mathematics

MDPI

Article

Application of Multivariate Statistical Techniques as an Indicator of Variability of the Effects of COVID-19 on the Paris Memorandum of Understanding on Port State Control

Jose Manuel Prieto [1,*], Víctor Amor-Esteban [2], David Almorza-Gomar [3], Ignacio Turias [4] and Francisco Piniella [1]

1 Department of Maritime Studies, University of Cádiz, 11003 Cádiz, Spain; francisco.piniella@uca.es
2 Department of Statistics, University of Salamanca, 37008 Salamanca, Spain; vamor@usal.es
3 Department of Statistics and Operational Research, University of Cádiz, 11003 Cádiz, Spain; david.almorza@uca.es
4 Department of Computer Engineering, University of Cádiz, 11003 Cádiz, Spain; ignacio.turias@uca.es
* Correspondence: josemanuel.prieto@gm.uca.es

Abstract: The first pandemic of the 21st Century was declared at the beginning of the year 2020 due to the spread of the COVID-19 virus. Its effects devastated the world economy and greatly affected maritime transport, one of the precursors of globalisation. This paper studies the effects of the pandemic on this type of transport, using data from 23,803 Paris Memorandum of Understanding Port State Control (PSC) inspections conducted in the top 10 major European ports. Comparisons have been made between Pre-COVID (2013–2019) and COVID (2020–2021) years, by way of multivariate methodologies: CO-X-STATIS, X-STATIS, and correspondence tables. The results were striking and indicate a clear change in the conduct of inspections during the COVID period, both quantitatively and qualitatively, showing a drastic reduction in the number of inspections and a change in type, with exhaustive inspections assuming a secondary role. Another notable result came from the use of the same methodology to study the different countries of registry and their evolution within PSC inspections during the Pre-COVID and COVID periods, where different behaviours were identified based on a ship's flag. These results can help us to determine important supervisory objectives for each country's maritime administration and their inspectors, to indicate weaknesses in the inspection routines caused by the pandemic, and to attempt corrections to improve maritime safety.

Keywords: multivariate analysis; CO-X-STATIS; maritime safety; Port State Control; Paris Memorandum of Understanding; COVID-19

MSC: 62H99

check for updates

Citation: Prieto, J.M.; Amor-Esteban, V.; Almorza-Gomar, D.; Turias, I.; Piniella, F. Application of Multivariate Statistical Techniques as an Indicator of Variability of the Effects of COVID-19 on the Paris Memorandum of Understanding on Port State Control. *Mathematics* **2023**, *11*, 3188. https://doi.org/10.3390/math11143188

Academic Editor: Jinwen Ma

Received: 31 May 2023
Revised: 13 July 2023
Accepted: 17 July 2023
Published: 20 July 2023

1. Introduction

In the last few decades, maritime transport has proven to be one of the most efficient ways to transport large quantities of goods from one side of the world to the other. This has caused a considerable increase in the volume of goods being transported by registered ships of different nationalities. This country of registry is responsible for the ship complying with the appropriate safety standards set by the International Maritime Organisation (IMO) [1], which appear in different international conventions such as Safety of Lives at Sea, Prevention of Pollution from Ships, and the Standards of Training, Certification, and Watchkeeping (STCW), among others.

Alongside this phenomenon, a world tendency has grown for ships to be flagged to countries with open registries, also known as 'flags of convenience' [2], a term coined by the International Transport Federation. There is evidence that the countries with open registries struggle to hold their flagged ships to the previously mentioned international rules because the ships dock in their ports sporadically [3,4]. These countries help to facilitate and are flexible with the registration of a ship, therefore complicating control over safety matters [5].

With the objective of examining the state of ships in terms of safety throughout the world, the international community adopted inspection methods. The periodic inspections called Port State Control (PSC) [6] are enacted on foreign ships in docks by the corresponding national maritime administration. These PSC inspections are not globalised, that is to say, they are not enacted all over the world, but are grouped by region and each region has its own Memorandum of Understanding (MoU) that regulates these inspections. In the European Union (EU), the Paris Memorandum of Understanding [7] has been in place since 1982, and this is the subject of our study.

The Paris MoU PSC inspections are conducted by inspectors certified by the European Maritime Safety Agency (EMSA) [8]. These inspectors use a series of directives as guidance to conduct their inspections. The most important and recent directive is the ERIKA III (2009/15/CE) [9], which came into effect in 2011 and implements a new inspection regime (NIR). This new inspection system applies the 'prioritized inspections' method, assigning each ship a 'risk profile', which is established based on the results of previous inspections, the shipping company, and the flag state. This obtained profile of the vessel is used to inform inspectors in real time of the priorities and type of inspection that should be applied to each vessel. This new regulation unifies the criteria for the immobilisation and detention of ships and implements a co-ordinated system with the objective to avoid differences in inspection procedures within EU ports.

Three types of inspection are considered based on a ship's risk profile:

- Initial inspection: this will be conducted on ships chosen for inspection based on their risk profile and/or the concurrence of priority or unexpected factors.
- More detailed inspection: this will be conducted if the initial inspection highlights probable grounds for concern that the ship, equipment, or crew substantially breach a decree of any relevant International Convention.
- Expanded inspection: this will be carried out on certain ship categories that have a high-risk profile and/or are an old model.

Depending on the type of inspection conducted and the deficiencies found, the ship may be detained by the corresponding national maritime administration to avoid a lack of safety in their waters, something of great importance that will be addressed in this paper.

The PSC inspection system is connected to The Hybrid European Targeting and Inspection System (THETIS) [10]: a centralized information network run by EMSA. This management system was used to obtain the data for this study. THETIS is connected to the European network of vessel traffic monitoring in EU waters (SafeSeaNet) [11], which is an information and vessel traffic monitoring system that serves as an additional guarantee in the process of inspection and selection of vessels.

1.1. COVID-19: Maritime Transport and PSC Inspections

In December 2019, in Wuhan, People's Republic of China, the first cases of a grave illness that caused respiratory difficulties and fever were detected [12]. In many cases, there was evidence of bilateral pneumonia, which was frequently fatal and was reminiscent of that seen in the SARS (Severe Acute Respiratory Syndrome) epidemic of 2003.

The World Health Organization (WHO) was informed by China of the epidemic on 31 December 2019 and, in January 2020, the Betacoronavirus was isolated as the etiological agent of the illness. It would be known as SARS-CoV 2 (due to its similar structure to the SARS virus), and the illness it produced was named COVID-19 (Coronavirus Disease 2019). At the beginning of 2020, the virus spread throughout the world and the first pandemic of the 21st Century was declared by the WHO on the 11 March 2020.

This pandemic led to extreme restrictions on movement, including the closure of borders and ports throughout the world to avoid propagation. This caused a substantial impact on all types of transport, and even more so on maritime transport [13] due to the virus's implications on crew and close-quartered areas. Maritime transport is one of the main precursors to globalisation with vessels in constant movement transporting goods between ports all over the world. For this reason, the IMO, together with the United Nations Conference on Trade and Development, attempted to mitigate the effects of the pandemic by publishing a statement on the 8 June 2020 [14] calling for collaboration to keep the vessels sailing, ports open, and cross-border trade flowing during the COVID-19 pandemic.

The IMO also attempted to relax the PSC inspection procedures to adapt to the evolution of the pandemic. A videoconference took place in April 2020 involving all 10 PSC regimes to harmonise the inspections worldwide. One of the first steps taken was to present a circular letter in 2020, allowing surveys and renewals of vessel certificates to be delayed for up to 3 months [15]. This documentation is requested by the inspectors upon initiation of the inspection and certifies that the vessel is in good working condition. In the same year, another circular letter was released to allow flexible working conditions for crew [16] so that they could disembark quickly to receive medical attention on land during the COVID-19 pandemic. Various circular letters and directives were also aimed at inspectors and their work to guarantee safety in interactions between vessel personnel and ground crew [17].

The main objective of this paper was to take everything mentioned previously and assess if, and by how much, the Paris MoU PSC inspections were affected by the COVID-19 pandemic. In the following sections, we will review the state of the latest studies related to PSC inspections, and review documents that have considered the pandemic.

1.2. Review of the Latest Studies on Safety Controls

There have been numerous studies on PSC inspections; Knapp and Frances [4,18,19] were the pioneers in applying econometric methods, using binary logistic regressions to find differences between the different inspection regimes. They reviewed the frequency of inspections in relation to ship risk profiles and their recommendations were implemented by the Paris MoU. In 2011 an NIR came into effect, a topic that has been discussed in the previous section of this paper and was studied by [20,21].

Li and Zheng [3] studied the effectiveness of the system and the methods adopted by the different regional PSC agreements for the selection of vessels under inspection. The results of this showed that PSC inspections are effective at improving maritime transport safety. Later, Bayesian Networks (BN) were used to examine relationships between PSC inspections and ship accidents [22,23]. Özçayir [24] and Wu et al. [25] also conducted studies of this type. Ravira and Piniella [26] concluded that professional training and the use, or lack of use, of teams when conducting inspections influenced the result.

Graziano et al. [27] analysed inspection reports from the EMSA to determine levels of harmonisation and differences in inspection practices, and also evaluated discrepancies between member states after the NIR came into effect.

Chen et al. [28] conducted empirical analyses on detentions in port states of the Asian and Pacific Region (Tokyo MoU), providing the port states with effective measures to improve vessel safety inspections. In addition, a more recent study [29] highlighted that there are improvements to be made in the identification of vessels for inspection and priority areas within inspections. These improvements could help the maritime administrations with their selection of vessels.

Wang et al. [30] applied a new probabilistic model of risk to PSC based on a BN and studied the dependency and interdependency of risk factors associated with the PSC inspections based on big data, using data from the Tokyo MoU inspections between 2014 and 2017. They showed that safety deficiencies and technical characteristics of vessels are the most important factors in PSC inspections and vessel detentions.

Prieto and Amor [31] analysed inspections conducted between 2013 and 2018 in the top 10 major European ports of the Paris MoU by applying multivariate statistics (STATIS). They obtained important results as theirs coincided with the lists that are annually published by the Paris MoU, validating the method for classifying flags and societies. The method can also be applied by maritime administrations as an additional indicator of a ship's risk profile and to improve decisions on inspection priorities.

1.3. Review of the Latest Studies on Safety Controls and COVID-19

One of the most recent studies that have been published on how the COVID-19 pandemic has affected maritime transport and PSC inspections was conducted by Nam and Kim [32], in which they declared that the 3-month extension on vessel certificates granted by the IMO is not sufficient due to the evolution of the pandemic. They proposed the need for an analysis to amend the clauses of this exemption and avoid legal uncertainties surrounding any incident involving a vessel.

Akyurek and Bolat [33] also analysed the impact of the pandemic via a comparative analysis between the Paris MoU inspection and vessel detention figures, as well as a Gray relevance analysis based on entropy between the years 2017 and 2020. Their results showed that the number of vessels inspected by the Paris MoU had been drastically reduced, however, the rate of detentions per inspection remained the same. They also showed that the main reasons behind a detention have changed. In this sense, our study provides new insights by broadening the conclusions on the type of inspections conducted and their consequences.

In another study, Okerman and Tigerstrom [13] reviewed the impact of the pandemic on the maritime industry and concluded that there have been operative losses and inconveniences due to the health and safety restrictions set as a result of COVID-19.

These regulations have inevitably affected chartering rates, incomes, and gains, as well as the use of installations and human resources, which are directly related to PSC inspections. It is thought that PSC inspections based on IMO conventions and big data apps can contribute to the reduction in potential risk in the post-COVID-19 era and offer successful opportunities to respond. This study follows this sentiment by applying novel methodology to large datasets in order to detect deficiencies in different aspects of the inspections conducted within this time period.

Yan et al. [34] explored the possibility of global and regional PSC inspections being influenced by the pandemic via the analysis of real data that takes into consideration the number of inspections, the average number of deficiencies per inspection, and the rate of detention. The outcomes showed that the COVID-19 pandemic had an impact on the PSCs. Our study will also expand on this by including more PSC inspection variables in the analysis and reach conclusions relating to countries of registry.

The remainder of this document is organised in various sections. Section 2 details the chosen database and describes the methodology and techniques used throughout this paper. Section 3 presents and discusses the results obtained. Finally, the conclusions are presented in Section 4.

2. Materials and Methods

This study comprises PSC inspections conducted between 2013 and 2021. The data consist of 23,803 PSC inspections carried out in the top 10 European ports that participate in the Paris MoU (Table 1). The inspection data were obtained from the THETIS [10] platform and the ports were selected based on the weight of transported goods data taken from the Eurostat database [35].

Table 1. The 10 Major European Ports based on gross tonnage during the study period.

Port	Sample
Algeciras	2630
Amsterdam	1516
Antwerp	2795
Bremerhaven	536
Hamburg	4519
Immingham	5174

Table 1. *Cont.*

Port	Sample
Le Havre	1279
Marseilles	640
Rotterdam	2919
Valencia	1795
Total	23,803

The variables used in this investigation were the characteristics of the inspected ship (Table 2) and the type of inspection conducted and its outcomes (Table 3).

Table 2. Variables that describe the inspected ship.

Ship Variables	Description
Flag	Indicates the nationality of the ship
Age	Age of the ship
Gross Tonnage	Registered Gross Tonnage GT Indicates ship size

Table 3. Variables that describe the inspection.

Inspection Variables	Description
Type of Inspection	Degree of Inspection carried out on the ship depending on its level of risk
Number of Deficiencies	Number of deficiencies detected after inspections

Two multivariate analysis methodologies were used, X-STATIS and CO-X-STATIS, along with a simple correspondence analysis.

(i) The X-STATIS technique was used to analyse the period 2019–2021, which allows us to represent the compromise structure of all of the years and visualize behaviour patterns of flags based on the characteristics of the ship. This method will be very useful to observe the relationship between the variables and their evolution during these years, as well as to detect significant changes and characterize the 45 countries based on the inspection type, gross tonnage, age, and number of deficiencies. In this way, we will be able to study which countries submit ships to a more initial or more advanced type of inspection.

(ii) The simple correspondence analysis was used to analyse the years 2013–2021, separating the data into two periods, Pre-COVID and COVID; in this case, we will cross the top 10 European ports that participate in the Paris MoU with the types of inspection, initial, expanded, and more detailed (two qualitative variables: port and inspection type), with the aim of studying whether there were changes in the type of inspections carried out in each port, all the while understanding that one of the main consequences of the pandemic could be the use of less exhaustive inspections.

(iii) The CO-X-STATIS method was used to examine the entire study period of 2013–2021, dividing the Pre-COVID and COVID periods for comparison. In this analysis, we will compare the countries to see the evolution of the ships according to their flags in relation to the PSC inspections. The CO-X-STATIS is a co-inertia analysis of two compromise tables, that is, we compare the synthesized information from the Pre-COVID period with the synthesized information from the COVID period, which will allow us to identify those countries that have maintained a stable, positive, or negative evolution with the appearance of the pandemic. The results can be used as an additional risk indicator to establish a follow up of those vessels with flags that have a high degree of negative evolution, relating them to the different restrictions and regulations that each country implements during the COVID-19 pandemic, which could help improve safety in our waters.

Combining these techniques will show how PSC inspections have changed significantly over these time periods. A detailed description of how each method was applied to the data matrices and selected variables is presented in the following subsections.

2.1. X-STATIS Methodology

The first technique applied in this study is X-STATIS [36], which is used when data are structured in a three-way format. In the case of our data, we characterize the flags (first way, countries that make up the study) based on the results of the inspection with the variables that evaluate the characteristics of the ship (second way, variables of age, dimensions of the ship, number of deficiencies, and type of inspection) over time (third way, study years 2019–2021). This technique belongs to the STATIS method family [37,38], which has the objective of extracting stable information from k data tables. This method divides its process into three stages: interstructure, compromise, and intrastructure. Next, we will describe the first two stages (the third is not the subject of this study) for our data table with dimensions of 45 flags $\times$ 4 variables $\times$ 3 years.

The first stage of this method identifies the relationship between the years of study; it is a general comparison between the k data tables and is known as the study of the interstructure (flow chart in Figure 1). In order to analyse the similarities or differences between years and to be able to understand if the study period is considered stable or, on the contrary, presents significant changes, a vector covariance matrix is constructed from the scalar products between tables (each table corresponding with one year of study), obtaining a matrix where the element in row k and column l is calculated as $Covv\ (X_k,\ X_l) = Tr\ \left(X_k^t\ D_n\ X_l\ D_p\right)$; X_k is table k in the sequence, and D_n and D_p are the metrics for the rows and columns, respectively. Said matrix is represented in a low-dimensional Euclidean subspace, the factorial plane of the first two axes is plotted, where each year, each of the k data tables is represented as a point and these points are connected with the origin of coordinates; in this way, a graphical estimate of the vector correlations between tables can be obtained, where acute angles translate into positive correlations.

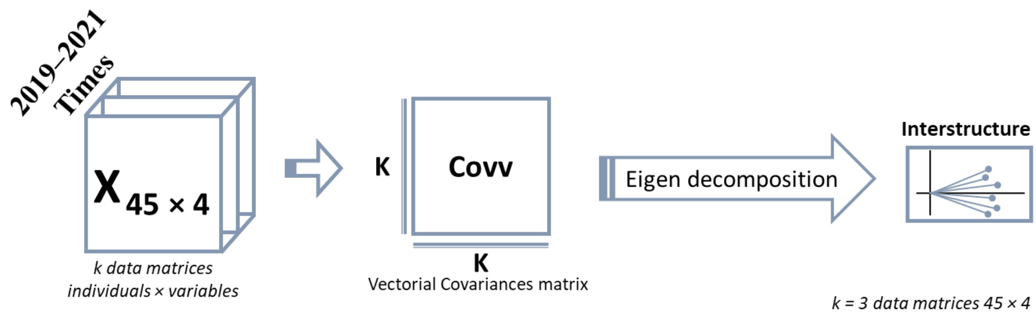


Figure 1. Interstructure analysis flow chart in X-STATIS. Source: [31].

The second stage of this technique summarizes the information contained in the k tables into a single table that contains the data from the different synthesized years representing the stable information and is known as the compromise analysis (flow chart described in Figure 2). This final matrix is called 'compromise' and maintains the initial dimensions of the k tables, in rows are show the 45 flags (study countries) and columns that present four variables that evaluate the particularities of the ship: 'Age', 'Def', 'Ins' and 'Ton' (age of ship, number of deficiencies, inspection type, and gross tonnage).

To create the 'compromise' matrix, we begin with the creation of the Z matrix, which is ascertained by vectorizing the original matrices (the k tables, one table per year), which means that the column vectors of each matrix are stacked vertically in the Z matrix. Each Z column corresponds to a different year, starting with the year 2019 and ending with the year 2021. As a result, a Z matrix of dimensions 180 $rows \times 3\ columns$ is obtained in rows that show the 45 countries with their values depicted via the four variables being studied, and in columns that present the years of research: 2019, 2020, and 2021. Now, we transform that Z matrix into the ZV matrix, with the same dimensions of Z but with the difference that now its columns are linear combinations of the columns of Z; we do this by means of the decomposition into singular values and vectors ($Z = U\Lambda V^t$). The ZV columns, being linear combinations of the Z columns, each contain joint information from all of the k tables, and they appear in decreasing order of importance. From the ZV matrix, we select its first component (180 rows) due to the fact that it is the one that carries the most information, and we place it horizontally in to a new matrix with four columns representing the variables that evaluate the ship: 'Age', 'Def', 'Ins' and 'Ton', and 45 rows, one for each country. As we can see, this matrix retains the dimensions of the initial k tables, 45 $rows \times 4\ columns$, and represents the stable information for the 2019–2021 period, contracting the dimension of time, and is known as the 'compromise' matrix.

By means of a principal component analysis (PCA), it is possible to represent the information contained in the 'compromise' matrix in a subspace of reduced dimensions, usually with the first two axes. In this representation, the rows of the matrix are represented as points (countries) and the columns as vectors connected to the origin of coordinates (ship' characteristic variables), in such a way that acute angles between vectors translate into positive correlations between variables; points close on the plane with similar characteristics between countries; and the projection of the points onto the vectors allows us to see the ordering of the countries in each of the variables, with higher values near the tip of the vector or ahead in the direction it marks. To carry out all of these calculations and create the representation, the ade4 software was used [39], is a software developed in the Biometry and Evolutionary Biology Lab (UMR 5558), University Lyon 1.

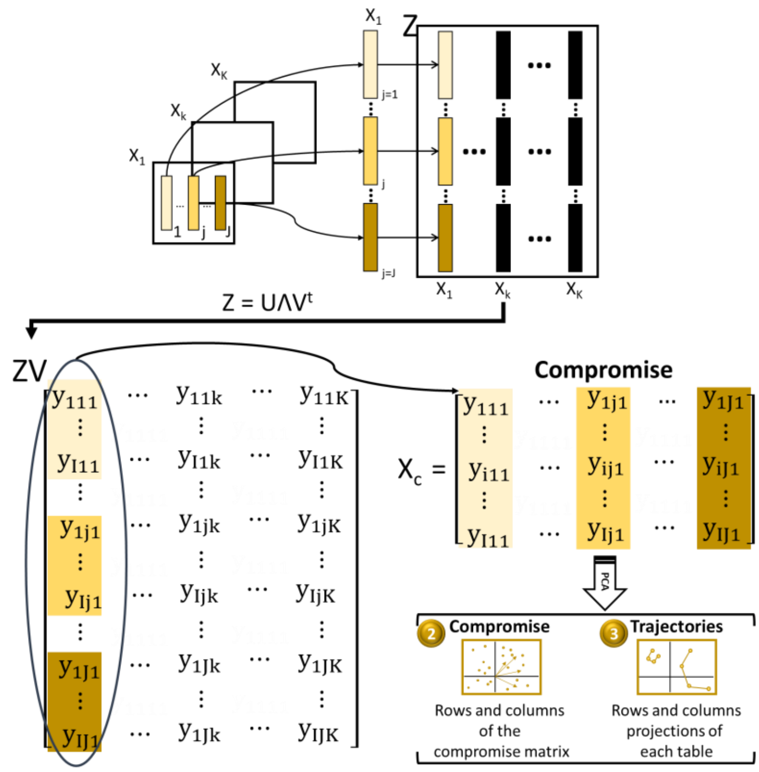


Figure 2. Compromise analysis flow chart in X-STATIS. Source: [31].

2.2. Correspondence Analysis Methodology

We have included a correspondence analysis in our study because it can reveal important information and corroborate the information obtained using other techniques, as we will see in Section 3.

The correspondence analysis is a technique used to represent two or more categories of qualitative variables on a low-dimensional plane. This means that the representation will be performed by grouping categories based on similarities between related variables. This is a technique used to study dependency relationships between categorical variables that are represented in contingency tables [40], therefore it shares similarities with the chi-squared test. The correspondence analysis can be classified into simple or multiple correspondent analyses. The difference is in the number of variables involved in the analysis, whereas the first one works with two variables or via two-by-two contingency tables; additionally, the multiple analysis can use more than two variables and, as a consequence, the contingency tables are more complex. In this study, we will be using the simple correspondence analysis.

The way the tables were created is described in Figure 3, where X and Y are two categorical variables with values $\{x_1, \ldots, x_k\}$ and $\{y_1, \ldots, y_m\}$, respectively. The variables are observed in N cases of the population. The intersection between row and column returns a cell, whose observed frequency is n_{ij}. In this case, the two variables are ports (X) and the type of inspection (Y) carried out in the ports.

X \ Y	y_1	y_2	.....	y_j	......	y_m	
x_1	n_{11} (e_{11})	n_{12}(e_{12})	....	n_{1j} (e_{1j})	....	n_{1m} (e_{1m})	$\mathbf{N_{1*}}$
x_2	n_{21} (e_{21})	n_{22} (e_{22})	....	n_{2j} (e_{2j})	....	n_{2m} (e_{2m})	$\mathbf{N_{2*}}$
.....	......	....	....		....	....	**.......**
x_i	n_{i1} (e_{i1})	n_{i2} (e_{i2})	....	n_{ij} (e_{ij})	....	n_{im} (e_{im})	$\mathbf{N_{i*}}$
.....	......	....	....		....	....	**.......**
x_k	n_{k1} (ek1)	n_{k2} (e_{k2})	....	n_{kj} (e_{kj})	....	n_{km} (e_{km})	$\mathbf{N_{k*}}$
	$\mathbf{N_{*1}}$	$\mathbf{N_{*2}}$		$\mathbf{N_{*j}}$		$\mathbf{N_m}$	$\mathbf{N_{**}}$

$$N_{i*} = \sum_{j=1}^{m} n_{ij}$$

$$N_{*j} = \sum_{i=1}^{k} n_{ij}$$

$$N_{**} = \sum_i N_{i*} = \sum_j N_{*j}$$

$$e_{ij} = \frac{N_{i*} N_{*j}}{N_{**}}$$

Figure 3. Structure of a simple correspondence table.

As a previous step to the correspondence analysis, we must determine if the data can adjust to a model, i.e., determine if there is a relationship between the variables that we wish to study. It would not make sense to conduct the correspondence analysis if there were no relationship between the variables. Because the variables are both qualitative variables, the chi-squared test is applied to the contingency table to test the goodness of fit of the data to the model. The chi-squared statistic for double entry tables tests the null hypothesis, H_0, that the categories of a variable are homogeneous, that is to say, the variables are independent. The degree to which the distributions of the categories of a variable differ from those of another variable will be related. In the case that the *p*-value associated with the statistic is below the defined level of significance, which is normally 0.05, the independence hypothesis will be rejected.

The next subsection describes another multivariate methodology we used to analyse all of the inspection data collected for the time period of 2013 to 2021.

2.3. CO-X-STATIS Methodology

This technique also belongs to the STATIS family of methods [37,38], and will be used to study the complete matrix, comparing the Pre-COVID (2013–2019) and COVID (2020–2021) ship flag structures. This will be conducted using two data cubes: (i) the first cube consists of 45 rows (countries), 4 columns (variables) and depicts 7 years (2013–2019); and (ii) the second cube comprises 45 rows (countries), 4 columns (variables) and depicts 2 years (2020–2021). For this reason, we have chosen the CO-X-STATIS method, which captures multivariate structures and allows for their comparison. This method is a two-step process; the first step builds the compromise matrix for each data cube (this is the X-STATIS step), which will represent a global overview of the tables, therefore each matrix summarises all of the information for each time period, one for Pre-COVID and one for COVID; and once the two matrices have been obtained, the second step consists in comparing the two structures, using a co-inertia analysis (see Figure 4).

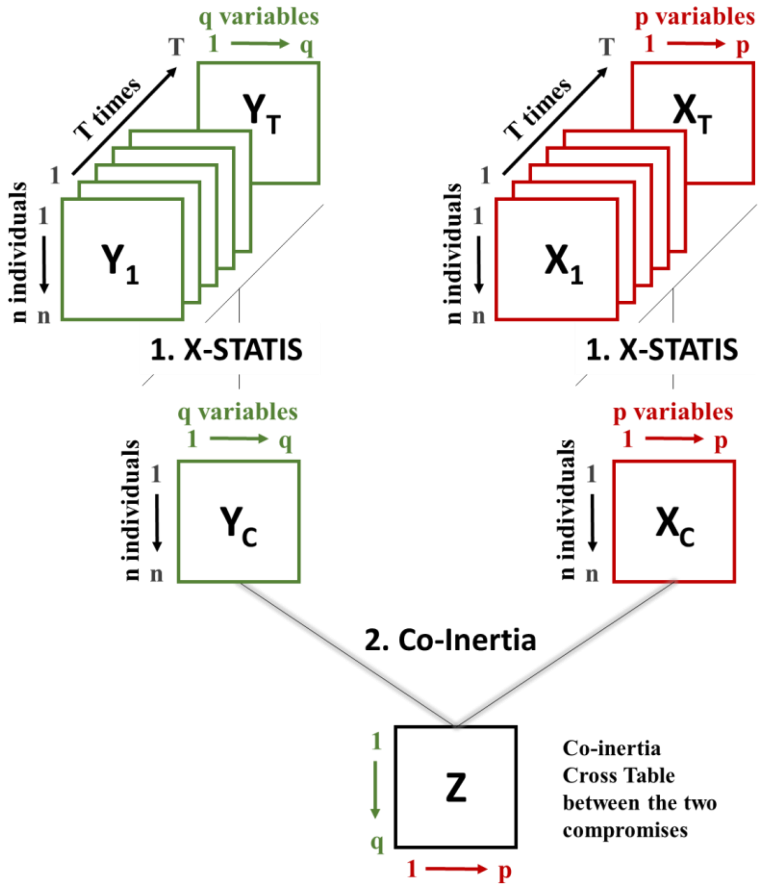


Figure 4. CO-X-STATIS flow chart.

Co-inertia analysis is a method whose objective is to identify a common structure between two groups of variables. To do this, a vector is searched for within the first set of variables and another within the second group, onto which we will project the individuals with maximum co-inertia.

For this analysis, there are two data tables that share individuals and evaluate them on p and q variables, respectively, where X_{nxp} is the first table and Y_{nxq} is the second table, and D_n is the $n \times n$ diagonal matrix of the row weights:

$$D_n = diag(\omega_1, \cdots, \omega_n),$$

and D_p and D_q are two metrics in $\mathbb{R}^p$ y $\mathbb{R}^q$, respectively.

It is necessary to analyse each table separately as a previous step to the co-inertia analysis. If D_n is the uniform row weight matrix ($\omega_1 = 1/n$), and D_p and D_q are identities (Euclidean metrics), then this will be a simple principal component analysis. The total inertia of each table, considering the columns of both centred tables, will simply be the sum of the variances:

$$Iner_X = \sum_{j=1}^{p} Var(X_j) \quad Iner_Y = \sum_{k=1}^{q} Var(Y_k)$$

Taking into account the context in which we are working and the weight of each element, we can define inertia as the distance between an element and its average profile, this being a measure of the variability of the data with the following expression:

$$Iner_X = trace\left(XD_PX'D_n\right) \quad Iner_Y = trace\left(YD_qY'D_n\right)$$

and, in this case, the co-inertia between X and Y is a sum of squares of covariances:

$$\begin{aligned} Co - Iner_{XY} = & \sum_{j=1}^{p}\sum_{k=1}^{q}\left(Cov\left(X_j, Y_k\right)\right)^2 = \sum_{j=1}^{p}\sum_{k=1}^{q}\left(\frac{1}{n}\sum_{i=1}^{n}x_{ij}y_{ik}\right)^2 \\ & = \sum_{j=1}^{p}\sum_{k=1}^{q}\left(\frac{1}{n}\sum_{i=1}^{n}(X')_{ji}(Y)_{ik}\right)^2 = \sum_{j=1}^{p}\sum_{k=1}^{q}\left((X'D_nY)_{jk}\right)^2 \\ & = \sum_{j=1}^{p}\sum_{k=1}^{q}(Y'D_nX)_{kj}(X'D_nY)_{jk} = \sum_{k=1}^{q}(Y'D_nXX'D_nY)_{kk} \\ & = trace\left[Y'D_nXD_pX'D_nYD_q\right] \end{aligned}$$

Therefore, the analysis of co-inertia is the analysis of vectors and eigenvalues of $Y'D_nXD_pX'D_nYD_q$ and $X'D_nYD_qY'D_nXD_p$, and we can calculate the coordinates in a subspace of dimension r obtained from the analysis to graph both the rows and columns of the two original matrices:

rows of X:	XD_pV_r		rows of Y:	YD_qU_r
columns of X:	$X'D_nYD_qU_r$		columns of Y:	$Y'D_nXD_pV_r$

with U_r and V_r as the first r columns of the eigenvector basis of the decompositions of $Y'D_nXD_pX'D_nYD_q$ and $X'D_nYD_qY'D_nXD_p$ respectively.

To interpret the results of this analysis, we will use the co-structure plots (see Figure 5). The co-inertia analysis seeks to study the co-structure between two matrices, maximizing the covariance between the coordinates of the rows of both matrices. The co-inertia will be high when both structures covary, either directly or inversely, in a similar way; otherwise, the co-inertia value will be low.

This figure (Figure 5) shows the information from a study of 10 individuals in relation to two sets of variables as two new sets of standardised co-ordinates projected upon the co-inertia axes. Extrapolating this example to our data, the individuals n = 10 would be the flags, p = 4 would be the descriptors for ships in the Pre-COVID period, and q = 4 would be the descriptors for ships in the COVID period (see Figure 4); in our case, these last two are the same. Therefore, each country is represented by a number accompanied by a vector; the green circle represents the co-ordinate position of the country based on the Pre-COVID period matrix $\left(X_{nxp}\right)$ and the end of the red vector marks the position based on the COVID period matrix $\left(Y_{nxq}\right)$.

This means that, for individuals with short vectors, the variables of matrix Y adequately explain the structure found in matrix X and vice versa. Furthermore, to provide this with context, countries with short vectors would have similar characteristics in both time periods (e.g., Figure 5, individuals 1, 3, and 6); in contrast, countries with large vectors will have changes between the two time periods. It is also possible to characterise each country based on its position on the plane by observing the quadrants; for example, in Figure 5, the observation '10' prioritises the variables 'VAR 4' of the Pre-COVID matrix and 'VAR 3 and 4' of the COVID matrix; and we can also observe that there is a relationship between these variables.

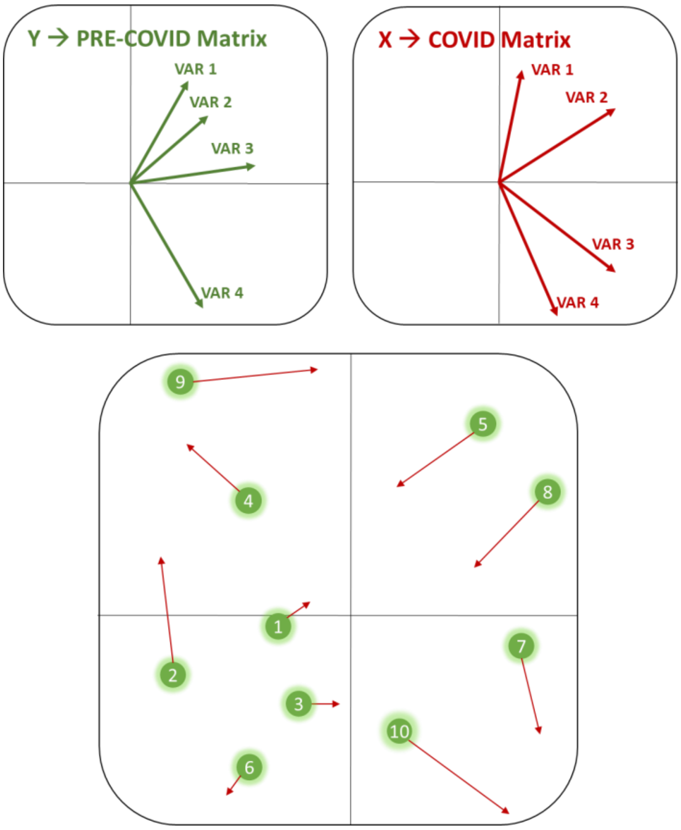


Figure 5. Graphical representation of a hypothetical cross-table between two compromise matrices containing information as an example on 10 individuals relating to two sets of variables.

3. Results and Discussion

In this next section, we will present and discuss the results obtained by applying the previously mentioned multivariate techniques to our data matrix. This will lead us to very important conclusions on how the COVID-19 pandemic has affected PSC inspections, which will be summarised in Section 4.

3.1. Study of the Paris MoU Ship Flags in the 2019–2021 Period Using X-STATIS

Following the study published in 2021 in the Mathematics journal under the title '*Evaluation of Paris MoU Maritime Inspections using a STATIS Approach*' [31], which included data until the year 2018, the present study aims to expand the investigation to the year 2021, contrasting the events within the time frame of the pandemic and comparing them to previous years.

The analysis focuses on the countries involved in the PSC inspections chosen, which includes a total of 45 different countries, listed in Table 4. Before conducting the study, it must be stated that, in the years 2013–2019, there were an average of 3037 PSC inspections, which drastically declined in the years of the pandemic, with 1633 inspections in 2020 and 1350 in 2021, thus highlighting one of its main consequences.

In this section with the application of the X-STATIS analysis, we will project the ship's countries of registry onto the variables that evaluate ship gross tonnage, age, inspection type, and number of deficiencies during the years 2019–2021. This information comes from a total of 5580 inspections (2642 in 2019, 1602 in 2020, 1336 in 2021) of ships originating from 45 different countries with respect to the four variables mentioned previously (GrossTonnage, Age, Inspection Type, and Ndeficiencies).

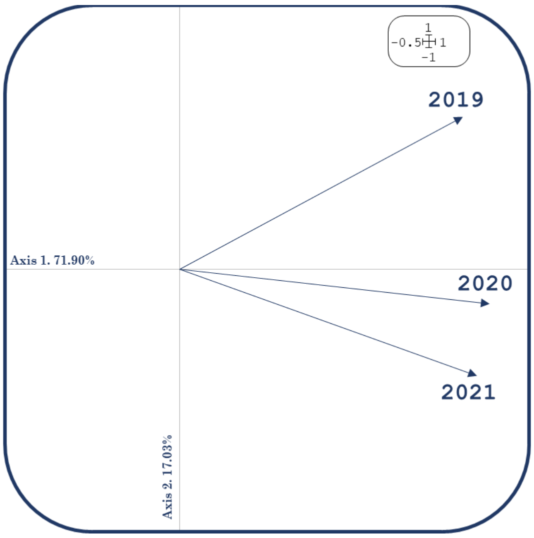
Table 4. Complete list of data sampled per selected country for the 2013–2021 period.

	Flag	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
1	Algeria	9	7	10	17	14	13	11	5	2	88
2	Antigua and Barbuda	225	186	176	130	136	106	90	58	39	1146
3	Bahamas	117	118	123	123	104	110	75	46	41	857
4	Barbados	15	13	14	14	15	14	17	7	7	116
5	Belgium	7	15	10	14	13	16	7	8	6	96
6	Bermuda	23	12	13	13	10	9	12	4	3	99
7	Cayman Islands	33	30	30	37	41	40	23	16	18	268
8	China	18	12	5	8	14	8	4	4	11	84
9	Croatia	7	4	5	3	6	4	6	4	4	43
10	Cyprus	121	130	108	82	95	97	100	71	51	855
11	Denmark	72	91	76	64	63	82	75	68	45	636
12	Dominica	1	1	1	0	1	0	1	1	2	8
13	Finland	22	7	1	8	5	7	6	7	2	65
14	France	9	15	9	10	17	21	21	11	12	125
15	Germany	50	34	40	19	19	19	24	17	16	238
16	Gibraltar	52	53	57	45	44	41	43	22	20	377
17	Greece	83	73	86	76	61	54	57	18	11	519
18	Hong Kong	150	149	174	152	204	158	164	75	77	1303
19	Iran	0	0	0	5	9	5	1	2	2	24
20	Ireland	4	4	5	10	4	4	10	2	2	45
21	Isle of Man	56	58	65	44	34	36	33	16	11	353
22	Italy	92	103	79	83	84	81	69	36	36	663
23	Japan	7	5	8	8	8	10	15	4	8	73
24	Korea	7	7	6	10	9	6	3	3	3	54
25	Liberia	441	407	362	360	346	350	337	205	219	3027
26	Luxembourg	19	32	15	19	14	7	15	7	6	134
27	Malta	231	263	272	241	250	235	255	140	104	1991
28	Marshall Islands	235	311	308	345	336	354	325	174	160	2548
29	Morocco	6	7	4	7	13	11	10	9	7	74
30	Netherlands	123	124	99	92	90	82	75	41	37	763
31	Norway	91	96	90	95	87	75	74	47	43	698
32	Panama	475	445	395	389	339	385	319	241	153	3141
33	Portugal	22	27	39	57	79	78	64	51	49	466
34	Qatar	2	2	1	2	0	1	1	1	1	11
35	Russia	35	29	27	30	37	28	25	8	8	227
36	Saudi Arabia	8	6	7	9	6	8	4	5	4	57

Table 4. *Cont.*

	Flag	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
37	Seychelles	2	1	4	1	1	0	2	3	1	15
38	Singapore	152	183	180	183	186	183	169	108	70	1414
39	Spain	4	2	7	5	4	3	2	4	3	34
40	Sweden	15	7	17	4	3	11	9	1	3	70
41	Tunisia	5	10	6	6	5	5	7	2	5	51
42	Turkey	38	25	23	22	22	19	11	4	7	171
43	United Kingdom	75	76	70	63	72	63	40	25	13	497
44	United States	32	26	30	34	29	30	29	20	12	242
45	Vanuatu	7	7	5	4	5	4	2	1	2	37
	Total	3198	3213	3062	2943	2934	2873	2642	1602	1336	23,803

We begin with a comparison of the yearly structures by studying the interstructure of the three-way X-STATIS analysis (way 1: 45 countries, way 2: 4 variables, way 3: 3 years). This study provides a graphical estimation of the vector correlation coefficient between matrices, which represents the years (see Figure 6); we apply some principal components to said matrix, in such a way that we reduce the dimensionality and obtain a representation in a low-dimensional Euclidean subspace, in which each matrix is represented by a point, in such a way that, if we connect each point with the origin of coordinates we will obtain an estimate of the existing correlation between the years of the study. Evaluating the angles formed between vectors, where narrow angles represent strong relationships, we can identify years with similar characteristics. The graph shows that there are differences between the year 2019 (Pre-COVID period) and the years 2020 and 2021 (COVID period). This representation contains approximately 89% of the information on the 1–2 factorial plane.



	2019	2020	2021
2019	1000		
2020	578	1000	
2021	500	655	1000

Figure 6. Study of the X-STATIS analysis interstructure, and ordering of sampled years.

The next step is the construction of the compromise matrix, which constitutes a global summary of all of the tables, and therefore summarises all of the information for the study period, and whose decomposition into singular values and vectors provides a Euclidean image in a low dimensional space. The representation on the first two factorial axes contains approximately 74% of the information, and every year has a similar weighting factor within the compromise matrix, as we can see in Table 5, where the column 'Weights' indicates the weight that each factor acquires from each matrix in the construction of the compromise (greater weight, greater contribution); and the column 'Cos^2' shows us the cosines squared, which indicate the quality of representation that each matrix has in the compromise (values close to 1, best representation in the compromise), where we observe a good representation of these matrices, which are somewhat higher for the COVID period.

Table 5. Weighting factors and quality of representation of each matrix to the compromise matrix.

Year	Weights	Cos^2
2019	5.504×10^2	0.480
2020	6.021×10^2	0.569
2021	5.783×10^2	0.541

In the compromise subspace created by this matrix, each country will be represented by a value that synthesises the information contained in all three years of the study relating to the four variables. This allows us to view the behaviour of each country in comparison to one another, capturing the multivariate information in this period, 'filtering out' the noise and maintaining the statistically relevant information. This information is represented in Figure 7, where we can observe the position of each of the 45 different countries' ships that were registered during the 2019–2021 period, in relation to the four variables that were chosen to evaluate their characteristics.

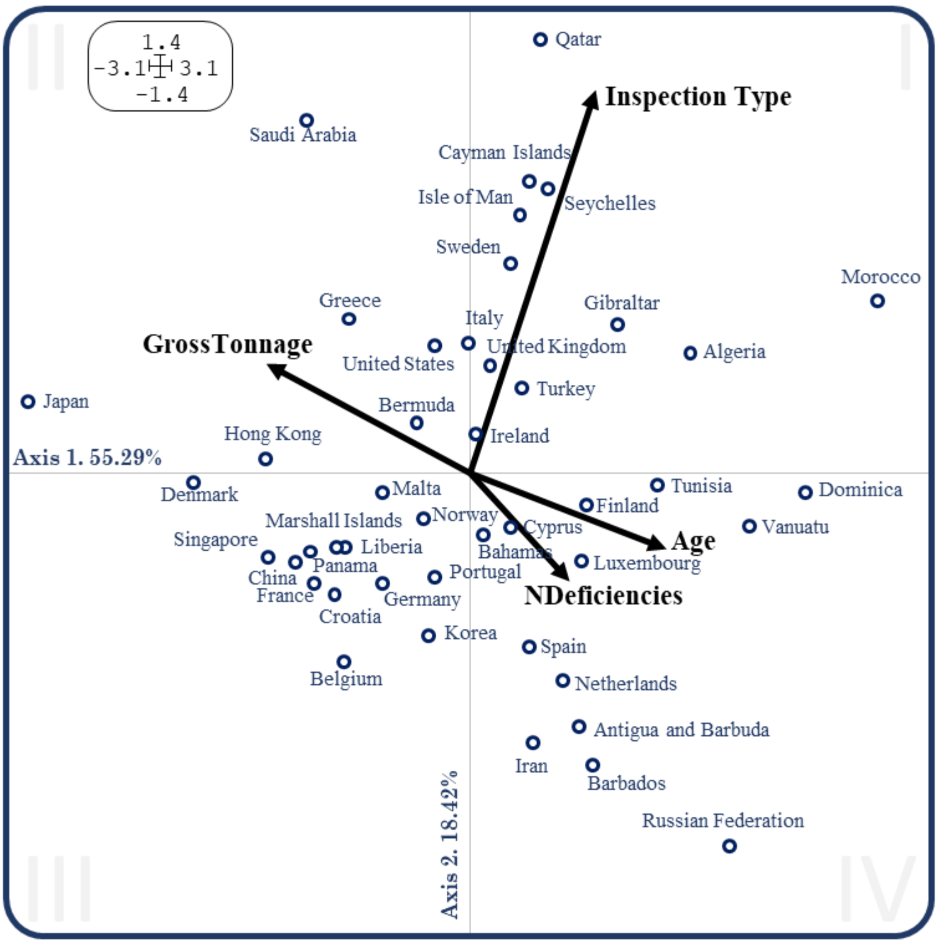


Figure 7. Representation of the compromise matrix subspace, 45 countries and 4 variables, in the 2019–2021 period.

In Figure 7, the countries (rows of the compromise matrix) are represented as points and the variables that assess the characteristics of their ships (columns of the compromise matrix) as vectors. This way of representing the data facilitates the projection of the points onto the vectors. The direction of the column vectors represents the direction in which the corresponding variable values increase, and the projections of all of the row points on a particular column vector approximately reproduce the elements, allowing for an approximate ordering of countries (rows) with respect to that particular variable (column). The relationships between individuals and variables are interpreted in terms of scalar product, through the projections of the points on the vectors. The distance between individuals are interpreted as dissimilarities between them, i.e., less distance, less dissimilarity between individuals. The variability is interpreted through the lengths of the vectors, the greater the length, the greater the variability. Finally, the correlations between the variables come from the angles formed by the vectors, where acute angles correspond with positive correlations, obtuse with negative, and straight with independent variables.

The figure shows how the different countries are distributed throughout the plane, showing high variability, which facilitates the visualisation of the differences between countries of registry. The countries are situated based on the structure of the variables, which are fairly clear, showing a strong relationship between ship's 'Age' and the number of deficiencies 'NDeficiencies'. This means that the older the vessel, the more deficiencies are found. This is interesting because it describes a sub-standard vessel, a small, ageing ship, because 'Age' is also inversely related to 'GrossTonnage'. The structure here, however, changes with respect to the 'Mathematics' article mentioned previously [31], in that the variable 'Inspection Type' appears to be independent to the rest of the variables, which is likely to be a consequence of the pandemic, as the 'more detailed' inspection was rarely conducted. Therefore, countries found in the lower half of the plane (Belgium, Croatia, France, China, Singapore, . . .) underwent more inspections of the 'initial' type, and those in the upper half of the plane underwent more 'expanded' inspections (Qatar, Saudi Arabia, Cayman Islands, Seychelles, Isle of Man, . . .).

This result is of interest, and therefore the types of inspection will be expanded upon in the next section. This will be performed by way of a correspondence analysis to determine which inspections were conducted and if there were any changes in type between the periods before and during the pandemic.

3.2. Study of the Types of Inspection Conducted in the Pre-COVID (2013–2019) and COVID (2020–2021) Periods by Way of Correspondence Analysis

In this section, we apply a correspondence analysis to tables, to see the type of inspections that were conducted and their frequencies, along with their representation on a factorial plane. We analyse if there were differences based on period, Pre-COVID and COVID, and if there were any changes in the type of inspections conducted in each port. The results of this analysis show there is statistical significance (p-values = 0.000. . .). This significance can be clearly seen in the change of inspection type, wherein in the Pre-COVID period, the type 'more detailed inspection' was prioritised, accounting for 45% of the inspections, whereas in the COVID period, they accounted for just 13% (see Tables 6 and 7). This information is clearly reflected in the ports in Figure 8, where we show its depiction on a factorial plane. All of the ports concentrate on less exhaustive inspections and the 'more detailed inspections' play a secondary role, shown to be further apart in the COVID period graph. This is one of the main consequences of the pandemic.

A more detailed inspection is carried out on a vessel when there are clear grounds to believe, during an initial inspection conducted by a PSC inspector, that the state of the ship, equipment, or crew do not comply with the safety standards required by international conventions.

A more detailed inspection includes the area(s) established to be breaching safety conditions as well as areas that the inspector deems relevant. A more detailed inspection will also take human resources into consideration, which are described by the International Labour Organisation, International Safety Management, and STCW and also include operational controls.

Table 6. Port correspondences by type of inspection and port. Pre-COVID period.

PRE-COVID	Initial Inspection	Expanded Inspection	More Detailed Inspection	Active Margin
Algeciras	958 (40%)	234 (11%)	1120 (48%)	2312
Amsterdam	731 (53%)	75 (9%)	527 (39%)	1333
Antwerp	779 (38%)	446 (23%)	785 (39%)	2010
Bremerhaven	235 (54%)	68 (13%)	176 (33%)	479
Hamburg	1983 (46%)	537 (14%)	1672 (40%)	4192
Immingham	1566 (31%)	814 (16%)	2693 (53%)	5073
Le Havre	431 (42%)	100 (13%)	472 (45%)	1003
Marseilles	186 (33%)	66 (16%)	319 (51%)	571
Rotterdam	764 (36%)	589 (28%)	766 (36%)	2119
Valencia	631 (36%)	225 (15%)	872 (49%)	1728
Active margin	8264 (39%)	3154 (16%)	9402 (45%)	20,820

Table 7. Port correspondence by type of inspection and port. COVID period.

COVID	Initial Inspection	Expanded Inspection	More Detailed Inspection	Active Margin
Algeciras	159 (50%)	85 (27%)	74 (23%)	318
Amsterdam	102 (56%)	63 (34%)	18 (10%)	183
Antwerp	338 (43%)	307 (39%)	140 (18%)	785
Bremerhaven	18 (32%)	38 (67%)	1 (2%)	57
Hamburg	129 (39%)	161 (49%)	37 (11%)	327
Immingham	62 (61%)	21 (21%)	18 (18%)	101
Le Havre	194 (70%)	49 (18%)	33 (12%)	276
Marseilles	20 (29%)	43 (62%)	6 (9%)	69
Rotterdam	430 54(%)	315 (39%)	55 (7%)	800
Valencia	25 (37%)	33 (49%)	9 (13%)	67
Active margin	1477 (50%)	1115 (37%)	391 (13%)	2983

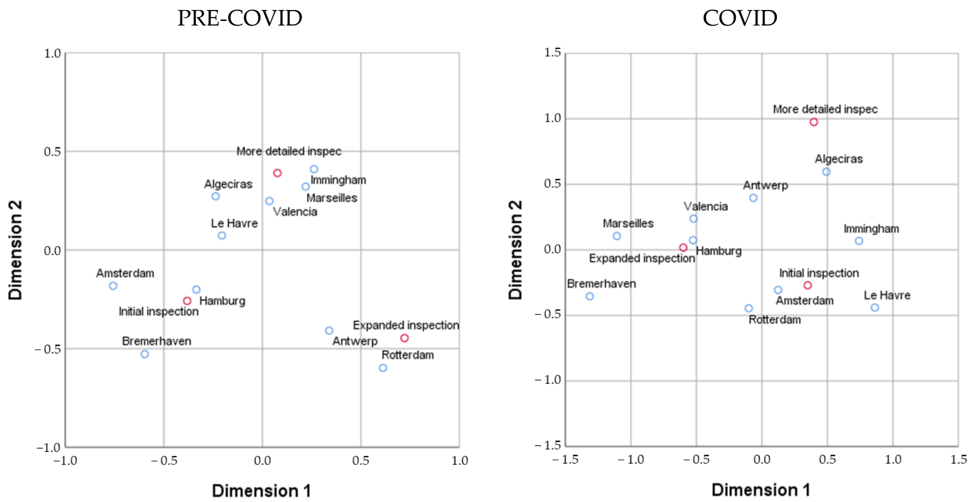


Figure 8. Graphical representation of the correspondence analysis by port and inspection type.

This type of inspection can lead to the detention of a ship if it is clearly in breach of these safety regulations, therefore, if this inspection is not carried out, said ship may leave the inspection port and be a danger to nautical traffic, the crew, and the environment. The heavy decline in the conduct of this type of inspection, as we have shown previously, should be a clear object of supervision by the different national maritime administrations of the Paris MoU if they wish to maintain adequate quality standards of PSC inspections and protect the safety of their waters.

Because of everything detailed previously and the verification changes that occurred between Pre-COVID and COVID periods, it would be of great use to work with the whole matrix and analyse the Pre-COVID (2013–2019) and COVID (2020–2021) period structures by country. Therefore, we considered the CO-X-STATIS to be an ideal method to capture and compare multivariate structures, by way of two compromise structures that represent both time periods and their comparison via a co-inertia analysis.

3.3. CO-X-STATIS Analysis of the Countries of Registry in the Pre-COVID (2013–19) and COVID (2020–21) Periods

In this section, we will be using a CO-X-STATIS analysis and working with the full matrix. We will compare the Pre-COVID (2013–2019) and COVID (2020–2021) structures in terms of the countries of registry, using two data cubes: (i) the first cube is made up of 45 rows (countries), 4 columns (variables), 7 years (2013–2019); and (ii) a second cube containing 45 rows (countries), 4 columns (variables), 2 years (2020–2021), which will be incorporated into the CO-X-STATIS method.

After applying this technique, we can observe the structure of the variables in Figure 9, where green represents the Pre-COVID period variables and red represents the COVID period variables. We find similarities between the two periods, however, there is a clear difference in the variable Inspection Type. This variable decreases its length and angle with respect to the other variables, highlighting the significant differences in the types of inspection conducted due to the pandemic. The next set of results (Figure 9) are from the co-inertia analysis of the compromise matrices for the countries of registry (Pre-COVID and COVID). To interpret the results of this representation, we will break the information down based on the vector directions and divide them into four figures to aid with visualization and improve understanding.

The co-structure graphs (see Figure 9 and derivatives thereof) are the final result of the CO-X-STATIS analysis, which is the application of a co-inertia analysis on the two Pre-COVID and COVID compromise matrices, that is, it highlights the relationships between two stable structures, since the compromise matrices summarize each period with stable information. In this type of graph, we observe the projection of two new sets of standardized coordinates of the individuals (countries) on the axes of co-inertia of the two data sets, so that the green circle marks the position according to the ordering of the Pre-COVID era and the arrow of the red vector marks the position according to the order of the COVID era. Therefore, the countries with short vectors indicate that for them, the variables of the Pre-COVID era explain the structure found in the COVID era and vice versa; these countries appear to be the least affected by the consequences of the pandemic (see Figure 9a). The countries represented in Figure 9a, such as Norway, Portugal, France, and Belgium, show that the inspections applied to their ships remained stable, that is to say, they have been relatively unaffected by the pandemic; these countries are found in the upper semiplane and the majority are in the first quadrant.

On the contrary, those countries that present long vectors will indicate a change and will correspond to the countries most affected by the different restrictions and regulations that each country imposed during the COVID-19 pandemic. If we look at Figure 9, referring to the position of the variables, most of them are located in the third quadrant (lower left semi-plane), therefore, those countries located in this area of the plane will correspond to older vessels with a more detailed type of inspection and a greater number of deficiencies. Thus, in Figure 9b, the observed movements are horizontal, therefore countries such as the UK, Luxembourg, the Isle of Man, and Greece present a shift towards the left-hand semiplane, which translates to their ships having an increased number of deficiencies, and the inspections of their ships being slightly stricter; on the other hand, Russia, Finland, and Barbados ships have shown a slight improvement in their evolution.

In Figure 9c, countries such as Spain, Panama, Japan, Morocco, and Algeria show vertical movements towards the lower semiplane. The countries in this figure are the most negatively affected by the pandemic in comparison to the others in this study, where their ship inspections have been affected by older ships with a higher number of deficiencies.

In Figure 9d, countries such as Turkey, the USA, Korea, and China have shown the complete opposite to those of the previous graph. These countries have been affected by the pandemic but their inspections have had more positive outcomes.

This evolutionary analysis of the different countries that we have presented here could be a good indicator to maritime administrations as to which should be the targets of prioritised inspections after the pandemic, to improve control over them, as we have shown to have poorer inspection results during the COVID-19 pandemic.

In this next section, we will finalise our study with a summary of the most important conclusions that we have obtained from applying three different multivariate methodologies to inspection data.

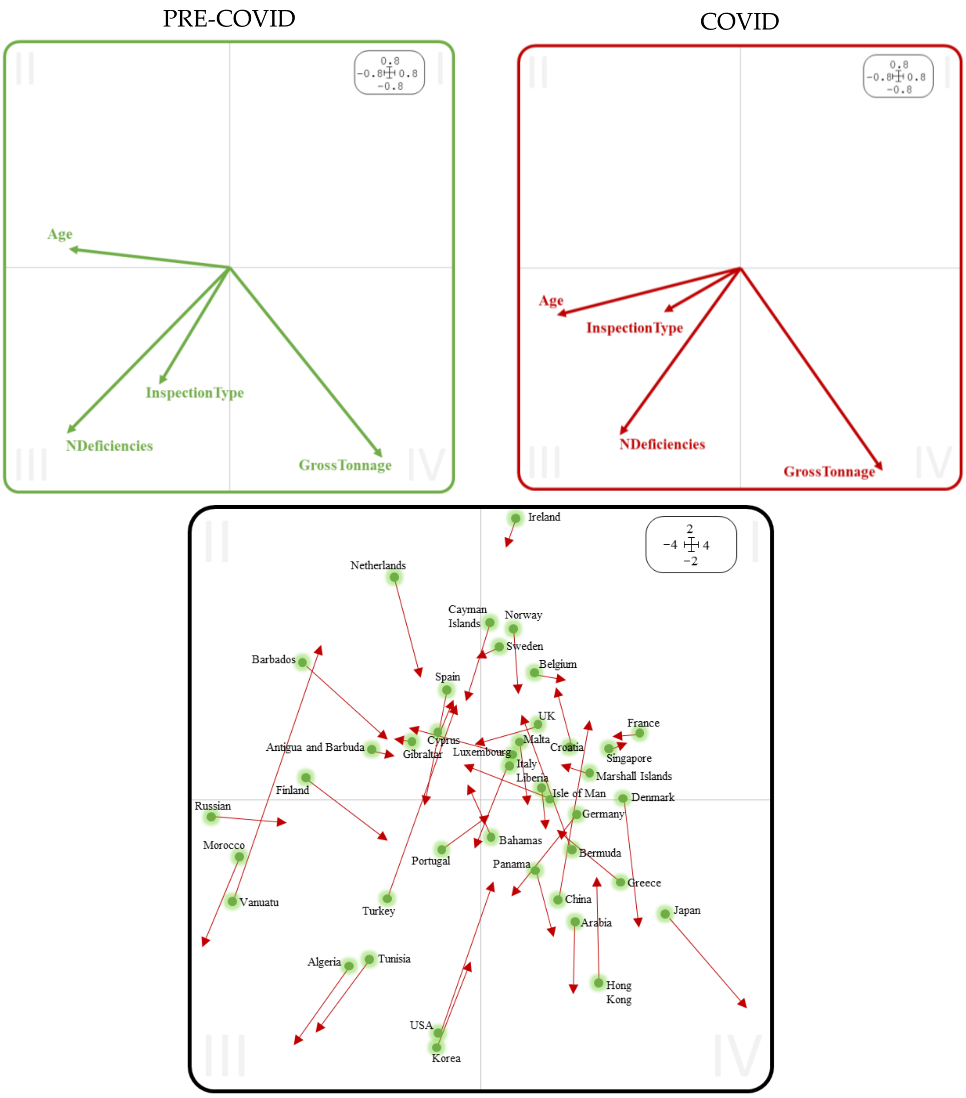


Figure 9. *Cont.*

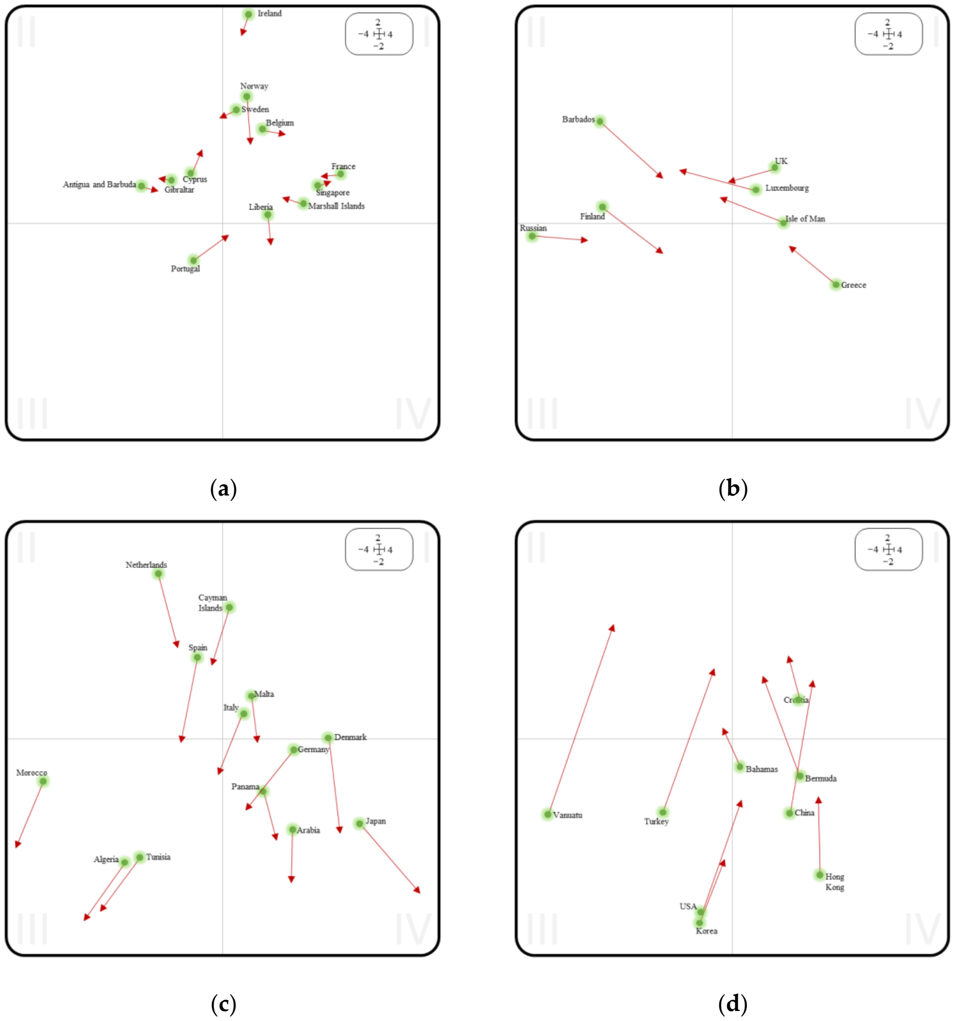


Figure 9. Structure of the variables for 2013–19 and 2020–21 Countries of Registry during Pre-COVID and COVID and co-inertia analysis of the compromise matrices (Pre-COVID in green and COVID in red) for countries of registry. (**a**) Countries with stable inspection evolutions; (**b**) Countries with slight evolution in their inspections during the pandemic; (**c**) Countries with a high negative evolution during the pandemic; (**d**) Countries with a highly positive evolution during the pandemic.

4. Conclusions

In the previous sections of this manuscript, we applied multivariate methodologies to our data matrix and obtained various results that indicate that the COVID-19 pandemic declared in 2020 significantly affected the PSC inspections carried out in the Paris MoU.

One of the first important conclusions of our study is found in the structure of the data shown by the X-STATIS analysis. Figure 6 shows the differences between the year 2019 (Pre-COVID period) and the years 2020 and 2021 (COVID period), and highlights that there are two clearly distinct periods, one before and one during the pandemic.

The next conclusion is a quantitative one: the number of inspections carried out decreased significantly in the two years after the pandemic was declared. However, it is from a qualitative standpoint that we obtain more important information as the variable 'Inspection Type' can be seen to be represented in the compromise matrix subspace (Figure 7) as an independent variable, namely, it does not interact with any of the others such as gross tonnage or age. This is in direct contradiction to the NIR, as this regime considers the age of a ship as one of the main contributing factors in selecting the inspection type.

We elaborated more on this in the correspondence tables, which clearly showed there was a change in the type of inspection conducted. In the Pre-COVID period 'more detailed inspection' types were prioritised (they accounted for 45% of the inspections) and in the COVID period this was not the case (they only accounted for 13% of inspections), see Tables 6 and 7.

This information is reflected in all of the analysed ports, where less exhaustive inspections were carried out and 'more detailed inspection' types became secondary. This could be one of the most notable consequences of the pandemic and it could tremendously affect maritime safety, as this is the type of inspection that determines if a ship should be detained based on the results of the inspection. Our study may indicate important targets of supervision, for both inspectors and national maritime administrations. It indicates a weakness in the inspection system as a result of the pandemic and could be used to rectify this in the new state of 'new normality'. It can be affirmed, due to the aforementioned, that maritime transport has seen its safety and environmental protection diminished. This is a direct consequence of the fact that the PSC inspection system has been negatively affected in its procedures due to the pandemic, reducing effective control over the ships subject to inspection.

With the implementation of the CO-X-STATIS methodology, we obtained an evaluation of the different countries of registry during the Pre-COVID and COVID periods, where we concluded that there were countries whose ships showed a stable evolution: Norway, Portugal, France, Belgium, etc. Another set of countries showed a slight evolution, either negative or positive: the UK, Luxembourg, the Isle of Man, and Greece, and conversely Russia, Finland, and Barbados, respectively. Finally, there was a third set made up of countries with extreme evolutions either high or low, of which the latter were: Spain, Panama, Japan, Morocco, and Algeria. These conclusions may be of great use to the maritime authorities, not only to those that conduct inspections but also to those that flag ships, as an additional indicator of risk, and to set up monitoring for targets such as the ships with flags that had highly negative evolutions during the pandemic, which could help improve safety in their waters.

This last section could be used as a starting point for a future study into the reasons behind the evolutions of the ships based on their flags in relation to PSC inspections, by relating them to the different restrictions and regulations that each country put in place during the COVID-19 pandemic.

Author Contributions: Conceptualisation, F.P. and I.T.; methodology, D.A.-G., V.A.-E. and I.T.; software, V.A.-E. and J.M.P.; validation, F.P. and I.T.; for-mal analysis, D.A.-G. and V.A.-E.; investigation, J.M.P.; resources, F.P. and I.T.; data curation, V.A.-E.; writing—original draft preparation, J.M.P., V.A.-E. and D.A.-G.; writing—review and editing, J.M.P., V.A.-E. and D.A.-G.; visualisation, F.P. and I.T.; super-vision, F.P., I.T. and D.A.-G.; project administration, F.P. and I.T.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Paris Memorandum of Understanding (Paris MoU), https://www.parismou.org/publications-category/performance-list (accessed on 14 January 2023); European Maritime Safety Agency (EMSA), https://portal.emsa.europa.eu/web/thetis (accessed on 12 February 2023); Eurostat, https://ec.europa.eu/eurostat/web/main/data/database (accessed on 27 January 2023).

Acknowledgments: We want to thank Pérez Jiménez, Francisco Javier and García Martínez, Angel María for their advice on this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Piniella, F.; Alcaide, J.I.; Rodríguez-Díaz, E. The Panama ship registry: 1917–2017. *Mar. Policy* **2017**, *77*, 13–22. [CrossRef]
2. Piniella, F.; Alcaide, J.I.; Rodríguez-Díaz, E. Identifying stakeholder perceptions and realities of Paris MoU inspections. *WMU J. Marit. Aff.* **2020**, *19*, 27–49. [CrossRef]
3. Li, K.X.; Zheng, H. Enforcement of law by the Port State Control (PSC). *Marit. Policy Manag.* **2008**, *35*, 61–71. [CrossRef]

4. Knapp, S.; Franses, P.H. A global view on port state control: Econometric analysis of the differences across port state control regimes. *Marit. Policy Manag.* **2007**, *34*, 453–482. [CrossRef]
5. Wang, S.; Yan, R.; Qu, X. Development of a Non-Parametric Classifier: Effective Identification, Algorithm, and Applications in Port State Control for Maritime Transportation. *Transp. Res. Part B Methodol.* **2019**, *128*, 129–157. [CrossRef]
6. IMO. Port State Control. Available online: https://www.imo.org/en/OurWork/MSAS/Pages/PortStateControl.aspx (accessed on 15 July 2022).
7. Paris MoU. Memorandum of Understanding on Port State Control in European Coastal States and the North Atlantic Basin from North America to Europe. Available online: https://www.parismou.org/ (accessed on 15 March 2022).
8. Home-EMSA—European Maritime Safety Agency. Available online: https://www.emsa.europa.eu/ (accessed on 19 September 2022).
9. Directive 2009/15/EC of the European Parliament and of the Council of 23 April 2009 on Common Rules and Standards for Ship Inspection and Survey Organisations and for the Relevant Activities of Maritime Administrations Marítimas. Available online: https://eur-lex.europa.eu/legal-content/EN/NIM/?uri=celex:32009L0015 (accessed on 2 March 2023).
10. European Maritime Safety Agency (EMSA). THETIS. Available online: https://portal.emsa.europa.eu/web/thetis (accessed on 6 May 2022).
11. SafeSeaNet-EMSA—European Maritime Safety Agency. Available online: https://www.emsa.europa.eu/ssn-main.html (accessed on 19 September 2022).
12. Huang, C.; Wang, Y.; Li, X.; Ren, L.; Zhao, J.; Hu, Y.; Zhang, L.; Fan, G.; Xu, J.; Gu, X.; et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet* **2020**, *395*, 497–506. [CrossRef]
13. Yazır, D.; Şahin, B.; Yip, T.L.; Tseng, P.H. Effects of COVID-19 on maritime industry: A review. *Int. Marit. Health* **2020**, *71*, 253–264. [CrossRef]
14. IMO. Circular No 4204/Add.21. 2020: Joint Statement IMO-UNCTAD—Call for Collaborative Action in Support of Keeping Ships Moving, Ports Open and Cross-Border Trade Flowing during the COVID-19 Pandemic. Available online: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/COVID%20CL%204204%20adds/Circular%20Letter%20No.4204-Add.21%20-%20Joint%20Statement%20Imo-Unctad%20-%20Call%20For%20Action%20Keeping%20Ships%20Moving.pdf (accessed on 7 February 2023).
15. IMO. Circular No 4204/Add.19/Rev.3. 2021: Coronavirus (COVID-19)—Guidance for Flag States Regarding Surveys and Renewals of Certificates during the COVID-19 Pandemic. Available online: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/COVID%20CL%204204%20adds/Circular%20Letter%20No.4204-Add.19-Rev.3%20-%20Coronavirus%20(Covid-19)%20-%20Guidance%20For%20Flag%20States%20Regarding%20SurveysAnd%20Renewals%20Of%20Cert.pdf (accessed on 23 February 2023).
16. IMO. Circular No 4204/Add.23. 2020: Recommendations for Port and Coastal States on the Prompt Disembarkation of Seafarers for Medical Care Ashore during the COVID-19 Pandemic. Available online: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/COVID%20CL%204204%20adds/Circular%20Letter%20No.4204-Add.23%20-%20Coronavirus%20(Covid-19)%20-%20Recommendations%20For%20Port%20And%20CoastalStates%20On%20medical%20care.pdf (accessed on 15 April 2023).
17. IMO. Circular No 4204/Add.16. 2020: COVID-19 Related Guidelines for Ensuring a Safe Shipboard Interface between Ship and Shore-Based Personnel. Available online: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/COVID%20CL%204204%20adds/Circular%20Letter%20No.4204-Add.16%20-%20Coronavirus%20(Covid%2019)%20-%20Covid-19%20Related%20Guidelines%20For%20Ensuring%20A%20Safe%20Shipboard.pdf (accessed on 18 March 2023).
18. Knapp, S. Analysis of the Maritime Safety Regime: "Risk Improvement Possibilities for the Port State Control Target Factor" (Paris MoU). In *Thesis in Maritime Economics and Logistics*; Erasmus University Rotterdam: Rotterdam, The Netherlands, 2004; p. 123.
19. Knapp, S.; Franses, P.H. Econometric analysis on the effect of port state control inspections on the probability of casualty: Can targeting of substandard ships for inspections be improved? *Mar. Policy* **2007**, *31*, 550–563. [CrossRef]
20. Knapp, S.; van de Velden, M. Visualization of Differences in Treatment of Safety Inspections across Port State Control Regimes: A Case for Increased Harmonization Efforts. *Transp. Rev.* **2009**, *29*, 499–514. [CrossRef]
21. Knapp, S.; Franses, P.H. Comprehensive Review of the Maritime Safety Regimes: Present Status and Recommendations for Improvements. *Transp. Rev.* **2010**, *30*, 241–270. [CrossRef]
22. Bang, H.-S.; Jang, D.-J. Recent Developments in Regional Memorandums of Understanding on Port State Control. *Ocean Dev. Int. Law* **2012**, *43*, 170–187. [CrossRef]
23. Li, K.X.; Yin, J.; Fan, L. Ship Safety Index. *Transp. Res. Part A Policy Pract.* **2014**, *66*, 75–87. [CrossRef]
24. Ozcayr, Z.O. The Use of Port State Control in Maritime Industry and Application of the Paris MoU. *Ocean Coast. LJ* **2008**, *14*, 201.
25. Wu, J.; Jin, Y.; Fu, J. Effectiveness Evaluation on Fire Drills for Emergency and PSC Inspections on Board. *TransNav Int. J. Mar. Navig. Saf. Sea Transp.* **2014**, *8*, 229–236. [CrossRef]
26. Ravira, F.J.; Piniella, F. Evaluating the Impact of PSC Inspectors' Professional Profile: A Case Study of the Spanish Maritime Administration. *WMU J. Marit. Aff.* **2016**, *15*, 221–236. [CrossRef]
27. Graziano, A.; Cariou, P.; Wolff, F.-C.; Mejia, M.Q.; Schröder-Hinrichs, J.-U. Port State Control Inspections in the European Union: Do Inspector's Number and Background Matter? *Mar. Policy* **2018**, *88*, 230–241. [CrossRef]

28. Chen, J.; Zhang, S.; Xu, L.; Wan, Z.; Fei, Y.; Zheng, T. Identification of Key Factors of Ship Detention under Port State Control. *Mar. Policy* **2019**, *102*, 21–27. [CrossRef]
29. Knapp, S.; Heij, C. Improved Strategies for the Maritime Industry to Target Vessels for Inspection and to Select Inspection Priority Areas. *Safety* **2020**, *6*, 18. [CrossRef]
30. Wang, Y.; Zhang, F.; Yang, Z.; Yang, Z. Incorporation of Deficiency Data into the Analysis of the Dependency and Interdependency among the Risk Factors Influencing Port State Control Inspection. *Reliab. Eng. Syst. Saf.* **2021**, *206*, 107277. [CrossRef]
31. Prieto, J.M.; Amor, V.; Turias, I.; Almorza, D.; Piniella, F. Evaluation of Paris MoU maritime inspections using a STATIS approach. *Mathematics* **2021**, *9*, 2092. [CrossRef]
32. Nam, D.; Kim, M. Implication of COVID-19 outbreak on ship survey and certification. *Mar. Policy* **2021**, *131*, 104615. [CrossRef] [PubMed]
33. Akyurek, E.; Bolat, P. Port state control at European Union under pandemic outbreak. *Eur. Transp. Res. Rev.* **2020**, *12*, 66. [CrossRef]
34. Yan, R.; Mo, H.; Guo, X.; Yang, Y.; Wang, S. Is port state control influenced by the COVID-19? Evidence from inspection data. *Transp. Policy* **2022**, *123*, 82–103. [CrossRef] [PubMed]
35. Eurostat. Database. Maritime Transport of Goods. Available online: https://ec.europa.eu/eurostat/web/main/data/database (accessed on 7 May 2022).
36. Jaffrenou, P.A. Sur L'analyse des Familles Finies de Variables Vectorielles: Bases Algébriques et Application à la Description Statistique. Postgraduate Thesis, University of Saint-Etienne, Saint-Etienne, France, 1978.
37. Escoufier, Y. Opérateur associé à un tableau de données. *Ann. INSEE* **1976**, *22–23*, 165–178. [CrossRef]
38. des Plantes, H.L. Structuration des Tableaux à Trois Indices de la Statistique: Théorie et Application d'une Méthode d'Analyse Conjointe. Ph.D. Thesis, Languedoc University of Sciences and Techniques, Montpellier, France, 1976.
39. Thioulouse, J.; Chessel, D.; Dolédec, S.; Olivier, J.M. ADE-4: A multivariate analysis and graphical display software. *Stat. Comput.* **1997**, *7*, 75–83. [CrossRef]
40. Michael, J. Correspondence Analysis. In *The Oxford Handbook of Quantitative Methods*; Statistical Analyses; Oxford University Press: Oxford, UK, 2013; Volume 2, pp. 142–153.