of the target ship. This can effectively distinguish the weight value difference between the flag of the target ships and global ships.

The selection system developed in this paper can be used for different the flags of the ships, so to give appropriate weight to ship deficiency category risks. This study can assist members that are not affiliated with a regional PSC MoU. They can efficiently judge the hidden risk of the inspected ship and then evaluate the inspected ship and ship deficiency categories. In addition, this system can provide them with great help for flags that are often classified as greylisted, or for situations where flags have multiple ships. However, there must be a prerequisite. The ships of these members must have inspection records registered in the PSC MoU database. The target ships in this article are Taiwanese ships.

The remainder of this paper comprises four sections. Section 2 reviews the screening mode of ships under the PSC system and the literature on PSC-related application inspection mechanisms, as well defining the research problem. Section 3 outlines the detailed steps of the proposed method. Section 4 discusses the analysis results that arise from the proposed method, and Section 5 presents conclusions and future applications.

2. PSC MoU Literature Review

2.1. Review of the Screening Mode and Inspection Mechanism for Ships in PSC

Before PSC took shape, the responsibility for ship management was assigned to the flag state, thus flag state control (FSC) was formed [3]. Yuan et al. [1] pointed out the drawbacks to the FSC. The port state jurisdiction is not only gradually shifting from an uncompelled basis on narrow subject areas toward an extensive and compulsory system based on regional and global organizations but also expanding in its acceptance as a countermeasure for the inability of flag states to effectively control their ships. As a result, the FSC ship inspection reports were difficult to be accepted by the public. According to scholars' research on PSC, the implementation of PSC by coastal countries can effectively reduce the occurrence of maritime accidents. Moreover, PSC has gradually become an effective line of duty against substandard ships, protecting the marine environment and improving the living conditions and working environments of crew members on ships [1,16]. In summary, PSC can be said to be an implementation method to protect crews and ships, as well as to maintain port operations and the marine environment.

On the basis of instructions on the official Tokyo MoU [17], in order to facilitate inspection operations, PSC classifies and codes the deficiency categories of ships. Before 2012, an old, four-digit code was used, and after 2012, a new, five-digit code (referred to below as the old five-digit code) was adopted. Then, the maritime labour convention 2006 (MLC 2006) officially came into effect on 20 August 2013, causing PSC to again revise the ship deficiency classification code. The old five-digit code originally adopted in 2012 was replaced by a new five-digit code, now including Labor Conditions (18000) and Dangerous Goods (12000). In recent years, due to the frequent occurrence of terrorist attacks, PSC has also separately added the ISPS code (16000) as a category to be inspected. Due to the adjustment of the new five-digit code, other items in the old five-digit code (18000) have been updated to a different code in the new system (99000), as shown in Table 1.

Table 1. Comparison table of the new and old PSC code deficiencies by category.

New Code	Nature of Deficiencies	Old Code
01000	Certificate & Documentation	01000
02000	Structural Conditions	02000
03000	Water/Weathertight conditions	03000
04000	Emergency Systems	04000
05000	Radio Communications	05000
06000	Cargo operations including equipment	06000
07000	Fire safety	07000
08000	Alarms	08000
09000	Working and Living Conditions	09000
10000	Safety of Navigation	10000
11000	Life saving appliances	11000
12000	Dangerous goods	No
13000	Propulsion and auxiliary machinery	13000
14000	Pollution prevention	14000
15000	ISM	15000
16000	ISPS	No
18000	Labour Conditions	No
99000	Other	17000

The deficiencies shown with a grey background in the Table 1 differ between the new five-digit code and the old five-digit code. In order to synchronize the ship selection system with the Tokyo MoU, Taiwan introduced the NIR of the Tokyo MoU in 2014. The NIR of the Tokyo MoU was formed in 2014 by simplifying the NIR of the Paris memorandum of understanding (Paris MoU) [18–20]. The ship risk selection system established in the maritime transport network portal (MTNet) refers to the NIR of the Tokyo MOU [20]. Ship targeting is based on a "Ship Risk Profile" (SRP). The SRP Calculator can evaluate if a ship will be considered a HRS, SRS or LRS. The SRP is based on the following factors, using details of ship inspections for the last 36 months: (1) Type and age of ship; (2) Number of deficiencies; (3) Number of detentions; (4) Performance of ship's flag: Black-Grey-White lists, Black-Grey-White lists of flag status based on 36 months of inspection data; (5) Performance of the recognized organization (RO): RO performance status (high, medium, low, very low) based on 36 months of inspection data; (6) Performance of the company responsible for the ISM management (holder of document of compliance): status as high, medium, low and very low, based on 36 months of inspection data. In this study, the NIR situations of Taiwan, the Tokyo MoU and the Paris MoU are shown in Table 2 below.

Table 2. Table of exemption times for ships with different risks under NIR regulations.

	High Risk Ship	Standard Risk Ship	Low Risk Ship
Paris MoU	5 to 6 months	10 to 12 months	24 to 36 months
Tokyo MoU	2 to 4 months	5 to 8 months	9 to 18 months
Taiwan	2 to 4 months	5 to 8 months	9 to 18 months

When an NIR is implemented in the above-mentioned regions, it can be seen in Table 2 that the inspection time for HRS, SRS and LRS are not uniform (Taiwan implements NIR in accordance with the Tokyo MoU). The NIR regulations of the Australian Maritime Safety Authority (AMSA) are different from the above PSC MoU [21]. If a ship has docked at an Australian port within six months and has not been inspected by AMSA, the ship may be listed as a ship under inspection. In order to enhance the effect of inspection, AMSA divides the levels of the ships to be inspected into four priority groups according to the state of each inspected ship. This classification method schedules the inspection priority of the inspected ships, as shown in Table 3.

Table 3. AMSA PSC target ship classification table.

Priority Group	Probability of Detention (Risk Factor)	Target Inspection Rate
Priority 1	More than 5%	80%
Priority 2	4% to 5%	60%
Priority 3	2% to 3%	40%
Priority 4	1% to less	20%

Table 3 shows the classification of AMSA PSC target ships. As the PSC inspection records of ships will be the selection source for screening the ships to be inspected. The NIR can use the PSC inspection results recorded by the regional PSC MoU to determine whether ships berthing at a port need to undergo PSC inspection. However, different PSC MoUs have different PSC inspection exemption times. This period of exemption from the PSC inspection process cannot guarantee that ships can maintain seaworthiness.

2.2. PSC Related Research

Currently, the PSC inspection process still has defects. Different PSC MoUs do not have a unified standard for the time of exemption from PSC inspection. This situation has caused some ships to use different PSC inspection exemptions to avoid PSC inspections when berthing at ports in PSC MoU member states. In order to repair this shortcoming, scholars began to collect relevant information and discuss the influential factors concerning port state control officers (PSCO) selection of inspected ships. Many scholars have pointed out that ship age, ship type, ship flag and recognized organization were listed as the main screening indicators. In addition to identify screening indicators of the inspected ships, related research also pointed out that some factors will affect the screening indicators, for example, the PSC implementation habits of different regions, the subject background and work experience of the PSCO, and the implementation of concentrated inspection campaign. This research collates the research results of the above-mentioned scholars and experts, as shown in Table 4.

Table 4. Papers summary of relevant PSCO selection of inspected ships.

Screening Indicators	Papers
Ship age	[7,8,13,14,16,22]
Ship type	[7,8,13,14,16,22]
Ship flag and recognized organization	[7,8,14,16,22]
Inspection Records	[2–4,7,9,11,12,14,22,23]
PSC implementation habits of different regions	[1,7,16]
The subject background and work experience of the PSCO	[1,16]
Concentrated inspection campaign	[16,23,24]

Previous scholars' research results on the screening indicators of the inspected ships by PSCO are shown in Table 4. However, the ship selection scheme is used, which gives different weights to basic ship information and historical inspection data. This monotonous weighted sum method may be not efficient enough to identify substandard ships. As the amount of data in the PSC database continues to increase, the subject of screening criteria for inspected ships has only been studied through outdated analytical models. It is easy to produce inappropriate or inaccurate research results. In this situation, several studies have proposed more efficient ship selection methods. Fu et al. [13] proposed an improved Apriori model to explore the intrinsic mutual correlations among ship deficiencies from the PSC inspection dataset. They used ship type, age, deadweight and gross tonnage to analyze the correlations for the ship parent deficiency categories and subcategories. Yuan et al. [1] investigated the factors influencing the implementation of ship selection methods for the PSCO through an analytical hierarchy process. He et al. [12] proposed a novel interpretable ship detention decision-making model based on machine learning for flag state control. The model adopted the extreme gradient boosting and synthetic minority oversampling technique algorithms to identify whether a ship should be detained. Chen et al. [3] proposed the factors behind the detention of ships under PSC using grey rational analysis model with improved entropy weight to understand how much the varied factors influence the decision of ship detention. Tsou [4] discovered that the adopting association rule mining techniques in big data analysis can precisely and objectively determine the regularity correlation between ship deficiency data as well as between these deficiencies and related factors.

However, the problem that some high-risk ships can easily be classified as SRS has not yet been resolved. Some ships are classified as SRS even though they have a large number of ship deficiencies. Therefore, this paper proposed a selection system using PSC inspection records to identify the hidden risks of target ships. Some scholarly research pointed out that the inspection records can influentially classify risks for NIR. Yang et al. [5] based on inspection data and records collected from the Paris MoU database. They revealed the influence of the implementation of NIR on the PSC inspection system and ship quality is revealed. Xiao et al. [7] proposed the NIR target factors including ship age, ship type, performance of flag state, and number of deficiencies significantly impact detention and must be closely monitored. Wang et al. [11] developed a new Bayesian network–based PSC risk probabilistic model. It investigated methods to improve model efficiency in ship detention prediction. The research results reveal that ship's safety condition related deficiencies as well as technical features of the inspected ship itself are among the most influential factors concerning PSC inspections and ship detention. Yan et al. [14] proposed a binary classification machine learning model to predict ship detention in port state control inspection considering data imbalance. Due to the inspection historical factors before an inspection is conducted is not a trivial task as the low detention rate leads to a highly imbalanced inspection records.

The analysis process adopted in this study is to mine inspection records in the database, in order to search for valuable ship defect correlations. This manner can search for useful and easily observable rules in a huge amount of data. The main purpose of the research is to establish a selection system for identifying hidden risk ships in the SRS category. This system can be used for self-assessment based on the inspection results of the target ships, and then to identify the hidden risks of the target ships in the SRS category. Additionally, it can assist target ship implement self-seaworthiness assessment and reinspection mechanisms, thus encouraging them to perform self-first improvement of ship deficiencies.

3. Research Method

This section describes the analytical methods and definitions used in this research, and details the processing mode of the research data analysis.

3.1. Fuzzy Theory

Fuzzy Theory, proposed by Professor L. A. Zadeh in 1965, aims to study uncertain things. It uses numbers to represent a fuzzy phenomenon, so that the data in the uncertain field can be described by a clear mathematical method. For the problem of unclear description or vague situation, this provides a more reasonable and feasible solution [25,26]. In order to simplify and facilitate the calculation, this study selects the triangular fuzzy number in the basic fuzzy theory for analysis. The basic definition of the triangular fuzzy number is shown in formula (1).

$$\mu_A(x) = \left\{ \begin{array}{c} \frac{x-L}{M-L},\ L \le x \le M \\ \frac{x-U}{M-U},\ M \le x \le U \\ 0,\ \text{otherwise} \end{array} \right\} \tag{1}$$

In the fuzzy method, A is called a standard triangular fuzzy number, denoted by $A = (L, M, U)$. L is the most conservative estimate, the lower bound of the triangular fuzzy number; M is the most probable estimate; and U is the most optimistic estimate, the upper bound of the triangular fuzzy number. In addition, since the comparison of a geometric mean will not be affected by extreme values, the geometric mean is used in this study as a membership degree of 1. The smaller the interval $[L, U]$, the higher the accuracy of the data. In order to determine the sorting situation of fuzzy values, this study uses the average integral value to represent membership degree as a basis for the fuzzy number ranking method. This membership degree representation method is a fuzzy sorting method, which has better analysis effect in an unclear analysis environment [26–28]. As for the triangular fuzzy number, its fuzzy ranking value is shown in the following Formula (2):

$$P(A_i) = \frac{L_i + 4 * M_i + U_i}{6} \tag{2}$$

This research provides examples of data and how it is used, as shown in Appendices A and B. After the data is fuzzified, it is sorted using the membership degree representation method described above, so that it can be more convincing.

3.2. Importance Performance Analysis

Importance performance analysis (IPA) is a research method proposed by Martilla and James in 1977. It was initially used to examine the service quality of auto sellers, and later to judge the performance of services or products. This method uses an evaluator to score the importance and performance of the service or product, then builds a two-dimensional matrix from the score results. There are four quadrants in the matrix, which can be used to show the performance of services or products. The meaning of the four quadrants is shown in Figure 1.

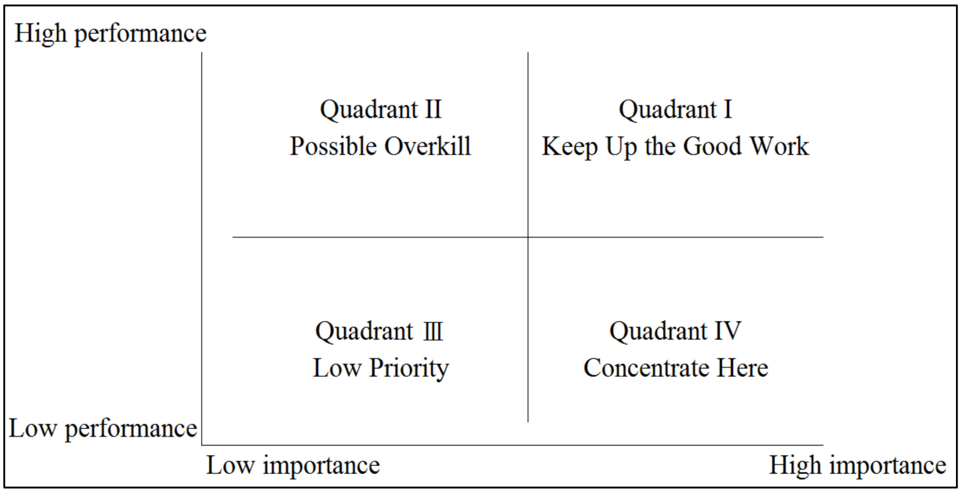

Figure 1. Traditional importance–performance grid.

Importance and performance ratings are displayed on a two-dimensional grid, and fall into one of four quadrants—"Keep Up the Good Work", "Possible Overkill", "Low Priority" and "Concentrate Here", as shown in Figure 1. Boley et al. [29], Phadermrod et al. [30], Tseng et al. [31] scholars have put forward three explanations of the characteristics of IPA. (1) Importance is related to performance. (2) There is a negative correlation between importance and performance; when performance reach a certain point, importance will begin to decline. (3) Importance is the causal function of performance; when performance change, importance will also change. As explained by the above scholars, IPA can change the quadrant position for evaluation purposes, and the relative position of each attribute will not change after this update. In the process of IPA analysis, this research compares Taiwanese ships and ships of other flags in the Tokyo MoU database. Then, the ship deficiencies registered for Taiwanese ships and ships of other flags are included in the IPA, in accordance with the 18 deficiency categories formulated by the PSC MoU. Subsequently, our method divides these deficiency categories into four quadrants, then identifies the parts of Taiwanese ships that urgently need improvement. The subsequent meaning of the four quadrants in the IPA is shown in Figure 2.

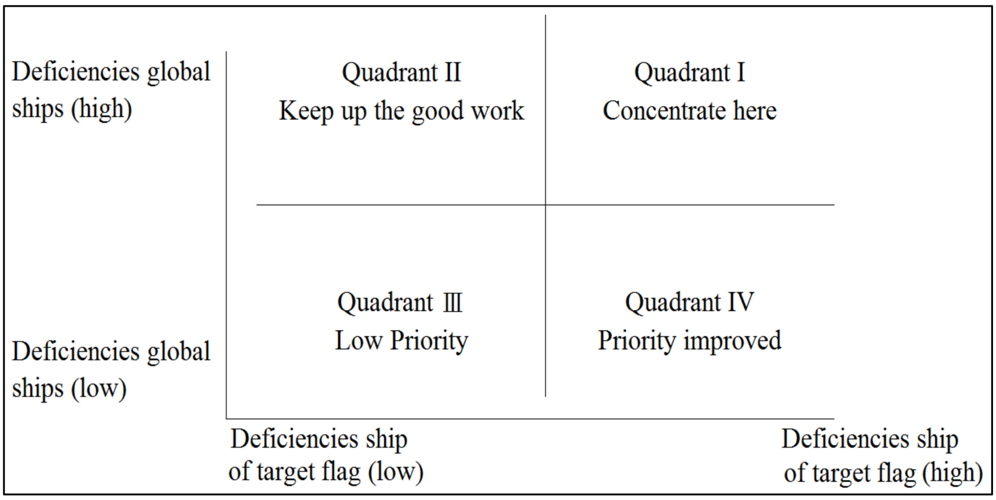

Figure 2. Updated importance-performance grid.

According to the Figure 2 of the research, the updated importance and performance ratings are displayed on a two-dimensional grid, and fall into one of four quadrants—"Concentrate here", "Keep up the good work", "Low Priority" and "Priority improved". Figure 1 is a schematic diagram of the original theory of IPA, where the evaluation indicators are all positive correlations. The larger a value on the horizontal or vertical axis, the more important the evaluation index. However, the evaluation indicators in this study are all expressed as negative correlations, so in addition to the changes in the quadrants, the meaning of each quadrant will also be different; for example, the original Quadrant I in Figure 1 will move to Quadrant III in Figure 2. The meaning of each quadrant category after the change is as follows:

- Quadrant I—Concentrate here

In the Tokyo MoU database, the deficiency categories of ships listed in this quadrant are ones to which both Taiwanese ships and ships of other flags are prone. Therefore, Taiwanese ships must be inspected for these items before leaving port to reduce the possibility of deficiencies being found by the PSCO.

- Quadrant II—Keep up the good work

In the Tokyo MoU database, the deficiency categories listed in this quadrant are those for which Taiwanese ships performed well. In this quadrant are deficiencies found by the PSCO less often on Taiwanese ships than on ships of other flags. This means that there is only a low probability that Taiwanese ships will have these deficiencies.

- Quadrant III—Low priority

In the Tokyo MoU database, the deficiency categories listed in this quadrant are difficult to find in both Taiwanese ships and ships of other flags. Therefore, the deficiencies in this quadrant do not need to be prioritized for improvement when a ship conducts its own ship inspection.

- Quadrant IV—Priority improved

In the Tokyo MoU database, the deficiency categories that PSCOs often find in Taiwanese ships will be listed in this quadrant. Taiwanese ships performed poorly for these deficiencies, indicating that these deficiencies must be inspected before the ship leaves the port.

The purpose of using important performance analysis (IPA) in the research is to find the deficiency relationships between ships recorded in each year. Comparing the registered flag of the target ships in the Tokyo MoU database and the inspection records of the deficiency categories of all registered ships of the flags for that year, then the corresponding weight of the ship's deficiency categories is given. For example, if the ship's deficiency categories fall into the Quadrant IV after IPA, this means that when PSCO inspects ships of the target flag, it finds these deficiency categories more often than for ships of other flags. Therefore, the weight value of the ship's deficiency categories in the Quadrant IV will be higher. This weight value will subsequently be used to build a risk assessment table and evaluate the hidden risk situation of the SRS under inspection.

3.3. Technique for Order Preference by Similarity to Ideal Solution

Yoon and Hwang developed the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in 1981. The basic idea of this method is to normalize the value first, and then compose a positive ideal solution and negative ideal solution with the best values of that criterion, as shown in Formulas (3) to (5):

$$\boldsymbol{R} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \tag{3}$$

$$\mathrm{A}^{+} = \{(max_i v_{ij} | j \epsilon C_b), (min_i v_{ij} | j \epsilon C_c),\ i = 1,2,3,\ldots m\} = \left\{ v_j^{+}\ | j = 1,2,\cdots,m \right\} \tag{4}$$

$$\mathrm{A}^{-} = \{(min_i v_{ij}|j\epsilon C_b),(max_i v_{ij}|j\epsilon C_c),\ i=1,2,3,\ldots m\} = \left\{v_j^{-}\ |j=1,2,\ldots,m\right\} \quad (5)$$

Among them, $C_b = \{C_j|j\ = 1,2,\ldots,m_1\}$, $C_c = \{C_j|j\ = 1,2,\ldots,m_2\}$, and $m_1 + m_2 = m$. The weighted, normalized value is represented by v_{ij}. The separation measures must be calculated using n-dimensional euclidean distance. The separation of an alternative A_i from the positive ideal solution is shown in Formula (6). Similarly, the separation of an alternative A_i from the negative ideal solution is shown in Formula (7).

$$S_i^{+} = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_j^{+}\right)^2} \quad (6)$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_j^{-}\right)^2} \quad (7)$$

The relative closeness indicator RC_i^* is used to measure the distance to the ideal solutions. The smaller the value of RC_i^*, the better the plan A_i, because the ideal solution is closer. According to the definition of RC_i^*, Formulas (8) and (9) can be obtained:

$$RC_i^* = \frac{S_i^-}{S_i^+ + S_i^-}\ ,\ \forall i \quad (8)$$

$$0 \le RC_i^* \le 1\ ,\ \forall i \quad (9)$$

In the solution, the criterion value with the lowest cost and the most benefit is the positive ideal solution, and the criterion value with the highest cost and the least benefit is the negative ideal solution [32,33]. This study adopts the positive ideal solution as the evaluation model. This study used TOPSIS to rank the deficiencies of Taiwanese ships inspected by PSCO from 2014 to 2018. This research provides examples of data and how it is used, as shown in Appendix C. Then, the quartile method defined a new weight standard for the results of the TOPSIS sorting. The quartile method is a special case of quantile and generally associated with probability distribution contains 25% of total observations. They are generally used to calculate the interquartile range, which is a measure of variability around the median [34]. After simultaneously considering the weight of TOPSIS and IPA, a MCDM model gives evaluation scores, thus providing a new evaluation scale and standard for giving weighted scores.

3.4. Risk Assessment Scale

In the past, when discussing research related to decision-making, most studies used hierarchical analysis procedures for evaluation. However, many decision-making problems do not meet the main assumptions of this research method. Because of the nature of the hierarchical analysis procedure, the elements of each level must be assumed to be independent. However, in the analysis process, the elements of each level will inevitably affect each other, resulting in a hierarchical structure without independence [1,16]. Taking this study as an example, although PSC currently divides ship deficiencies into 18 deficiency categories, the deficiencies among these 18 categories will affect each other [9,13,14]. For example, in the fire safety (07000) and alarms (08000) deficiency categories, some deficiencies overlap. Therefore, this study cannot directly adopt the hierarchical analysis procedure method. This study uses the weight obtained after IPA and TOPSIS analysis to construct a risk assessment scale. Later, according to the quartile method, the risk scale is divided into four levels: Low-risk, Medium-risk, Medium-high-risk, and High-risk, as shown in Figure 3.

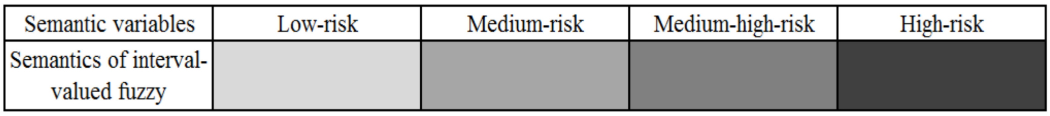

Figure 3. Schematic diagram of risk assessment scale.

In the Figure 3, the darker the color, the higher the risk. In the analysis process, the evaluation scale is divided into four types. The purpose is to categories in the NIR. This research has transformed the SRS attributes currently set in the flag of the risk into Medium-risk attributes and added Medium-high-risk attributes. At the same time, the frequency of inspections for High-risk attributes has changed to implement inspections at ports, as shown in Table 5.

Table 5. Ship risk attributes and inspection frequency table.

Ship Risk Attributes	Inspect Frequency
Low-risk	9 to 18 months
Medium-risk	5 to 8 months
Medium-high-risk	2 to 4 months
High-risk	Inspect upon entering the port

This study divided NIR into four ship risk attributes, as shown in Table 5. The screening system built in this study is mainly for SRS evaluation. In the original definition of the NIR, if a ship is not a HRS or a LRS, it will be listed as an SRS. This situation overestimates the seaworthiness of the SRS, causing some SRS to still have extremely high risks of navigation safety. Therefore, the research subjects of this study are mainly classified as SRS. The screening system built in this research can identify SRS with overestimated seaworthiness.

4. Data Analysis Process

This system is organized by ship data in the Tokyo MoU database from 2014 to 2018. First, the data is fuzzified and the fuzzy average is found, and then it is incorporated into the IPA, so that the deficiency records of Taiwanese ships and other flags of the ships in the Tokyo MoU database are in a two-dimensional matrix and the four quadrants can be presented. Then the system adopts the TOPSIS and sorts out the situation of deficiency ships of Taiwanese ships. Finally, it utilizes the results of IPA and TOPSIS analysis to design different weights and establish an evaluation scale, and this evaluation scale can be used as a basis for evaluating the seaworthiness of a ship.

4.1. Data Analysis

In this study, the deficiency data for Taiwanese ships and ships of other flags recorded in the Tokyo MoU database from 2014 to 2018 was collected and compiled into Table 6.

In this study, the ship deficiency data of Taiwanese ships and global ships were sorted out, as shown in Table 6. According to the Table 6 of the research, in 2014, the statistics for the ship deficiency category Certificate & Documentation (01000) were 40/10,395. 40 represents the number of times that Taiwanese ships were caught with these deficiencies, and 10,395 represents the number of times that ships worldwide were caught with these deficiencies. Next, the sorted data is fuzzified and arranged, as shown in Table 7. This research provides examples of data and how it is used, as shown in Appendices A and B. In Appendix A, this study explains the calculation process of the fuzzification of the flags of the ships' deficiency data, as shown in Tables A1–A3. In Appendix B, it explains the calculation process of the fuzzification of the Taiwanese ships' deficiency data, as shown in Tables A4–A6.

Table 6. Statistics on the deficiencies of ships in Taiwan and ships in the world in the Tokyo MoU from 2014 to 2018.

Code	Nature \ Year	2014	2015	2016	2017	2018
01000	Certificate & Documentation	40/10,395	34/8003	35/7723	34/7352	23/6744
02000	Structural Conditions	14/2671	10/2422	15/2471	5/2324	2/2046
03000	Water/Weathertight conditions	41/5812	29/5584	76/5587	40/5283	7/5017
04000	Emergency Systems	29/5093	23/5771	42/5011	8/4350	5/4128
05000	Radio Communications	7/2259	25/2231	6/2062	9/1798	2/1570
06000	Cargo operations including equipment	2/613	4/500	9/1382	4/744	0/711
07000	Fire safety	86/16,654	93/15,143	98/14,960	69/13,707	36/13,340
08000	Alarms	4/634	1/577	1/573	1/455	1/520
09000	Working and Living Conditions	36/4663	33/3215	34/2904	16/2671	13/2536
10000	Safety of Navigation	73/14,231	117/12,619	77/12,207	60/11,701	30/10,127
11000	Life-saving appliances	53/10,515	66/11,213	59/10,981	45/9787	14/9363
12000	Dangerous goods	0/183	2/352	1/287	0/272	0/195
13000	Propulsion and auxiliary machinery	38/4549	29/4137	50/3817	24/3731	10/3785
14000	Pollution prevention	11/5276	24/5067	23/4859	16/4822	11/6917
15000	ISM	19/2699	20/2803	29/2192	10/1987	5/1616
16000	ISPS	0/1615	0/1389	0/1624	0/1345	0/1516
18000	Labour Conditions	10/2437	23/3247	33/3718	23/4562	5/4258
99000	Other	10/876	3/722	16/537	2/562	4/568
Total		473/91,175	536/84,995	604/82,895	366/77,453	168/74,957

Table 7. Statistics on the fuzzified deficiency categories of ships in Taiwan and ships in the world in the Tokyo MoU from 2014 to 2018.

Code	Taiwanese Ships	Global Ships
01000	0.0906	0.0988
02000	0.0201	0.0289
03000	0.0836	0.0663
04000	0.0453	0.0599
05000	0.0238	0.0239
06000	0.0075	0.0102
07000	0.1855	0.1794
08000	0.0044	0.0066
09000	0.0622	0.0398
10000	0.1700	0.1469
11000	0.1063	0.1254
12000	0.0013	0.0031
13000	0.0685	0.0485
14000	0.0435	0.0691
15000	0.0369	0.0273
16000	0.0000	0.0183
18000	0.0422	0.0443
99000	0.0163	0.0079
Above average	0.0560	0.0558

The IPA model adopted an evaluator to score the ship deficiency categories of global and Taiwan, then builds a two-dimensional matrix from the average value of ship deficiency categories. This study adopted the data in Table 7 is inputted into the IPA model, and the results are shown in Table 8.

Table 8. F-IPA collation table.

Quadrant II—Keep Up the Good Work	Quadrant I—Concentrate Here
PSC Code: 04000, 14000	PSC Code: 01000, 03000, 07000, 10000, 11000
Quadrant III—Low priority	Quadrant IV—Priority improved
PSC Code: 02000, 05000, 06000, 08000, 12000, 15000, 16000, 18000, 99000	PSC Code: 09000, 13000

Table 8 shows that the most commonly overlooked deficiency categories for Taiwanese ships are working and living conditions (09000) and propulsion and auxiliary machinery (13000). For the emergency systems (04000) and pollution prevention (14000) deficiency categories, Taiwanese ships perform better than global ships. It is necessary to a follow-up procedure to adjust the corresponding deficiency categories in each quadrant in IPA. In this study, we will again conduct a TOPSIS assessment on various deficiencies of Taiwanese ships from 2014 to 2018. After analysis, the top three deficiency categories in which Taiwanese ships are most often inspected by PSCO are certificate and documentation (01000), fire safety (07000) and pollution prevention (14000), as shown in Table 9.

Table 9. Table of TOPSIS analysis results.

Code	Positive Ideal Solution	Negative Ideal Solution	Assessment Value	Rank	Corresponding Weight
01000	0.0587	0.8375	0.9345	1	4
02000	0.4895	0.5168	0.5136	9	2
03000	0.5349	0.4450	0.4541	12	2
04000	0.5572	0.4292	0.4351	14	1
05000	0.6086	0.3877	0.3891	15	1
06000	0.6502	0.3849	0.3719	16	1
07000	0.2088	0.7002	0.7703	2	4
08000	0.5228	0.4467	0.4608	11	2
09000	0.2799	0.6557	0.7008	4	4
10000	0.3723	0.5459	0.5945	6	3
11000	0.3517	0.6217	0.6387	5	3
12000	0.7679	0.3457	0.3104	17	1
13000	0.4194	0.5173	0.5522	7	3
14000	0.2346	0.6914	0.7466	3	4
15000	0.4704	0.4783	0.5041	10	2
16000	0.8644	0.0000	0.0000	18	1
18000	0.4746	0.5191	0.5224	8	3
99000	0.5444	0.4281	0.4402	13	1

The analysis results of TOPSIS are shown in Table 9. The calculation process of TOPSIS is shown in Appendix C. The Appendix C explains the process of the deficiency data for Taiwanese ships adopted TOPSIS analysis is shown in Tables A7–A11. The ship risk assessment scale established in this research can set the weight for the target ship. Considering both the IPA weight and the TOPSIS weight, this study redesigned a weight suitable for evaluating Taiwanese ships, as shown in Table 10.

According to the Table 10 of the research, the following information can be obtained. First, the perspective of "F-IPA weight", Certificate & Documentation (01000), Water/Weathertight conditions (03000), Fire safety (07000), Safety of Navigation (10000) and Life-saving appliances (11000) are High-risk deficiency categories of ship. Moreover, Structural Conditions (02000), Radio Communications (05000), Cargo operations including equipment (06000), Alarms (08000), Dangerous goods (12000), ISM (15000), ISPS (16000), Labour Conditions (18000) and Other (99000) are Low-risk deficiency categories of ship. Next, the perspective of "TOPSIS weight", Certificate & Documentation (01000), Fire safety

(07000), Working and Living Conditions (09000) and Pollution prevention (14000) are High-risk deficiency categories of ship. Moreover, Emergency Systems (04000), Radio Communications (05000), Cargo operations including equipment (06000), Dangerous goods (12000), ISPS (16000) and Other (99000) are Low-risk deficiency categories of ship. During the analysis, all ship deficiency data came from the Tokyo MoU database. Among them, "F-IPA weight" represents the flag of the target ships for deficiency category's weight (independent variable). "TOPSIS weight" represents target ships (Taiwanese ships) for deficiency category's weight (independent variable). "Target ship weight" represents Taiwanese ships for updated deficiency category's weight (dependent variable).

Table 10. Collation table of TOPSIS weight, F-IPA weight and Taiwanese ships weight.

Code	F-IPA Weight	TOPSIS Weight	Target Ship Weight
01000	4	4	4
02000	1	2	1.5
03000	4	2	3
04000	2	1	1.5
05000	1	1	1
06000	1	1	1
07000	4	4	4
08000	1	2	1.5
09000	3	4	3.5
10000	4	3	3.5
11000	4	3	3.5
12000	1	1	1
13000	3	3	3
14000	2	4	3
15000	1	2	1.5
16000	1	1	1
18000	1	3	2
99000	1	1	1

The weight of the evaluation index will be changed according to the flag of the target ship and its latest inspection record. Therefore, the risk assessment scale is suitable for the target ship. The subsequent construction of Taiwanese ships risk assessment scale is shown in Figure 4.

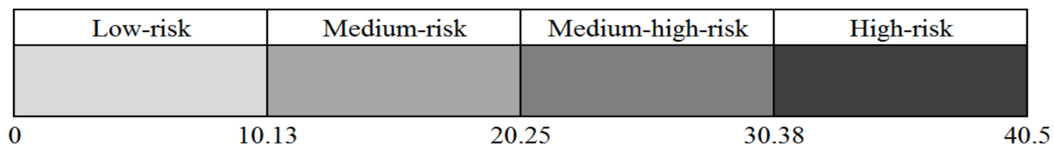

Figure 4. Schematic diagram of the Taiwanese ships risk assessment scale.

The risk classification of Taiwanese ships is shown in Figure 4. The risk assessment value of Taiwanese ship is 0~10.13, which is a low-risk ship. The assessment value is 10.13~20.25, which is a Medium-risk ship. The assessment value is 20.25~30.38, which is a Medium-high-risk ship. The assessment value is 30.38~40.5, which is a High-risk ship.

4.2. Example Test

This research screened out the ship inspection records from January to June 2019 from Tokyo MoU. According to the screening results, a total of 16 Taiwanese ships were inspected by PSCO that had deficiencies were discovered. Among these, four ships were HRSs and 12 were SRSs, as shown in Table 11 below. In order to verify the validity of the ship risk assessment scale established in this study, the study incorporates the Taiwanese SRS data in Table 11 into the ship risk assessment scale. The results are shown in Table 12.

Table 11. Inspection data of Taiwanese ships.

IMO Number	Ship Code	Date	Place	Tokyo MoU-Risk Semantics
9167461	A	01/03	Hong Kong	HRS
9132894	B	01/15	Hong Kong	HRS
9299329	C	01/17	Hong Kong	HRS
9462718	D	01/21	San Antonio (Chile)	SRS
9172387	E	01/23	Onomichi (Japan)	HRS
9629108	F	02/13	Hong Kong	SRS
9692428	G	02/15	Vietnam	SRS
9299317	H	02/20	Indonesia	SRS
9702558	I	03/01	Australia	SRS
9604158	J	03/13	Japan	SRS
9462720	K	04/01	Hong Kong	SRS
9479230	L	04/09	Australia	SRS
9629055	M	04/15	Hong Kong	SRS
9373620	N	04/20	Indonesia	SRS
9462706	O	06/03	Korea	SRS
9784128	P	06/19	Japan	SRS

Table 12. Weighted score of ship risk assessment.

Ship Code	Place	Deficiency Categories (Code)	Number	Weight	Weighted Score
D	San Antonio	Certificate and Documentation (01000) Fire Safety (07000) Safety of Navigation (10000)	1 3 1	4 4 3.5	19.5
F	Hong Kong	Working and Living Conditions (09000)	1	3.5	3.5
G	Vietnam	Emergency Systems (04000) Life Saving Appliances (11000)	1 1	1.5 3.5	5
H	Indonesia	Emergency Systems (04000) Other (99000)	1 1	1.5 1	2.5
I	Australia	Safety of Navigation (10000)	1	3.5	3.5
J	Japan	Safety of Navigation (10000)	1	3.5	3.5
K	Hong Kong	Water/Weathertight Conditions (03000) Fire Safety (07000) Labour Conditions (18000)	1 2 1	3 4 2	13
L	Australia	Certificate and Documentation (01000) Propulsion and Auxiliary Machinery (13000)	1 1	4 3	7
M	Hong Kong	Life Saving Appliances (11000)	1	3.5	3.5
N	Indonesia	Radio Communications (05000) Alarms (08000) Safety of Navigation (10000) Life Saving Appliances (11000)	1 1 1 2	1 1.5 3.5 3.5	13
O	Korea	Fire Safety (07000) Safety of Navigation (10000) Life Saving Appliances (11000)	1 1 1	4 3.5 3.5	11
P	Japan	Fire Safety (07000) Propulsion and Auxiliary Machinery (13000)	2 1	4 3	11

In order to facilitate identification, the ship name is replaced by a ship code (A, B, C ect.,), as shown in Table 11. In the calculation process, this study multiplies the number of deficiencies registered by Taiwanese ships for the weight of the deficiency categories, as shown in Table 12. The weights of these deficiency categories are determined by Section 4.1. For example, Ship D has one (01000) deficiency (the 01000 deficiency category's weight is

4), three (07000) deficiencies (the 07000 deficiency category's weight is 4) and one (10000) deficiency (the 10000 deficiency category's weight is 3.5). Therefore, when calculating the evaluation value, the total weighted score is 1*4+ 3*4+1*3.5 = 19.5.

This research has transformed the SRS attributes currently set in the flag of risk into Medium-risk attributes and added Medium-high-risk attributes. After analysis, this study assumed ships D, K, N, O are Medium-risk. Later, PSCOs found deficiencies. Conversely, although ship P was assumed to be a Medium-risk ship according to this study, the next PSCO inspection did not find any deficiencies for it. This means that when evaluating ship P, an incorrect result was predicted. Ships F, G, I, J, L and M were assumed to be Low-risk by this research. The next PSCO inspection did not find deficiencies for these ships. Ship H was assumed to be a Low-risk ship in this study, but the next time a PSCO conducted an inspection, it discovered deficiencies. This means that when evaluating ship H, an incorrect result was predicted, all these results are summarized in Table 13.

Table 13. Result of example test.

IMO Number	Ship Code	Tokyo MoU-Risk Semantics	This Study-Risk Semantics	Next Inspection Date	Deficiencies Detected
9462718	D	SRS	Medium-risk	08/14	Yes
9629108	F	SRS	Low-risk	12/09 ***	No
9692428	G	SRS	Low-risk	07/30 ***	No
9299317	H	SRS	Low-risk	08/02	Yes
9702558	I	SRS	Low-risk	11/13 ***	No
9604158	J	SRS	Low-risk	10/15 ***	No
9462720	K	SRS	Medium-risk	04/24	Yes
9479230	L	SRS	Low-risk	—	Not yet inspected
9629055	M	SRS	Low-risk	—	Not yet inspected
9373620	N	SRS	Medium-risk	05/19	Yes
9462706	O	SRS	Medium-risk	11/05	Yes
9784128	P	SRS	Medium-risk	2020/01/12 ***	No

Note: *** Indicates that no deficiencies were found after the second inspection,—Indicates that a ship has not yet been inspected by a PSCO.

The above overall model can identify ships that belong to the SRS category but whose seaworthiness is overestimated, as shown in Table 13. For example, ships D, K, N and O are all listed as SRS by Tokyo MoU. In particular, the PSCO designated ships K and N as targets to be inspected within one month, and inspection discovered deficiencies in these two ships. According to the PSC MoU specification, the SRS exemption inspection time is 5–8 months, which means that the PSCO knows that the seaworthiness of ships is overestimated in the current SRS.

The ship risk assessment scale established in this study aims to more accurately distinguish ships within the hidden risk in the SRS category. Due to the wide range of standards for ships listed as SRS, it is impossible to effectively screen out ships that really need to be inspected. As a result, a PSCO will overestimate the seaworthiness of ships under inspection when screening them. After screening through the evaluation mechanism established in this study, 12 SRSs were reclassified. Among these, five ships were recategorized medium-risk ships and the other seven ships were recategorized low-risk ships, although among the five medium-risk ships and seven low-risk ships, the predictions for ships P and H were incorrect. However, the screening mechanism established in this study has an accuracy rate of 83.3% (within the exemption time) and can effectively identify hidden risk ships in the SRS category.

5. Discussion and Conclusions

At present, marine accidents often occur, and many of the ships involved in these marine accidents passed a PSC inspection when last berthing at port. As the time for exemption from inspection approved by various regional PSC MoUs is not the same, it is difficult to ensure that a ship is still seaworthy during this period of exemption.

Furthermore, as the amount of data in the PSC database continues to increase, and the problem that some high-risk ships can easily be classified as SRS category has not yet been resolved. Based on this, the target ship needs a selection system for identifying hidden risk ships in the SRS category. This system will assist with PSC inspection so to improve the safety levels of ships. It can be used to enhance the seaworthiness of the target ship, maintain the safety of water navigation and protect the marine ecological environment.

In the original definition of the NIR, if a ship is not HRS or LRS, it will be listed as an SRS. The criteria for being judged as an SRS are too broad, and it is easy to classify some ships that should belong to the high-risk ship category as SRS. Some ships are classified as SRS even though they have a large number of ship deficiencies. This situation overestimates the seaworthiness of the SRS, causing some SRS to still have extremely high risks of navigation safety. Therefore, this paper develops a selection system that uses PSC inspection records to identify hidden risks of target ships in the SRS category. This is the innovation of this research. The evaluation database for this selection system is a stable and correct source of ship inspection information. By updating ship inspection records each time, the screening system can keep evaluation and screening weights up-to-date and then appropriate assessment of the target ship. In addition, when new ship inspection records are uploaded to the Tokyo MoU database, the evaluation weights of the selection system will be changed accordingly to achieve a dynamic update effect. However, this selection system had the limitations. The target ships must have inspection records registered in the PSC MoU database. In order to achieve the purpose of distinguishing the difference in the weight value of the flag of the target ships and global ships. Otherwise, it is impossible to understand the initial value of the weight value of the ship's deficiency categories. In addition, there is no way to increase the weight value of the ship deficiency categories that is easy to detect for the flag of the target ship.

This study constructed a set of ship risk assessment standards using deficiency data on ships in the Tokyo MoU database. To verify the validity of the ship risk assessment system, this system made use of the data on the inspection status of Taiwanese ships from January to June 2019 in the Tokyo MoU database. After testing 12 SRSs in actual cases, the results of the next PSC inspections were successfully predicted for 10 SRSs, but failed to be correctly predicted for the other teo. From the analysis results, the hidden risk of most Taiwanese ships can be detected by the system in the SRS category. After adopting the evaluation system proposed in this study, it is possible to predict whether the seaworthiness of Taiwanese ship is overestimated with an accuracy of up to 83.3%.

This result can be provided to the inspection unit of the Taiwanese Maritime Port Bureau. It can be used to force ships into dock repair or to eliminate ships with insufficient seaworthiness from our nation. In the black-grey-white lists developed by the PSC MoU, Taiwanese ships can reduce the situation of being judged as a grey or blacklist. It can reduce the number of cases in which ships are found to have deficiencies and also reduce the number of arrests. Then, they can achieve the result of reducing the loss of their nation's shipping industry. Companies need to have data as a source of reference when implementing management and policy changes. Based on the results of this analysis, the company can understand the current situation of its ships and make improvements. This allows the registered flag of the ships to reduce the likelihood of being greylisted or blacklisted. Some topics for future study. For example, understanding the Interrelation between the smart navigation and PSC. In addition, comparing the correlation between ship defect categories will be an interesting topic.

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Appendix A

The process of the deficiency data of the flags of the ships collected and fuzzified is shown in Tables A1–A3. These data sources come from the Tokyo MoU database from 2014 to 2018.

Table A1. Statistics on the deficiencies registered by the flags of the ships in the Tokyo MoU from 2014 to 2018.

Code	Nature \ Year	2014	2015	2016	2017	2018
01000	Certificate & Documentation	10,395	8003	7723	7352	6744
02000	Structural Conditions	2671	2422	2471	2324	2046
03000	Water/Weathertight conditions	5812	5584	5587	5283	5017
04000	Emergency Systems	5093	5771	5011	4350	4128
05000	Radio Communications	2259	2231	2062	1798	1570
06000	Cargo operations including equipment	613	500	1382	744	711
07000	Fire safety	16,654	15,143	14,960	13,707	13,340
08000	Alarms	634	577	573	455	520
09000	Working and Living Conditions	4663	3215	2904	2671	2536
10000	Safety of Navigation	14,231	12,619	12,207	11,701	10,127
11000	Life-saving appliances	10,515	11,213	10,981	9787	9363
12000	Dangerous goods	183	352	287	272	195
13000	Propulsion and auxiliary machinery	4549	4137	3817	3731	3785
14000	Pollution prevention	5276	5067	4859	4822	6917
15000	ISM	2699	2803	2192	1987	1616
16000	ISPS	1615	1389	1624	1345	1516
18000	Labour Conditions	2437	3247	3718	4562	4258
99000	Other	876	722	537	562	568
	Total	91,175	84,995	82,895	77,453	74,957

Table A2. The first step of fuzzification of the flags of the ships deficiency data in Tokyo MoU.

Code	2014	2015	2016	2017	2018
01000	0.1140	0.0942	0.0932	0.0949	0.0900
02000	0.0293	0.0285	0.0298	0.0300	0.0273
03000	0.0637	0.0657	0.0674	0.0682	0.0669
04000	0.0559	0.0679	0.0604	0.0562	0.0551
05000	0.0248	0.0262	0.0249	0.0232	0.0209
06000	0.0067	0.0059	0.0167	0.0096	0.0095
07000	0.1827	0.1782	0.1805	0.1770	0.1780
08000	0.0070	0.0068	0.0069	0.0059	0.0069
09000	0.0511	0.0378	0.0350	0.0345	0.0338
10000	0.1561	0.1485	0.1473	0.1511	0.1351
11000	0.1153	0.1319	0.1325	0.1264	0.1249
12000	0.0020	0.0041	0.0035	0.0035	0.0026
13000	0.0499	0.0487	0.0460	0.0482	0.0505
14000	0.0579	0.0596	0.0586	0.0623	0.0923
15000	0.0296	0.0330	0.0264	0.0257	0.0216
16000	0.0177	0.0163	0.0196	0.0174	0.0202
18000	0.0267	0.0382	0.0449	0.0589	0.0568
99000	0.0096	0.0085	0.0065	0.0073	0.0076

Table A3. The second step of fuzzification of the flags of the ships deficiency data in Tokyo MoU.

Code	Min	Average	Max	Fuzzy
01000	0.0900	0.0972	0.1140	0.0988
02000	0.0273	0.0290	0.0300	0.0289
03000	0.0637	0.0664	0.0682	0.0663
04000	0.0551	0.0591	0.0679	0.0599
05000	0.0209	0.0240	0.0262	0.0239
06000	0.0059	0.0097	0.0167	0.0102
07000	0.1770	0.1792	0.1827	0.1794
08000	0.0059	0.0067	0.0070	0.0066
09000	0.0338	0.0385	0.0511	0.0398
10000	0.1351	0.1476	0.1561	0.1469
11000	0.1153	0.1262	0.1325	0.1254
12000	0.0020	0.0031	0.0041	0.0031
13000	0.0460	0.0487	0.0505	0.0485
14000	0.0579	0.0661	0.0923	0.0691
15000	0.0216	0.0272	0.0330	0.0273
16000	0.0163	0.0182	0.0202	0.0183
18000	0.0267	0.0451	0.0589	0.0443
99000	0.0065	0.0079	0.0096	0.0079

Appendix B

The process of the deficiency data of Taiwanese ships collected and fuzzified is shown in Tables A4–A6. These data sources come from the Tokyo MoU database from 2014 to 2018.

Table A4. Statistics on the deficiencies registered by Taiwanese ships in the Tokyo MoU from 2014 to 2018.

Code	Year / Nature	2014	2015	2016	2017	2018
01000	Certificate & Documentation	40	34	35	34	23
02000	Structural Conditions	14	10	15	5	2
03000	Water/Weathertight conditions	41	29	76	40	7
04000	Emergency Systems	29	23	42	8	5
05000	Radio Communications	7	25	6	9	2
06000	Cargo operations including equipment	2	4	9	4	0
07000	Fire safety	86	93	98	69	36
08000	Alarms	4	1	1	1	1
09000	Working and Living Conditions	36	33	34	16	13
10000	Safety of Navigation	73	117	77	60	30
11000	Life-saving appliances	53	66	59	45	14
12000	Dangerous goods	0	2	1	0	0
13000	Propulsion and auxiliary machinery	38	29	50	24	10
14000	Pollution prevention	11	24	23	16	11
15000	ISM	19	20	29	10	5
16000	ISPS	0	0	0	0	0
18000	Labour Conditions	10	23	33	23	5
99000	Other	10	3	16	2	4
	Total	473	536	604	366	168

Table A5. The first step of fuzzification of Taiwanese ships deficiency data in Tokyo MoU.

Code	2014	2015	2016	2017	2018
01000	0.0846	0.0634	0.0579	0.0929	0.1369
02000	0.0296	0.0187	0.0248	0.0137	0.0119
03000	0.0867	0.0541	0.1258	0.1093	0.0417
04000	0.0613	0.0429	0.0695	0.0219	0.0298
05000	0.0148	0.0466	0.0099	0.0246	0.0119
06000	0.0042	0.0075	0.0149	0.0109	0.0000
07000	0.1818	0.1735	0.1623	0.1885	0.2143
08000	0.0085	0.0019	0.0017	0.0027	0.0060
09000	0.0761	0.0616	0.0563	0.0437	0.0774
10000	0.1543	0.2183	0.1275	0.1639	0.1786
11000	0.1121	0.1231	0.0977	0.1230	0.0833
12000	0.0000	0.0037	0.0017	0.0000	0.0000
13000	0.0803	0.0541	0.0828	0.0656	0.0595
14000	0.0233	0.0448	0.0381	0.0437	0.0655
15000	0.0402	0.0373	0.0480	0.0273	0.0298
16000	0.0000	0.0000	0.0000	0.0000	0.0000
18000	0.0211	0.0429	0.0546	0.0628	0.0298
99000	0.0211	0.0056	0.0265	0.0055	0.0238

Table A6. The second step of fuzzification of Taiwanese ships deficiency data in Tokyo MoU.

Code	Min	Average	Max	Fuzzy
01000	0.0579	0.0871	0.1369	0.0906
02000	0.0119	0.0197	0.0296	0.0201
03000	0.0417	0.0835	0.1258	0.0836
04000	0.0219	0.0451	0.0695	0.0453
05000	0.0099	0.0216	0.0466	0.0238
06000	0.0000	0.0075	0.0149	0.0075
07000	0.1623	0.1841	0.2143	0.1855
08000	0.0017	0.0041	0.0085	0.0044
09000	0.0437	0.0630	0.0774	0.0622
10000	0.1275	0.1685	0.2183	0.1700
11000	0.0833	0.1078	0.1231	0.1063
12000	0.0000	0.0011	0.0037	0.0013
13000	0.0541	0.0685	0.0828	0.0685
14000	0.0233	0.0431	0.0655	0.0435
15000	0.0273	0.0365	0.0480	0.0369
16000	0.0000	0.0000	0.0000	0.0000
18000	0.0211	0.0423	0.0628	0.0422
99000	0.0055	0.0165	0.0265	0.0163

Appendix C

The process of the deficiency data for Taiwanese ships adopted TOPSIS analysis is shown in Tables A7–A11. These data sources come from the Tokyo MoU database from 2014 to 2018.

Table A7. Statistics on the deficiencies registered by Taiwanese ships in the Tokyo MoU from 2014 to 2018.

Code	Year / Nature	2014	2015	2016	2017	2018	Max
01000	Certificate & Documentation	40	34	35	34	23	40
02000	Structural Conditions	14	10	15	5	2	15
03000	Water/Weathertight conditions	41	29	76	40	7	76
04000	Emergency Systems	29	23	42	8	5	42
05000	Radio Communications	7	25	6	9	2	25
06000	Cargo operations including equipment	2	4	9	4	0	9
07000	Fire safety	86	93	98	69	36	98
08000	Alarms	4	1	1	1	1	4
09000	Working and Living Conditions	36	33	34	16	13	36
10000	Safety of Navigation	73	117	77	60	30	117
11000	Life-saving appliances	53	66	59	45	14	66
12000	Dangerous goods	0	2	1	0	0	2
13000	Propulsion and auxiliary machinery	38	29	50	24	10	50
14000	Pollution prevention	11	24	23	16	11	24
15000	ISM	19	20	29	10	5	29
16000	ISPS	0	0	0	0	0	0
18000	Labour Conditions	10	23	33	23	5	33
99000	Other	10	3	16	2	4	16

Table A8. The first step of TOPSIS analysis is adopted for the deficiency data of Taiwanese ship.

Code	2014	2015	2016	2017	2018
01000	1.0000	0.8500	0.8750	0.8500	0.5750
02000	0.9333	0.6667	1.0000	0.3333	0.1333
03000	0.5395	0.3816	1.0000	0.5263	0.0921
04000	0.6905	0.5476	1.0000	0.1905	0.1190
05000	0.2800	1.0000	0.2400	0.3600	0.0800
06000	0.2222	0.4444	1.0000	0.4444	0.0000
07000	0.8776	0.9490	1.0000	0.7041	0.3673
08000	1.0000	0.2500	0.2500	0.2500	0.2500
09000	1.0000	0.9167	0.9444	0.4444	0.3611
10000	0.6239	1.0000	0.6581	0.5128	0.2564
11000	0.8030	1.0000	0.8939	0.6818	0.2121
12000	0.0000	1.0000	0.5000	0.0000	0.0000
13000	0.7600	0.5800	1.0000	0.4800	0.2000
14000	0.4583	1.0000	0.9583	0.6667	0.4583
15000	0.6552	0.6897	1.0000	0.3448	0.1724
16000	0.0000	0.0000	0.0000	0.0000	0.0000
18000	0.3030	0.6970	1.0000	0.6970	0.1515
99000	0.6250	0.1875	1.0000	0.1250	0.2500
SUMSQ	8.2703	9.9463	13.1784	4.2528	1.1813
SQRT	2.8758	3.1538	3.6302	2.0622	1.0869

Table A9. The second step of TOPSIS analysis is adopted for the deficiency data of Taiwanese ship.

Code	2014	2015	2016	2017	2018
01000	0.3477	0.2695	0.2410	0.4122	0.5290
02000	0.3245	0.2114	0.2755	0.1616	0.1227
03000	0.1876	0.1210	0.2755	0.2552	0.0847
04000	0.2401	0.1736	0.2755	0.0924	0.1095
05000	0.0974	0.3171	0.0661	0.1746	0.0736
06000	0.0773	0.1409	0.2755	0.2155	0.0000
07000	0.3051	0.3009	0.2755	0.3414	0.3380
08000	0.3477	0.0793	0.0689	0.1212	0.2300
09000	0.3477	0.2907	0.2602	0.2155	0.3322
10000	0.2170	0.3171	0.1813	0.2487	0.2359
11000	0.2792	0.3171	0.2463	0.3306	0.1952
12000	0.0000	0.3171	0.1377	0.0000	0.0000
13000	0.2643	0.1839	0.2755	0.2328	0.1840
14000	0.1594	0.3171	0.2640	0.3233	0.4217
15000	0.2278	0.2187	0.2755	0.1672	0.1586
16000	0.0000	0.0000	0.0000	0.0000	0.0000
18000	0.1054	0.2210	0.2755	0.3380	0.1394
99000	0.2173	0.0595	0.2755	0.0606	0.2300
A+	0.3477	0.3171	0.2755	0.4122	0.5290
A−	0.0000	0.0000	0.0000	0.0000	0.0000

Table A10. The third step of TOPSIS analysis (positive ideal distance) is adopted for the deficiency data of Taiwanese ship.

Code	2014	2015	2016	2017	2018	SQRT
01000	0.0000	−0.0476	−0.0344	0.0000	0.0000	0.0587
02000	−0.0232	−0.1057	0.0000	−0.2505	−0.4064	0.4895
03000	−0.1601	−0.1961	0.0000	−0.1570	−0.4443	0.5349
04000	−0.1076	−0.1434	0.0000	−0.3198	−0.4195	0.5572
05000	−0.2504	0.0000	−0.2094	−0.2376	−0.4554	0.6086
06000	−0.2705	−0.1762	0.0000	−0.1967	−0.5290	0.6502
07000	−0.0426	−0.0162	0.0000	−0.0708	−0.1911	0.2088
08000	0.0000	−0.2378	−0.2066	−0.2909	−0.2990	0.5228
09000	0.0000	−0.0264	−0.0153	−0.1967	−0.1968	0.2799
10000	−0.1308	0.0000	−0.0942	−0.1635	−0.2931	0.3723
11000	−0.0685	0.0000	−0.0292	−0.0816	−0.3339	0.3517
12000	−0.3477	0.0000	−0.1377	−0.4122	−0.5290	0.7679
13000	−0.0835	−0.1332	0.0000	−0.1794	−0.3450	0.4194
14000	−0.1884	0.0000	−0.0115	−0.0889	−0.1073	0.2346
15000	−0.1199	−0.0984	0.0000	−0.2450	−0.3704	0.4704
16000	−0.3477	−0.3171	−0.2755	−0.4122	−0.5290	0.8644
18000	−0.2424	−0.0961	0.0000	−0.0742	−0.3896	0.4746
99000	−0.1304	−0.2576	0.0000	−0.3516	−0.2990	0.5444

Table A11. The fourth step of TOPSIS analysis (negative ideal distance) is adopted for the deficiency data of Taiwanese ship.

Code	2014	2015	2016	2017	2018	SQRT
01000	0.3477	0.2695	0.2410	0.4122	0.5290	0.8375
02000	0.3245	0.2114	0.2755	0.1616	0.1227	0.5168
03000	0.1876	0.1210	0.2755	0.2552	0.0847	0.4450
04000	0.2401	0.1736	0.2755	0.0924	0.1095	0.4292
05000	0.0974	0.3171	0.0661	0.1746	0.0736	0.3877
06000	0.0773	0.1409	0.2755	0.2155	0.0000	0.3849
07000	0.3051	0.3009	0.2755	0.3414	0.3380	0.7002
08000	0.3477	0.0793	0.0689	0.1212	0.2300	0.4467
09000	0.3477	0.2907	0.2602	0.2155	0.3322	0.6557
10000	0.2170	0.3171	0.1813	0.2487	0.2359	0.5459
11000	0.2792	0.3171	0.2463	0.3306	0.1952	0.6217
12000	0.0000	0.3171	0.1377	0.0000	0.0000	0.3457
13000	0.2643	0.1839	0.2755	0.2328	0.1840	0.5173
14000	0.1594	0.3171	0.2640	0.3233	0.4217	0.6914
15000	0.2278	0.2187	0.2755	0.1672	0.1586	0.4783
16000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18000	0.1054	0.2210	0.2755	0.3380	0.1394	0.5191
99000	0.2173	0.0595	0.2755	0.0606	0.2300	0.4281

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