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Analyzing Port State Control Data to Explore Future Improvements to GMDSS Training

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Abstract: This article uses data generated by Port State Control (PSC) inspections of ships in national ports (Paris MoU) to assess their compliance with radio-communications safety regulations. By mainly applying binary logistic regression methods, the aim is to examine and understand the relationship between the severity of deficiencies in maritime communications and some characteristics of inspected ships. The raw data from the PSC detention database from 2005 to 2022 undergoes post-processing before being analyzed to explore patterns and coincidences with the rest of the potential risk areas. To do so, 23,725 PSC inspections were used. Several classification criteria have been proposed that can better gauge the risk related to distress communications at sea from the dataset. The results connect the probability of detention with the ship age at the inspection date, the flag of the registry, the type of ship, and the location of the port within the countries adhering to the Paris MoU. Another achievement is that the number of PSC inspections of maritime communications in a given period is a better indicator of the risk to safety than the total number of deficiencies detected in these inspections during the same period. This study also explores inspection deficiencies related to competency gaps identified in the Global Maritime Distress Safety System (GMDSS) operators, and precisely using the number of PSC inspections as a criterion of risk for safety is consistent with the recommendations of the Maritime Safety Committee Circular (2006), MSC.1/Circ.1208. Another finding from the time series is that a greater rate of decrease is identified for GMDSS equipment-related deficiencies compared to GMDSS training-related deficiencies. This alone poses a review of the refreshing courses and methods to maintain the General Operator Certificate (GOC) qualification to operate maritime radio communications facilities belonging to the (current and future) GMDSS.

Keywords: GMDSS; PSC inspections; maritime communication safety; General Operators Certificate

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1. Introduction

The importance of maritime safety and sustainability is growing [1–4] in the global context of increasing maritime traffic and the expansion of the global fleet [4]. Despite fleet growth, shipping losses have declined significantly in recent years, demonstrating the positive impact of safety programs, training, and changes in shipping regulations [5]. However, maritime accidents continue to cause human, environmental, and material losses, all of which have political and economic costs whose consequences are difficult to assess a priori [6]. Basically, these arguments are enough to justify investigating the risk level based on the deficiencies of the PSC inspection [7,8] or on the factors that affect accidents [9–12]. The most notable factor in research on the risk of maritime accidents is undoubtedly the human factor [9,13], which, according to some authors, is the cause of 80% of accidents [14].

Next, it is the particularities of the vessel, such as age, size, and flag, that concern maritime risk management professionals [15–17]. Therefore, it seems straightforward to deduce that the identification of risks and their modeling have a significant impact on accident prevention. The responsibility for compliance with the rules, according to the United Nations Convention on the Law of the Sea (UNCLOS) in its Art.91.1, lies primarily with the flag State, and therefore, according to Art.94, it is this State that must take the necessary measures to ensure safety at sea [18,19]. The weak supervision by some flag States often provides an incentive for companies to register their ships in those countries with the clear objective of saving costs, e.g., in crew training requirements. There is an increase in the number of open registries, and as a consequence, there is greater difficulty in complying with international regulations [20]. To address this difficulty, States can delegate the inspections to Classification Societies that will comply with the requirements established by Maritime Administrations, according to SOLAS Regulation 6—Inspection and Survey. Nevertheless, these controls carried out by both the State and the Classification Society do not succeed in reducing the number of substandard ships.

All of this has generated a sustained concern over time on the part of the International Maritime Organization (IMO) to continue working for maritime safety [21]. It is well known that the IMO's concern for maritime safety is reflected in the creation of international Conventions such as SOLAS (Convention for the Safety of Life at Sea), STCW (Convention on Standards of Training, Certification and Watchkeeping for Seafarers), MARPOL (Convention for the Prevention of Pollution from Ships), etc., which are frequently modified to assimilate changes in the maritime sector [22]. Despite this, accident prevention is complicated as a consequence of the inherent complexity of the maritime environment [23–25].

Another preventive measure adopted by the IMO about maritime safety is Port State Control (PSC), which implies the ability of the PSCO (PSC Officer) to inspect areas and departments on board ships to verify that the ship complies with the requirements of the International Conventions. At the EU level, Directive 2009/16/EC (now in revision) was implemented with the purpose "to help to drastically reduce substandard shipping in the waters under the jurisdiction of Member States" [26]. The purpose of the inspections is to check, among other things, certificates, documentation, and the conditions of the vessel, equipment, and crew. The data generated worldwide by the nine regional PCS agreements has been the basis for numerous interesting approaches, to name a few of the most recent [27–29]. One of the areas on board ships that is part of the set "maritime safety" is the communications department. This area must be at least reliable and effective to actively collaborate in safety, and this can only be achieved when the Officer of the Watch (OOW) in charge of communications reaches a level of experience that allows them to adequately operate and manage the station.

In recent decades, the role developed by technology in radio communications for navigation safety has been notable [30–35]. The present study focuses precisely on maritime communications and the problems detected during PSCO inspections on board ships. A look back at the past attests to the IMO's continued concern for safety based on radiocommunications. Unfortunately, many of these advances have been motivated by accidents with catastrophic consequences. It should not be forgotten that the first version of SOLAS was adopted in 1914, in response to the Titanic disaster, and whose consequences on onboard communications related to distress represented a qualitative leap.

The latest revolution resulted in the creation of a global emergency system, which encompasses the International Convention on Search and Rescue (SAR) and the automation of radio communications through the implementation of the Global Maritime Distress and Safety System (GMDSS). It should be taken into account that the automation of certain communications processes (transmitting and receiving distress alerts, continuous watching, etc.) is achieved by applying digital techniques to traditional equipment (VHF/MF/HF) as well as to the newest satellite communications systems (INMARSAT and EPIRBS). It was in February 1999 when the GMDSS definitively came into force, forcing passenger and cargo ships over 300 gross tons (GT) to comply with the requirements of international radiocommunication regulations [36]. The main objective of the GMDSS is to alert search and rescue authorities on land, as well as vessels close to the maritime incident, in the shortest possible time to receive the necessary help without delay. The system also provides not only distress, urgent, and safety communications but also commercial and routine communications.

To this end, SOLAS contemplates the minimum equipment required for ships depending on the maritime areas where they carry out their activity. The entry into force of the GMDSS implies the non-obligation of the Radioelectronic Officer on board, in charge of radio communications, maintenance, and repair of the equipment. Both the IMO and the ITU, aware of the importance of the tasks and jobs entrusted to the radio officer, established in the amendments to the SOLAS Convention that ships required to comply with the GMDSS should have trained personnel, in accordance with the following:

- International Convention on STCW Chapter IV Section IV/2;
- SOLAS 2014, chapter IV, article 16, personal radio;
- European Radiocommunication Committee articles 9 and 10.

Therefore, SOLAS establishes that ships, depending on the area in which they navigate, must comply with the maintenance requirements described in the Rules of Part C of Chapter IV 15.6 and 15.7, as well as that both Captain and Deck Officers have the necessary training that allows them to fulfill the functions of the GMDSS, following IMO Resolution A.703 (17) and A702 (17) [37,38]. For this purpose, both the GMDSS General Operator Certificate (GOC) and the GMDSS Restricted Operator Certificate are issued by the National Maritime Administration.

There are some maritime incidents whose outcomes (whether positive or negative) have been influenced by radio communications, which justifies the importance of the study even in the era of satellite communications. There are many examples, but one of the most striking of the current century is the Costa Concordia (a cruise ship). In 2012, the accident investigation revealed that the chain of communications during the accident was not very orthodox. First, a passenger called the Italian Coast Guard, and then the Coast Guard contacted the captain of the ship. So the delay implied that the evacuation began one hour late. The ship ran aground, resulting in 20 fatalities, 2 missing persons, and the rescue of 4197 passengers and crew members [39].

There are not too many studies focused on radio communications inspections by PSCO. It is worth highlighting that the study focused on how the communications logbook is filled out [40]. That is why the main objective of this study is to analyze the data on communications deficiencies provided by the Paris Memorandum of Understanding (MoU) over 18 years, which includes 27 maritime authorities covering the maritime zone of Europe and the North Atlantic (Atlantic coast of Canada). The Memorandum aims to improve maritime safety and the protection of the marine environment through the inspection and control of the condition of foreign ships and their equipment, which call at ports in the Member States. Therefore, the challenges of maritime safety analysis and the perspective used to quantify risks were analyzed before, for example [41]. Among other things, the need to consider the periodicity of inspections according to the risk profile of the vessel has also been discussed, for example [42].

The inspections make it possible to control compliance with the regulatory requirements included in international regulations on maritime safety, pollution prevention, and living and working conditions on foreign ships that use ports or facilities located in national jurisdictional waters. It is worth highlighting the contributions of other researchers in the detailed analysis of these inspections, such as verifications of the conditions of the ship, its equipment, or its crew [26,28,29]. There are nine other Memoranda that cover, with some exceptions, all the ports of the world. Therefore, it is worth mentioning that even the effectiveness of the PSC has been questioned, being one of the reasons that the methods adopted to select the vessels were not appropriate [43]. Some aspects of the inspections have been questioned [44]. Some authors criticize the inspections of the Port State of Venezuela, considering the lack of PSCOs and good practice guides for conducting inspections [45]. Another study warns about some parameters that determine the presence of accidents in the area, including meteorological conditions and the geographical particularities of some high-traffic routes [46]. Among the highest-risk areas identified were the United Kingdom, Denmark, Singapore, and Shanghai (China).

Three main objectives support this study. Firstly, based on data on deficiencies in radio communications, (i) classify and order these vessels based on risk criteria, and then filter those that pose a high risk to safety in terms of communications. At least two classifiers are going to be proposed and applied. One is based on the ships that present defective codes that can lead to detention, and the other is focused on those ships affected by defective codes that are closely related to the training and competencies of the OOWs on board the ship. These two classifiers are developed under "hypothesis 1". This hypothesis proposes that it is more accurate to use as a risk indicator in maritime communications the number of times a ship has had a radio inspection with GMDSS-related findings than the number of failures found in the aforementioned inspections. Secondly, (ii) analyze the relationship between the potential risk of maritime safety linked to communications at sea and different explanatory variables, especially the ship flag, ship type, and age of the ship. Using the literature, check whether the subsets of ships classified as showing the worst performance in safety communications at sea coincide with the same factors that influence the risks in the rest of the inspection areas onboard ships. Finally, (iii) draw some lessons that could be applied to obtaining the GOC certificate and keep important knowledge and skills up to date by studying the data that warn of possible deficiencies in the competencies of onboard personnel in charge of maritime communications.

2. Materials and Methods

2.1. Description of the Database

The data set for this study consists of a database that covers a period from 2005 to 2022 (18 years). The universe of data is 23,725 PSC inspection records in the ports included in the MoU of Paris. They are the total number of inspections revealing deficiencies regarding SOLAS Chapter IV (radiocommunications and the GMDSS). Each record (each row of the database) contains a data set that (directly or after post-processing) will form part of this study and will be explained below this subsection. The total number of different vessels that are included at least once in this database consists of 13,178 different ships. This implies that some of these ships have been inspected with findings related to the GDMSS several times within the past 18 years. Before moving forward, it is worth highlighting the following about the chosen time interval:

- In 2005, there was a concentrated inspection campaign (CIC) focused on the Global Maritime Distress Safety System (GMDSS). Some part of the number of deficiencies encountered may be due to this fact.
- During 2020–2021, the effects of the COVID-19 pandemic were felt in global maritime traffic.
- In 2022, there was a concentrated inspection campaign (CIC) focused on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW).
- In 2022, the Russian Federation was temporarily excluded from the Paris MoU.

The general description of the database and its most relevant figures are those that will be presented in Tables 1–3. Specifically, Table 1 states that the percentage of GMDSS inspections with respect to the total number of inspections year after year within the Paris MoU tends to decrease since they have gone from 10% (2007) to 3% (2022).

Raw data were downloaded from the Paris MoU inspections database, which can be located at https://parismou.org/inspection-Database/inspection-search/ (accessed on 11 December 2023).

The THETIS system offers information on vessels that help create the risk profile that is used to select the vessel that has to be inspected.

The data available refers to the vessels inspected with findings related to the GDMSS. Therefore, those vessels that have been inspected with positive results in the radio communications department are not included in the database and the following analysis. The original database downloaded in MS Excel format, actually consists of 30,911 rows with the original information per deficiency.

Table 1. Summary of the Radio Communications inspections and general inspections results year by year.

	Paris MoU. Total Figures		Paris MoU. Total Dataset of GMDSS			
	Inspections	Ships	Inspections	Ship Age	Ships	Deficiencies
Years	Total Evaluated per Year	Total Number of Different Ships Involved per Year	Total Evaluated per Year	Mean Age	Total Number of Different Ships Involved per Year	Total Number of Radio Deficiencies per Year
2005	21,302	13,024	2297	20.5	2003	3511
2006	21,566	13,417	2304	21.9	2001	3255
2007	22,877	14,182	2467	22.2	2128	3457
2008	24,647	15,237	2347	22.0	2093	3238
2009	24,186	14,753	1903	21.5	1718	2494
2010	24,058	14,762	1735	21.3	1561	2267
2011	19,058	15,268	1369	21.9	1289	1718
2012	18,308	14,646	1228	22.2	1158	1505
2013	17,687	14,108	1100	20.9	1043	1326
2014	18,447	15,386	1021	20.8	972	1255
2015	17,878	15,255	870	21.9	849	1024
2016	17,845	15,237	813	21.8	779	985
2017	17,925	15,358	799	22.1	762	927
2018	17,957	15,304	802	23.4	771	937
2019	17,916	15,447	768	22.3	744	874
2020	13,168	12,092	491	24.9	480	562
2021	15,401	13,800	642	23.7	631	724
2022	17,289	15,433	769	23.1	749	852

Table 2. Summary of the Radio Communications inspections (year by year) that lead to detention.

	Detention Data			
	Inspections	Ship Age	Ships	Deficiencies
Years	Number of Inspections Involved in Detentions per Year	Averaged Age	Total Number of Different Ships Involved per Year	Total Number of Radio Deficiencies that Cause Detention per Year
2005	242	27.3	226	409
2006	205	29	196	295
2007	244	28.1	233	329
2008	175	29.8	171	228
2009	167	28.2	160	235
2010	103	29.1	102	136
2011	92	27.8	92	133
2012	79	28.6	79	100
2013	79	25.2	79	100
2014	84	28	81	99
2015	66	29.8	65	85
2016	95	27.1	95	121
2017	78	29.3	77	95
2018	67	29.2	65	86
2019	59	31.3	58	86
2020	39	31	38	53
2021	45	27.1	44	55
2022	60	28.4	60	71

Table 3. Summary of the Radio Communications inspections (year by year) that detect deficiencies that can be used as an indicator of lack of competencies of the deck officers responsible for the GMDSS.

Data Related to Possible Deficiencies in the Training of OOWs				
	Inspections	Ship Age	Ships	Deficiencies
Years	Number of Inspections Involved Training Deficiencies per Year	Averaged Age	Total Number of Different Ships Involved per Year	Total Number of Radio Deficiencies Identified with Training per Year
2005	646	21	625	728
2006	711	23.4	664	802
2007	881	25.5	801	992
2008	836	24.3	781	947
2009	665	24	625	766
2010	681	22.9	643	772
2011	500	23.1	493	554
2012	453	22.9	453	499
2013	430	21.3	418	468
2014	428	20.7	420	464
2015	354	22.3	348	373
2016	375	21	374	402
2017	362	22.2	351	384
2018	401	22.7	394	424
2019	397	22.3	392	410
2020	271	25.9	264	280
2021	325	24.9	321	327
2022	400	24	393	411

PSC inspection database contains (among others) data referring to the inspected ship and the inspection results. The following are taken into consideration in this study:

- IMO number
- Ship type description
- Ship age
- Ship flag description
- Inspection date
- Port name
- Country code of the port
- Outcomes of inspection
  - Type of deficiency (Defective Item Code)
  - Detention, whether the deficiency causes the detention of the ship or not

2.2. Data Management

The structure of the database has changed over the years, and homogenization work has had to be done, which has resulted in the need to work with different aggregated variables. Not all the data were employed for all the possible analyses. MATLAB 2022a was used to create different scripts to post-process the raw data, as described below:

The treatment of explanatory (independent) variables.

- The 133 different flags of the vessels were finally codified in four categories, a white, grey, black list, and a four-category "out-of-the-list". This categorization has been made taking into consideration the year of the inspection, as the WGB list is updated according to the information released by the MoU of Paris about the risk performance of flags.
- The 27 different types of ships were grouped into four categories: passenger ships, cargo ships, tankers, and other purposes ships.
- The age of the ship at the moment of inspection ranges from 0 to 112 years.

- The 27 country's ports were reduced to only two categories: Mediterranean ports (Black Sea ports included) and Atlantic ports (Baltic Sea ports included).

The processing of dependent variables.

A disaggregated list of radio defective codes found per inspection date and per ship needs several transformations before providing an adequate data structure for all analyses planned to respond to the objectives. The universe of data comprises the total number of inspections of ships that have shown GDMSS deficiencies. Therefore, a classification process is necessary to filter out a subset of ships based on their safety communications performance scores. When the original annual data from Table 1 is consolidated into a single database spanning all 18 years, the inspection database contains a total of 23,275 inspections, the vessel database contains 13,178 vessels, and the defective code database contains 30,911 codes, as already mentioned. The databases exchange and recalculate information with each other. For example, in the inspection database, a specific ship is recorded with inspection details such as the date, the flag on that date, the age of the vessel during the inspection, the port of inspection, etc. But it also includes extensive about the same ship spanning 18 years, such as the total number of inspections conducted and the total count and type of deficiencies identified during the period. Accounting for this information allows for the sorting and classification of ships using various criteria, such as the number of inspections, the number (and types) of radio failures, and other variables. This study introduces two criteria (Table 4), namely 2 and 3, as they are based on the annual information provided in Tables 2 and 3.

Table 4. The results of the classification process split the total database into the two subsets of "High Risk" and the rest correspond to "Moderate Risk". The period considered for the calculations is 18 years from 2005 to 2022.

Subsets of Data Generated by the Two Indicators Accounting for Risk of Safety Communication at Sea	Condition 1	Condition 2	Inspections	Deficiencies
	Number of Ships Belonging to High Risk	**Number of Inspections per Ship Showing Poor Performance**	**Number of Inspections Forming Part of the Group High Risk**	**Number of Radio Deficiencies Forming Part of the Subset High Risk**
SUBSET HRSC2	1665 (12.6%)	All inspections	1979 (8.3%)	2716 (8.8%)
SUBSET HRSC2-extended	1665 (12.6%)	Extended to all inspections of the same ships involved	4992 (21%)	2716 (8.8%)
SUBSET HRSC3	1725 (13.1%)	$\geq$2 only ships that exhibit repetition of the problem	4276 (17.9%)	4748 (15.4%)
Total dataset as a reference	13,178 (100%)	----	23,725 (100%)	30,911 (100%)

Criterion 2. The count of the total number of inspections in which defective codes that caused detention were found per ship within the period of time considered (18 years) would lead directly to a "High-Risk-Subset". A less strict version of criterion 2 assigned this count (value) to all the inspections in which this particular ship was presented.

Criterion 3. The total number of inspections found defective codes that can be linked to deficiencies in GMDSS training of the deck officers in charge of communications per ship per 18 years can be also assigned. This criterion will be described in more depth in the following section.

The dependent variables used to describe the Risk of Safety Communication at sea were initially codified as ordinal variables, although it was finally decided to transform them into binary variables. This decision was due to the large number of cells with few cases, so the model would be unstable. Not having any other additional information (i.e., incidents in which radio communications play a fundamental role) about the analyzed vessels, the size of the subset will be selected for practical reasons. In this way, it was obtained by dividing the original database into two subsets: High Risk (1) to maritime safety (in terms of communications) and Moderate Risk (0), as shown in Table 4. From now on, it will be referred to as the HRSC2 (High Risk for Safety Communication) subset, the set of ships with the lowest scores in safety communications performance using classification criterion 2 (detention). The complementary subset will be of moderate risk, and it will not be described and explained most of the time.

2.3. The Treatment of the Deficiencies Linked to Poor Training of OOW on Board

The catalog of deficiencies that PSCO can include in the radio inspection report has a unique code, as shown in Table 5. One of the most important parts of the radio inspection is to ensure the ability of the GMDSS operators to use all the equipment and follow the correct communication procedures. The officer of the watch should be capable of transmitting and receiving distress alerts and distress traffic operating all GMDSS installation possibilities. The deficiencies related to codes 5101, 5115, 5116, and 5118 are selected in this study as more direct indicators of possible deficiencies in the continuing training of shipboard officers in charge of maritime communications (Table 5).

Table 5. Communication defective codes and explained failures. A re-categorization with statistics and analytical purposes is proposed: (1) equipment failure, (2) training failure of OOWs, and (3) other radio communication problems.

Radio Communications Defective Item	Code	Label
Distress messages: obligations and procedures	5101	Training
Functional requirements	5102	Equipment
Main installation	5103	Equipment
MF radio installation	5104	Equipment
MF/HF radio installation	5105	Equipment
INMARSAT ship earth station	5106	Equipment
Maintenance/duplication of equipment	5107	Equipment
Performance standards for radio equipment	5108	Equipment
VHF radio installation	5109	Equipment
Facilities for the reception of marine safety information	5110	Equipment
Satellite EPIRB 406 MHz/1.6 GHz	5111	Equipment
VHF EPIRB	5112	Equipment
SART/AIS-SART	5113	Equipment
Reserve source of energy	5114	Equipment
Radio log (diary)	5115	Training
Operation/maintenance	5116	Training
Operation of GMDSS equipment	5118	Training
Other (radio communication)	5199	Others

The classification of ships according to the proposed HRSC3 (Table 4), would yield a total of 9116 inspections (38.4%), which involves 6566 ships (49.8%) and 10,003 defective codes (32.4%). Trying to prevent isolated cases, the subset considered for the analysis will be made for those ships in which this deficiency has been found repeatedly (at least two inspections in the period, as appears in condition 2 in Table 4). The problems related to Certificates for radio personnel (codes 01203) are excluded from this paper because the interest lies in the evidence of the fluid operation of the radio communications installation and its management rather than whether a certificate is expired.

2.4. Statistical Tools and Data Analysis

SPSS Statistics v.29 is going to be used as statistical package software for running the presented test and regression based on logit.

2.4.1. A Chi-Square (χ^2) Goodness of Fit Test Using SPSS

This test was used to test whether the observed distribution (subset) of a categorical variable differs from expectations (the total database). The greater the discrepancy, the more it can be questioned that there are no significant differences.

2.4.2. *t*-Test and Wilcoxon–Mann–Whitney Test Using SPSS

Two independent samples *t*-test is used to check if these two groups belong to the same population. So the null hypothesis is H_0: μ1 = μ2 ("the population means are equal"), so there are no statistically significant differences between the means of the independent groups. The dependent variable should be measured on a continuous scale, and the independent variable should consist of two categorical, independent groups. The Mann–Whitney U test is a rank-based and non-parametric (the dependent variable does not need to be normally distributed) method to test whether a group of data comes from the same population. Intuitively, it is identical to the *t*-test, but the continuous data can be replaced by ordinals.

2.4.3. Binary Logistic Regression Analysis Using SPSS

In this paper, a binary logistic regression is used to estimate the odds of having a high number of inspections with poor results in radiocommunications on a specific type of ship. This kind of regression was previously used by some authors to analyze PSC inspection records, for example [27,47].

In general, regression is used to look for significant relationships between variables. In particular, binary logistic regression is used basically for the following main purposes: (i) classifying the samples of a dataset according to at least two subsets; (ii) clarifying the existence of interaction between covariates with respect to the dependent variable; and (iii) explaining, quantifying, and even predicting the values of some binary outcome, the dependent variable, in its relationship with each of the covariates (explanatory variable). Therefore, the objective of logistic regression is not, as in linear regression, to predict the value of the variable from one or several predictor variables but to predict the probability of something known occurring from the values of the independent variables, so it will fail to predict continuous variables. Since the outcome is a probability, a logit transformation is applied to the odds of the dependent variable (natural logarithm of odds or log-odds). Odds is defined as the ratio of the probability of success to the probability of failure. The coefficients (beta parameters) generated in this kind of model are commonly estimated via Maximum Likelihood Estimation (MLE). Finally, a chi-square goodness of fit (or similar test) is used to evaluate how well the model predicts the dependent variable. The odd ratio compares the outcome of a model when a particular event takes place compared with the outcome in the absence of this event. When the Odds Ratio is greater than 1, then the event is associated with higher odds of occurrence, and when the odds ratio is less than 1, then the event is associated with lower odds.

Although the possibility of using Ordinal Regression was initially considered, because the nature of the dependent variable was ordinal, it was soon discarded. Ordinal means two things: the categories can be ranked and the distance between a category and the adjacent one, which is the case. Unfortunately, the distribution of dependent variables recommends deciding between two levels instead of multiple levels, many of them with few-moderate sample sizes, and the test of parallel lines in SPSS recommends not choosing this model. Since the ordered logit model estimates one equation overall levels of the response variable, check whether the generated one-equation model is valid. Rejecting the null hypothesis based on the significance of the Chi-Square statistic means that ordered logit coefficients are not equal across the levels of the outcome, and it would be better to fit a less restrictive model as a binary logistic. Binary logistic regression models the relationship between a set of independent variables and a binary dependent variable. This study presents two dependent variables that are ordinal but perfectly associable with variables of a dichotomous nature (i.e., does the inspection detect a ship with radio deficiencies that led to detention? YES/NO).

3. Results

3.1. Checking the Hypothesis-1: HRSC1 vs. HRSC4

The first research question is whether the total number of deficiencies in the period of time considered is a better indicator of risk of safety in maritime communications than the number of times in which a vessel has been involved in inspections with findings related to the GDMSS (no matter how many deficiencies) in the same period. To carry out this diagnostics, both outcomes of binary logistic models are assessed. On this occasion, the classification criteria to define the risks (high: 1 and moderate: 0) will be carried out taking into account the decile of vessels (or the value closest to 10%) that reflects the worst performance either by part of the number of inspections (criterion 1); or the number of failures (criterion 4) that the ship has suffered in 18 years of records. To avoid creating inconsistencies, a cut-off criterion is added (Table 6). This does not allow one ship to be in the high-risk subset and another with the same number of inspections (or defects) to be in the complementary (moderate-risk) subset.

Table 6. Comparison of subsets classified as "High Risk" following different criteria, HRSC1 vs. HRSC4.

Subsets Description	Cut-Off Criterion to Approach the Decile of Ships with the Worst Performance	Number of Vessels Included (Mean Age)	Percentage Considering the Total of Ships (13,178)	Number of Inspections within the Cut-Off Criterion	Percentage Considering the Total of Inspections (23,725)	Number of Failures within the Cut-Off Criterion	Percentage Considering the Total of Deficiencies (30,911)
HRSC1. Based on the number of inspections with deficiencies	4 inspections in the period or more	1297 (31.4 years)	9.8%	6616	27.9%	8992	29.1%
HRSC4. Based on the number of deficiencies	5 deficiencies or more	1552 (30.3 years)	11.8%	6894	29.1%	10,949	35.4%

The results of the Chi-square show a large statistical significance with a p-value less than 0.001. Several outcomes from the dichotomous model predictor have been taken into consideration (Table 7). The comparison between −2 log-likelihood, the Nagelkerke pseudo-R Square, and the Classification Table gives the best alternative (cut value 0.5). Independent variables Flag List, Type of ship, and Ship age.

Table 7. Results of comparison between binary logistic results applied to both subsets.

Subsets Description	−2 Log Likelihood	Nagelkerke Pseudo R Square	Sensitivity of the Model	Specificity of the Model	Overall Relation Predicted/Observed of the Model
HRSC1. Based on the number of inspections with deficiencies	22,712	0.292	Correctly classify the 43.5% of High-Risk cases	Correctly classify the 89.5% of Moderate Risk cases.	76.7% improving the intercept-only model
HRSC4. Based on the number of deficiencies	34,365	0.236	Correctly classify the 46.1% of High-Risk cases	Correctly classify the 84.6% Moderate Risk cases	71% improving the intercept-only model

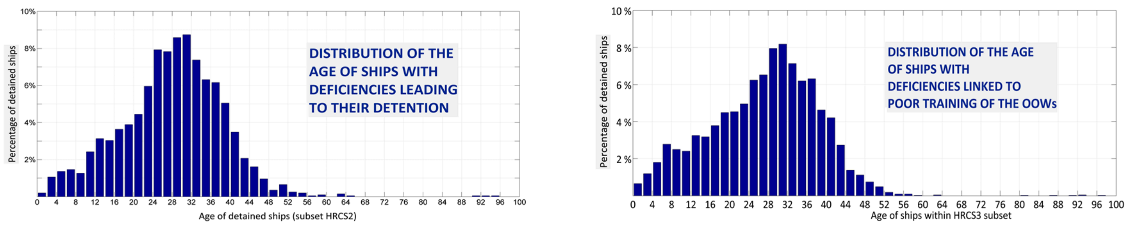
It is more robust to use for the classification tool the number of times a ship has had a radio inspection with findings related to the GDMSS in a given period than the number of findings in that period. That is why it will be used for the number of inspections from now on and the classification tools.

3.2. Examining the Independence of Subset HRSC2 and HRSC3

Now consider the Chi-square tests in which the null hypothesis is that no relationship exists between the categorical variables in both subsets (HRSC2 and HRSC3), so they are independent. The results of the "Pearson Chi-Square" $\chi(3) = 25{,}459$, $p < 0.001$, indicate there is not any statistically significant association between the distribution of the independent variable "country flags" between the subsets HRSC2 and HRSC3. Again, Pearson Chi-Square" $\chi(3) = 27{,}173$, $p < 0.001$ indicates that there is not any statistically significant association between the independent variable distribution "ship-type" between the subsets HRSC2 and HRSC3. Concerning the category "port situation", the results of the "Pearson

Chi-Square" $\chi(3) = 594$, $p < 0.001$, indicate there is not any statistically significant association between the distribution of the independent variable "port situation" between the subsets HRSC2 and HRSC3. Therefore, the null hypothesis can be rejected and we can conclude that there are statistically significant differences between the data proportions of both subsets, HRSC2 and HRSC3, regarding the three categorical explanatory variables revised.

When examining the distribution of the continuous variable ship age (Figure 1), Levene's Test for Equality of Variances shows there are significant differences between the variances of both sub-groups. Even so, the study found that HRSC3 had a statistically significantly lower age of 26.7 years compared with HRSC2, with a higher age mean of 28.4 years with $t(4084.987) = -5.911$, $p < 0.001$.



(**a**) (**b**)

Figure 1. The age of the ships was calculated considering the 18 years of inspections. (**a**) The histogram of the ages of ships with which to define the subset HRSC2. (**b**) The histogram of the ages of ships with which to define the subset HRSC3.

In these circumstances (violating the normality of data and equality of variances), the alternative non-parametric test has been applied, which shows the same results. The mean rank and sum of ranks for the two groups tested show that the HRSC2 subset has ships with higher ages. Facing the results of the Mann-Whitney U test of independent variable ship-age of both distributions (HRSC2 vs. HRSC3) subsets, it can be concluded that there were statistically significant differences between both subsets ($U = 3{,}898{,}401$; $p = 0.014$).

3.3. Binary Regression Analysis Results Were Applied to Databases of Table 4

Despite their recent extended use and success in many areas, machine learning algorithms perform poorly when they encounter (no stationary time series) distribution shifts at test time. When considering the gradual decrease over the years shown in Tables 1–3 in the number of samples, the truth is that the ratio between HRSC2 and HRSC3 subsets related to the total number of recorded inspections does not show a lack of stationarity, as shown in Figure 2. These last 3 years should probably be treated as anomalies caused by the end of the pandemic and the war in Ukraine.

When applying the binary logistic regression in SPSS, the intercept-only model in all cases shows a lower explanatory capacity than when adding the independent variables. The categorical predictors are: Flag, Ship Type, and Port location, and the continuous predictors are: the ship's age and years. All of them are added to the study, but not all cases have explanatory power. Omnibus tests of Model Coefficients give Chi-square values with 7, 8, and 9 degrees of freedom with a significance beyond 0.001. So there is a significant improvement in fit after comparing with the intercept-only model. Using a Likelihood Ratio (LR) test to see if there is a significant improvement (p-value < 0.05) on the null model in the 'Model' row of the 'Omnibus Tests of Model Coefficients' Table 8. The number of explanatory analyses used depends on the behavior of some parameters. For example, when introducing more predictors, noticing that -2 log Likelihood statistics increase or the pseudo-R-square decrease is a symptom that the expanded model performs worse than the previous one. Another indicator is the capacity of the model to provide a better success rate regarding classification.

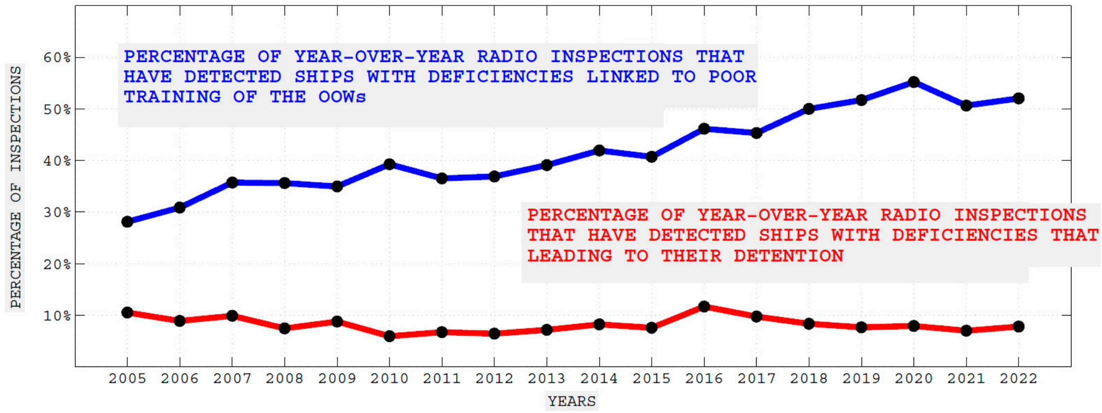


Figure 2. The time-changing relationship between the number of cases in both subsets (HRSC2 in red and HRSC3 in blue) per year as a ratio using the total number of inspections per year (data from Tables 2 and 3).

Table 8. Results of the significance of the test.

Omnibus Tests of Model Coefficients	HRSC2	HRSC2-Extended	HRSC3
Chi-square Model	1171.507	3284.189	1295.02
df	8	8	9
p-value	<0.001	<0.001	<0.001

The list of explanatory variables is selected after comparing the behavior of the model after checking −2 log Likelihood statistics and the pseudo-R-square:

- For HRSC2 and HRSC2-expanded, the explanatory variables are Ship Flag, Ship Type, Ship Age, and Port situation.
- For HRSC3 the explanatory variables are Ship Flag, Ship Type, Ship Age, Port situation, and Year.

The results of the Chi-square show a large statistical significance with a *p*-value less than 0.05. The null hypothesis claims that adding these explanatory variables to the model does not significantly improve the capacity decision of the model. That is why the hypothesis is rejected and the predictors are added to the model.

The Hosmer and Lemeshow statistics indicate a poor fit if the significance value complies with the *p*-value < 0.05. Smaller Chi-square values with a larger *p*-value closer to 1 indicate a good logistic regression model fit. In this case, the null hypothesis states that there is no difference between the observed and predicted models. Following the Hosmer and Lemeshow tests, only HRSC2-extended shows a poor fit. Unfortunately, some doubts about the consistency of this test have been expressed in some studies, as this kind of test doesn't take overfitting into account, but it is preferred not to split the continuous explanatory variables into bins.

The Nagelkerke Pseudo-R Square (approximately) estimates the value of the total variation explained by the full model. In this case, the calculation of pseudo-R^2 includes a correction so that the maximum value is equal to 1, suggesting that all predictions (R^2_{HRSC2} = 0.11, $R^2_{HRSC2\text{-}extended}$ = 0.21, and R^2_{HRSC3} = 0.09) are NOT fairly reliable.

Tables 9 and 10, show if any of the independent variables have a statistically significant effect on the dependent variable. Wald statistics test the significance of individual logistic regression coefficients for each independent variable. For the categorical variables, the first *p*-value indicates whether there is an association between that independent variable and the dependent and the other rows compare the individual categories with the reference category.

Table 9. Parameters estimation regarding the indicator HRSC2.

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B) Lower	Upper
Grey list	0.541	0.050	118.150	1	<0.001	1.718	1.559	1.895
Black list	0.932	0.045	432.550	1	<0.001	2.538	2.325	2.771
Out of list	0.865	0.101	73.428	1	<0.001	2.375	1.949	2.895
Tank	0.595	0.129	21.199	1	<0.001	1.813	1.407	2.336
Cargo	1.106	0.110	101.551	1	<0.001	3.022	2.437	3.748
Special Purposes	0.614	0.129	22.532	1	<0.001	1.848	1.434	2.382
Age	0.040	0.002	544.952	1	<0.001	1.041	1.038	1.045
Atlantic ports	0.737	0.036	419.650	1	<0.001	2.090	1.948	2.243
Constant	−4.108	0.121	1156.048	1	<0.001	0.016		

Table 10. Parameters estimation regarding the indicator HRSC3.

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B) Lower	Upper
Grey list	0.264	0.052	25.629	1	<0.001	1.302	1.175	1.442
Black list	0.639	0.047	188.035	1	<0.001	1.895	1.729	2.076
Out of list	0.217	0.116	3.479	1	0.062	1.243	0.989	1.561
Tank	−0.517	0.113	20.944	1	<0.001	0.596	0.478	0.744
Cargo	0.192	0.086	4.948	1	0.026	1.211	1.023	1.434
Special Purposes	−0.416	0.114	13.329	1	<0.001	0.660	0.528	0.825
Age	0.024	0.002	199.266	1	<0.001	1.024	1.021	1.028
Atlantic ports	0.292	0.036	65.664	1	<0.001	1.339	1.248	1.437
Year	0.026	0.003	54.963	1	<0.001	1.026	1.019	1.033
Constant	−4.108	0.121	1156.048	1	<0.001	0.016		

Table 9 shows that all variables are significant with $p < 0.001$. References for every category are the white list (for flag), passenger ships (for ship type), and Atlantic ports (for port location).

For categorical variables, it can be affirmed that the model predicts that the odds that a ship facing a radio inspection resulting in detention are as follows:

- 2.54 times higher if the ship is black-listed than white-listed.
- 2.38 times higher if the ship is grey-listed than white-listed.
- 1.72 times higher if the ship is "out-of-list" than white-listed.
- 3.02 times higher if the ship is a cargo ship than it is a passenger ship.
- 1.85 times higher if the ship is a special-purpose ship than it is a passenger ship.
- 1.81 times higher if the ship is a tanker than it is a passenger ship.
- 2.09 times higher if the ship is inspected at a Mediterranean port than at Atlantic ports.

For continuous variables, it can be affirmed that the model predicts that the odds that a ship facing a radio inspection will result in detention are as follows:

- 1.041 times greater for each year of increase in the ship's age.

Table 10 shows that all variables are significant with $p < 0.001$, except the category of "Out of the list" of the explanatory variable "Ship Flag". References for every category are the white list (for Flag), passenger ships (for Ship Type), and Atlantic ports (for Port Location).

For categorical variables, it can be affirmed that the model predicts the odds that a ship will face a radio inspection in which deficiencies are linked to poor competencies of OOWs regarding GMDSS skills:

- 1.895 times higher if the ship is black-listed than white-listed.
- 1.302 times higher if the ship is grey-listed than white-listed.
- 1.243 higher if the ship is not included in any list than white-listed (with a lack of significance of $p = 0.062$)

- 1.211 times higher if the ship is a cargo ship than it is a passenger ship (with a significance of $p = 0.026$).
- 0.596 times lower if the ship is a tanker than it is a passenger ship.
- 0.660 times lower if the ship is a special-purpose ship than it is a passenger ship.
- 1.339 times higher if the ship is inspected at a Mediterranean port than at Atlantic ports.

For continuous variables, it can be affirmed that the model predicts that a ship will face a radio inspection in which deficiencies are linked to poor competencies of OOWs regarding GMDSS skills:

- 1.024 times greater for each year of increase in the ship's age.
- 1.026 times greater for each year that passes on the calendar compared to 2015.

3.4. The Distribution of Independent Variables Ship-Flag, Ship-Type, Port Situation, and Ship-Age in the Subsets HRSC2 and HRSC3

The chi-square test is employed to check if there is any relationship between two categorical variables. The analysis consists of comparing the goodness of feet between the expected distribution of flags, ship types, port location, and ship ages and the observed distribution of the two subsets (Tables 11 and 12 show the distributions). The age of the ships has been categorized into 5 groups in 10-year steps (Table 12). That is, what is expected from the total database and what is observed in the subset are compared. The null hypothesis is that the proportion is the same, so there are no statistically significant differences in the distribution of the variables in the subsets with respect to the distribution of variables in the entire dataset.

Table 11. Crosstabulation of country flags, and ship types using the database of ships.

FLAG	Total Database		HRSC2 Subset		HRSC3 Subset	
	N of Ships	%	N of Ships	%	N of ships	%
White	9224	70.0%	658	39.5%	810	47.0%
Grey	1690	12.8%	281	16.9%	261	15.1%
Black	1981	15.0%	659	39.6%	617	35.8%
Out of the list	283	2.1%	67	4.0%	37	2.1%
SHIP TYPE	**Total Database**		**HRSC2 Subset**		**HRSC3 Subset**	
	N of Ships	**%**	**N of Ships**	**%**	**N of Ships**	**%**
Passenger	615	4.7%	47	2.8%	69	4.0%
Tanker	1707	13.0%	125	7.5%	85	4.9%
Cargo	9667	73.4%	1363	81.9%	1489	86.3%
Special purposes	1189	9.0%	130	7.8%	82	4.8%

Table 12. Crosstabulation of ship ages and port location using the database of inspections.

AGE	Total Database		HRSC2 Subset		HRSC3 Subset	
	N of Ships	%	N of Ships	%	N of Ships	%
<10 years	4512	19.0%	106	5.4%	429	10.0%
10–20	6052	25.5%	319	16.1%	779	18.2%
20–30	7195	30.3%	688	34.8%	1363	31.9%
30–40	4655	19.6%	666	33.7%	1323	30.9%
>40 years	1311	5.5%	200	10.1%	382	8.9%
PORT SITUATION	**Total Database**		**HRSC2 Subset**		**HRSC3 Subset**	
	N of Ships	**%**	**N of Ships**	**%**	**N of Ships**	**%**
Mediterranean Ports	11,318	47.7%	1433	72.4%	2495	58.3%
Atlantic Ports	12,406	52.3%	546	27.6%	1781	41.7%

Table 11 results. The chi-square goodness of fit tests are statistically significant for subsets HRSC2 and HRSC3: $\chi^2(3) = 1165$ and $\chi^2(3) = 632$ of country flag distribution with $p < 0.001$. Also, chi-square goodness of fit tests are statistically significant for subsets HRSC2 and HRSC3, $\chi^2(3) = 4304$ and $\chi^2(3) = 6994$ for ship type distribution, with $p < 0.001$.

Table 12 results. The chi-square goodness of fit tests are statistically significant for subsets HRSC2 and HRSC3: $\chi^2(4) = 645$ and $\chi^2(4) = 550$ of ship-age distribution with $p < 0.001$. The chi-square goodness of fit tests is statistically significant for subset HRSC2 $\chi 2(1) = 23.1$ port location distribution with $p < 0.001$. However, for subset HRSC3: $\chi^2(1) = 4$ with a p-value = 0.0453, which is significant at $p < 0.05$.

Therefore, the null hypothesis can be rejected and conclude that there are statistically significant differences between the data distribution (proportions) of flags and ship types in both subsets with respect to the total of the record.

4. Discussion

4.1. Which Criterion Best Highlights the Worst Performance in Communications Safety of Inspected Ships?

Various authors also highlight that the number of deficiencies and the number of detentions in the last 36 months serve as risk indicators, for example [48]. However, in the study carried out, it was revealed that the number of times a ship repeats a radio inspection throughout any period considered is a better estimator of risk than the number of deficiencies found. In fact, the number of deficiencies may indicate a tendency to decrease, while inspections with deficiencies are still present in the analyzed time history. It must be taken into account that, regarding the period of time considered for the evaluation, the longer the better. The variability of the number of inspections over time and the variation of the time elapsed between two inspections will be studied. In the records, the 10 ships that showed the worst performance using the subset HRSC1, the relationship (a/b) between (a) the extension in years detecting problems in the GMDSS of ships (the first and the last year), respect to (b) the number of years in which at least one inspection is detected is 11/10, 13/11, 16/8, 13/9, 14/8, 13/9, 15/10, 8/6, 16/10, 13/8 (in total 132/89), while in the subset HRSC4, the ratio (a/b) is 15/5, 4/3, 10/6, 11/8, 13/8, 3/3, 1/1, 14/4, 4/4, 8/5 (in total 83/47). The temporal prevalence of the subset HRSC1 is higher than that of HRSC4. Care has been taken to eliminate those ships that appear in both groups (four in this case), which will allow their differences to be better appreciated. In these 10 ships of the subset HRSC1, 20 inspections that were conducted to detention and 50 inspections that include failures that have been labeled as due to poor training in this study have been detected. When subset HRSC4 is examined, these quantities drop to 9 and 38, respectively. There is no big difference when comparing the average ages of ships when using the age of the first inspection carried out in the records (28.7 vs. 27.5 years). Regarding the composition of flags and types of ships, interesting differences are evident. The relationship between the 10 worst-performing ships in the subset HRSC1 and HRSC4 about the flags is 8 ships against 3 within the blacklist, and about the type of ship, 9 against 3 are cargo ships and 1 against 6 are passenger ships.

Certain studies have used as an indicator of the effectiveness of inspections the number of deficiencies found after several successive inspections that used to exhibit a negative trend [49,50]. Also, a causal relationship is established between the time elapsed between two inspections, the age of the ship, the type of ship, and the registration flag as predictors [50]. This document shows that the number of repetitions of inspections per sampling period (in this study, 1 year has been used) is a more consistent indicator since it shows the prevalence of the problem, and also that the subset HRSC1 fits better to a model than the rest of the proposals set out in Section 2.2.

4.2. Relationship between Explanatory Variables and Radio Inspections That Lead to the Detention of the Vessel

It is well known that data from PSC inspections allow for characterizing the influence of the ship's static risk factors, such as the type of ship, age, and flag, on the safety level of ships. Much detailed analysis of PSC inspection records proves that the age of the ship was the most important factor in predicting ship quality [15,47,51] followed by other ship attributes: Ship type, flag [15,47,48,51], and ship inspection history [47,48]. The study of the impact of the combination of factors is also of interest. For example, cargo vessels and vessels on the black list are ships with the highest probability of problems in the inspections [47,51], and the combination age/tonnage/ship type (more than 20 years/less than 5000 tons/and cargo vessel) are characteristics influencing the probability of detention [15]. Tankers are situated on the opposite side of the safety scores. Other studies confirm that tonnage [47] is significant for casualties as following a negative relationship (the smaller the vessel, the higher the risk). However, the GMDSS requires ships to carry various types of communications equipment depending upon the voyages of the ship rather than the gross tonnage. For this reason, this characteristic has not been taken into account in this paper. The importance of the ship age when evaluating the probability of detention is confirmed by several authors referring to different areas of inspection. Although some authors refer to the little relevance of the problems related to maritime radio communications [28] in detentions (with a correlation coefficient between 0.55 and 0.65), the importance of the findings of this study confirms this relationship between static risk factors and the probability of detention. Generic statements about the relationship between vessels 20 years and older and the deficiencies regarding radio communications had previously been made [52].

This is not the first time that this link between the probability of detention and port states has been detected [47,53–55]. In turn, analyzing what is behind these specificities between countries in terms of detected deficiencies and detention of vessel probabilities within the Paris MoU ports can be attributed to two areas. The first is about the training and experience of the PSCO, and the second is about the local characteristics of the fleet, for example, ferry traffic connecting ports outside the Paris MoU with ports inside the memorandum. In the present work, it is interesting to note that of the total of 1667 ships involved, 244 were inspected more than once, with the same result of detention. When analyzing the proportion of these MoU port inspections, country by country, some significant data targets the Mediterranean ports (Table 13).

Table 13. Importance of Country Mediterranean ports in the identification of radio failures that lead to detention putting the focus on HRSC2 subset.

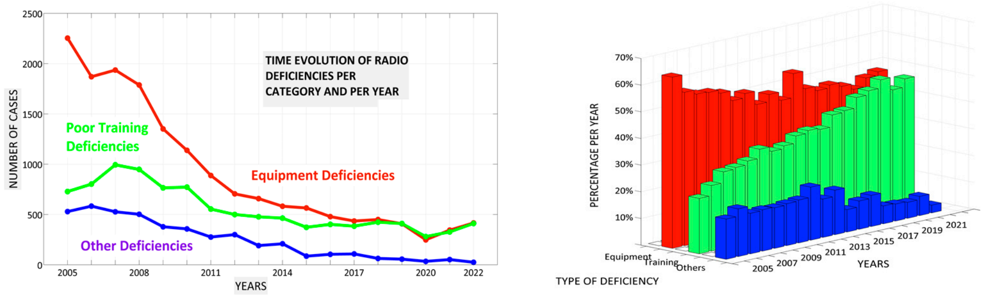
Country	Proportion of Inspections Using Different Datasets Values in % of the Total	
	Total 23,175 Inspections	HRSC2 Subset. 1979 Inspections that Led to the Detention of 1667 Ships
Spain	12.5%	17.8%
Romania	7.6%	7.1%
Italy	6.7%	18.7%
Greece	5.1%	11.2%
France	3.3%	3.6%
Croatia	1.3%	3.3%
Malta	1%	2.0%

4.3. Radio Deficiencies Linked to a Lack of Competencies in Maritime Communications of OOWs

In the review [56], the analysis of deficiencies that were behind the port state control inspection was conducted. Three major factors were highlighted: (i) onboard crew training; (ii) the insufficient number of correctly trained and educated seafarers onboard; and (iii) the age of the ship. The idea revolving around these findings is clear and implies that better continuous training on board the crew will reduce the number of deficiencies. Paradoxically, the same study reflects that the largest number of recommendations are located around safety systems and the smallest has been recorded in crew training and drills for emergencies. When the former is caused by the latter, it is like putting the cart before the horse.

Certainly, PSCOs are authorized to verify that OOWs are certified for the functions they perform, but also that they are competent in their watchkeeping and are guarantors of safety. If there is reason to believe that standards are not being met, the inspector has the right to assess the seafarer's ability to maintain watchkeeping standards [57]. It should be remembered that the choice of the HRSC3 subset is made in terms of repeat inspections where training problems are detected. This indicator connects with the IMO recommendation [57] that continuous familiarization with the GMDSS operational performance of OOWs (particularly in DISTRESS situations) should be verified during port State Control. And in case the inspections turn out to be negative, the company must take appropriate measures. Therefore, to evaluate poor compliance with this recommendation, again, the number of inspections with findings related to the GDMSS per time unit is more revealing than the number of deficiencies.

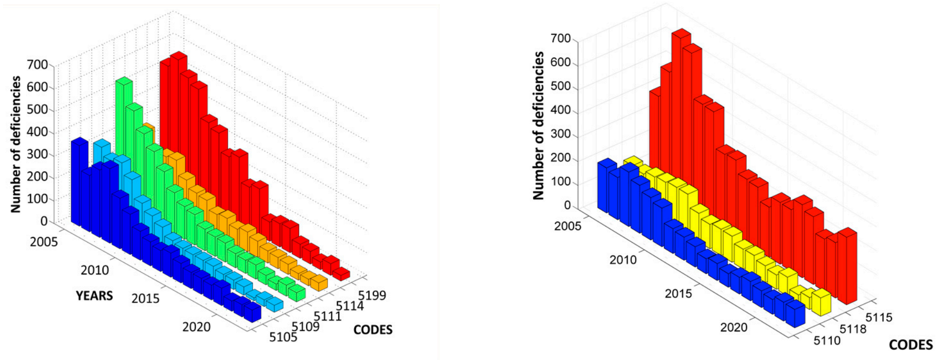
Figure 3 shows that the total number of radio deficiencies has been decreasing until it has stabilized in recent years, which is good news. This stabilization is camouflaged by the years of the pandemic, mainly the year 2020. Another thing that is striking is that the ratio of deficiencies re-coded as "equipment" and those re-coded as "lack of OOWs training" has evened out over time. When seeing the time evolution of the proportion of deficiencies labeled as "training", it seems to indicate a tendency to surpass the deficiencies labeled as "equipment" in importance. Deficiencies labeled "Others" (5199) are decreasing, which can perhaps be attributed to better training of the PSCOs themselves.



(**a**) (**b**)

Figure 3. Time series showing the time variability in the 18 years of records of the year-over-year of the 3 types of deficiencies once re-coded as "equipment", "training", and "others" (Table 5). On the left (**a**), the time evolution of the frequency distribution of the 3 categories is shown. On the left (**b**) is the same, but comparing the relative distribution (percentages).

The common deficiencies in the category "Equipment" are due to causes such as unsatisfactory levels of transmission and reception of radio equipment, deteriorated aerials, emergency power sources with supply problems, and automatic alarms that do not do their job for multiple reasons. Many of these failures are not noticeable at first glance since the officer does not appreciate the lack of communication performance while interacting with the human-machine interface. All this could reveal a lack of adequate maintenance, and consequently, it could also be attributed in certain cases to a lack of training in checkup routines and maintenance procedures, which should be investigated. The common deficiencies in the category "training" have to do with a lack of knowledge and familiarity with the operation of communications equipment and procedures, especially distress, false distress alert procedures, lack of maintenance routines, and not having correctly carried out radio-electronic watchkeeping tasks, especially when negligence is shown in not warning about distress messages at radio logs. When examining the time evolution of radio deficiency codes (Figure 4), the radio log (5115) leads the ranking practically from the beginning of the record, which is represented by the red bars in Figure 4b.



(**a**) (**b**)

Figure 4. The most significant radio defective codes (Table 5), due to their high number, are shown in their progression over 18 years. The codes represented on the left (**a**) have decreased considerably, while those shown on the right (**b**) have had a smaller decrease.

In article [58], a survey of 112 OOWs presents the perceptions of these professionals regarding future trends in radio logs. It is worth noting that 56% of the deck officers are in favor of automating the recording and storage of the radio log. However, it should be noted that out of the 32 respondents who provided additional commentary and expressed their personal opinions on this specific topic, 13 were against the automatic filling of the radio log. It is important to keep in mind that the radio log must contain a record of both sea and radio incidents that are relevant to the radio communications service during watchkeeping. Some incidents may not be automatically registered, such as (i) breakdowns or malfunctions of GMDSS equipment; (ii) communication interruptions with coast stations, earth stations, or satellites; (iii) poor propagation and atmospheric interference causing message reception issues; (iv) significant violations of radio procedures by other ship stations; (v) any occurrence related to radio service, such as false distress alerts; and (vi) distress, urgency, and safety voice traffic. The shortcomings of radio logs may appear to be of minor importance, but they raise the question of whether implementing new technologies alone would be sufficient to address these deficiencies.

GMDSS Education and Training

The detention of the ship is undoubtedly the most drastic repercussion of any PSC inspection. Regarding maritime communications, the immobilization of the ship is not only connected with serious defects in the radio equipment dedicated to distress communications but may also be motivated by the incompetence of the officers when addressing the distress operation of any equipment at GMDSS and the lack of knowledge of procedures. Figure 5 shows that this fault (code 5118) related to training is one of the most important causes of detention because it is a critical factor in an emergency.

However, maintaining proper GMDSS usage capabilities is crucial because emergencies at sea rarely occur. Therefore, the deck officers require regular updating to refresh relevant knowledge and skills and maintain safety at sea [57,59]. The project E-GMDSS is an example of how e-learning can solve the Maritime Education and Training (MET) requirements for refreshing radio communications competencies. Even though some technological solutions [58] can alleviate and automate some processes related to the correct use of the GMDSS, in this study deficiencies 5115 and, of course, 5118 have been used as an indicator that identifies a problem of a higher nature, which is the correct qualification of the OOWs in the management of communications equipment. In other words, it is an indicator of ships with safety deficiencies, possibly due to a lack of training in marine communications. MET is an essential component in ensuring maritime safety, given its reliance on human factors. Inadequate MET procedures may result in insufficient competency, which can lead to potential accidents [60].

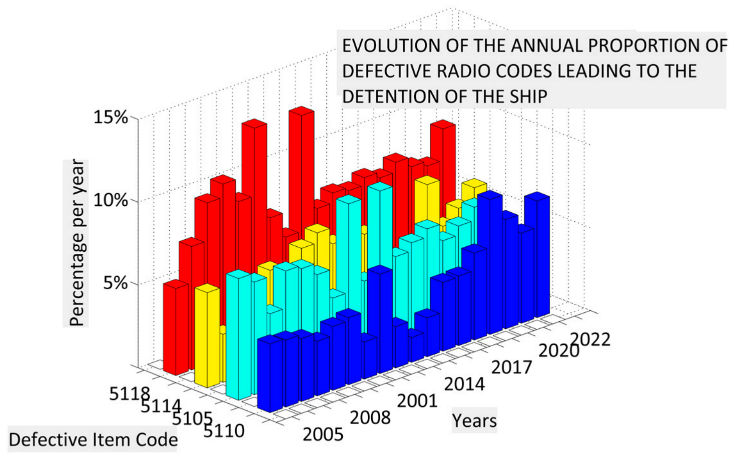


Figure 5. Time series showing the variation in the 18 years of records of the year-over-year of the 4 types of most frequent radio deficiencies 5118, 5114, 5105, and 5110, causing the detention of the ship, represented by relative frequency distribution (percentages).

The inevitable transition towards Industry 4.0 is also being implemented in maritime transport, which implies a constant review of some aspects of education and training in digital and technological competencies adapted to seafarers. When exploring the concerns of current publications on this topic, we find an increasing number of publications, of course, without pretending to be exhaustive. E.g., [61–64] and the review [65]. New concepts come into place, and seafarers and nautical students need to become familiar with decarbonization, sustainability, cybersecurity, autonomous ships, smart ports, e-navigation, and many others. Nothing has been found in the literature about the MET needs with the modernization of the GMDSS facing its next entry into force.

But far from these concerns, the current maritime communications are supported by a communications system that has barely changed in the last 30 years. Today's students have smartphones in their pockets that allow for much more sophisticated communications than those provided by the current GMDSS. Faced with this reality, some things will have to change, whether it is the GMDSS equipment itself seeking greater simplicity, automation, and transmission/reception capacity [58,66] or how to maintain and improve knowledge and skills through continuous training. In recent years, an informal survey has been carried out on those students enrolled in the course "Maritime Communications" at the University of Cadiz who had no previous experience in navigation on board ships or radio communication about their perception of the contents and skills they are about to acquire during theoretical and practical classes in simulators (posed as an open question). This course leads to the GMDSS general operator certificate. This survey (with this and other questions) has been formalized starting this year. In general, students believe that the course is about the operation of radiocommunication equipment, both from the point of view of hardware and software. They imagine one of the most digitalized areas of the ship with very sophisticated (high-bandwidth) data communication possibilities with land and other ships. They are convinced that DISTRESS communications will be something simple, whether they are senders or receivers of those messages. And the reality is quite discouraging for them during the immersive experience within a radio communications simulator and onboard ship. Communication procedures are as important as the handling of equipment. There is a maintenance protocol and a radio log that must be filled out. There is responsibility regarding the misuse of the GMDSS. During the officer cadet period, other problems arise: (i) lack of planning, supervision, and oversight of deck cadets; and (ii) lack of instructions and procedures to guide the officer-in-charge in tests/checks, and maintenance of equipment, GMDSS installation, and reserve power supply. The reality of today is that obtaining the GMDSS general operator certificate is only the first step that requires a commitment to continuous training. According to the current IMO's Model Course 1.25, the training period for obtaining GOC is about a total of 108 h, accounting for theory, practices with real equipment, simulators, and exams. Whether this is sufficient is the subject of study in another article [67], where a questionnaire is answered by 90 OOWs. One of the results is precisely that the officers themselves recognize unsatisfactory knowledge about communications in dangerous situations. Memory deficiencies when trying to reproduce the things learned during the courses joined to the exceptional use of these procedures, make 70% of those surveyed estimate the need for mandatory and regular refreshing training. It seems to follow from all this that the minimum requirements for updating GOC certificates should be harmonized to guarantee continued familiarization and ship-specific training of GMDSS operators on board ships. Another challenge is the necessary training of OOWs on the new equipment and procedures that are necessary to guarantee the correct operation of the updated GMDSS equipment.

4.4. Limitations of the Study

This study has limitations due to external factors already mentioned in the database description that may have affected the temporal trends of the data. The anomaly related to the 2005 concentrated inspection campaign focused on the GMDSS cannot be evaluated because we do not have data from previous years. Regarding the years impacted by the COVID-19 pandemic, there has been a measurable effect on both inspection rates and reported deficiencies [68]. Once the 2023 GMDSS inspection data becomes available, statistical analysis can be performed to estimate the extent of the true impact of the pandemic.

5. Conclusions

After analyzing the Paris MoU PSC data associated with inadequate continuous training of deck officers, the study's interesting findings can be summarized as follows: During the 18-year examination period, although the total number of deficiencies identified in GMDSS inspections decreased, those attributed to lack of officer skills did not reduce at the same rate. In recent years, deficiencies related to officer skill deficiencies were the type most detected and were most frequently associated with ship detention. The most common cause of vessel detention in recent years is the inability of OOWs to demonstrate their proficiency in handling radio equipment, especially in distress, emergency, and safety communications procedures. The radio communication deficiencies leading to ship detentions are linked to the same identified explanatory variables as in previous studies. These factors disproportionately affect older ships, flags of convenience, cargo ships, and Mediterranean ports.

Although the introduction of new technology can help address some of these issues, it is recommended to establish consistent use of shipboard communication courses to review essential safety skills and knowledge that are rarely used. Mentoring cadets and inexperienced officers by experienced ex-officers and publishing good practice guides for testing and maintaining facilities and backup power sources is a topic that requires further investigation.

In the methodology section, it has become apparent that a more reliable approach to identifying ships with inadequate communication safety performance is to focus on the frequency of inspections revealing deficiencies during a given time frame instead of solely focusing on the total number of deficiencies found during that same period. This leads to a hypothesis for future research: testing whether a ship's poor safety performance relates to the neglected radio competence of officers in operation and maintenance. Such neglect may cause repeated deficiencies over long periods, which form a long-term indicator of performance and a potential predictor of failure over time. In addition, this selection criterion aligns with the recommendations outlined in IMO Circular (2006) MSC.1/Circ.1208 by objectively examining inadequacies related to training and skill upgrading.

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