Shipping Inspections, Detentions, and Accidents:

An Empirical Analysis of Risk Dimensions

Christiaan Heij[1] and Sabine Knapp[1]

Econometric Institute Report 2018-36

Erasmus University Rotterdam

Abstract

Inspections play a key role in keeping vessels safe. Inspection authorities employ different policies to decide which vessels to inspect, including type of vessel, age, and flag. Attention for vessel history is usually restricted only to past detentions. This paper shows that it helps to combine past detention with past accident information to target risky vessels for inspection and to prevent serious and very serious accidents. Five methods are presented to classify risk of vessels based on these two risk dimensions, i.e., detention risk and accident risk, each of which involves an extensive set of risk factors. It is shown that these classification methods have predictive power for future serious and very serious accidents. Compared to using only detention information, incorporation of accident risk improves inspection hit rates for vessels with future accidents by 30-50%, depending on the applied inspection rate. It is recommended to focus on vessels where both risks are relatively high. A practical example shows management implications for inspection authorities how to prevent missing risky ships and how to prioritize inspection areas defined in terms of eight risk domains that include collisions, groundings, engine and hull failures, loss of life, fire, and pollution.

Keywords

Maritime safety; inspection policy; vessel-specific risk; detention risk; accident risk; risk domains

[1] Econometric Institute, Erasmus School of Economics, Erasmus University Rotterdam,
P.O. Box 1738, 3000 DR Rotterdam, Netherlands.

1. Introduction

Even though worldwide vessel numbers are steadily increasing, accident rates and detention rates show an overall declining trend. Despite these positive safety trends, there is still ample opportunity for improving maritime safety. Yang et al. (2013) state in their review paper that current safety challenges are related mainly to increased ship size, especially of cruise ships, crew quality, lack of reliable failure data, poor regulation implementation, and piracy, and they mention that risk quantification can help to replace reactive policies by proactive ones. Luo and Shin (2016) conclude from their review study that analysis of accident data, use of multiple data sources, and multidisciplinary approaches can help in developing preventive policies to improve safety. Port state control (PSC) inspections play an important role in this respect. Cariou et al. (2008) report positive safety impacts of PSC inspections, as the number of deficiencies of a vessel tends to diminish for repeated inspections. Cariou et al. (2007) find that deficiencies are related mainly to type of vessel, age, and flag of registry. Data-based policies involving rich sets of risk factors for targeting vessels for inspection have been proposed by Knapp (2006), Knapp and Franses (2008), and Li et al. (2016). Predictive approaches for PSC inspections can be found in Heij and Knapp (2011) to improve vessel survival gains and in Yang et al. (2018) to predict detention probabilities.

Knapp (2006) reports that targeting protocols used by various Memoranda of Understanding (MoU) for PSC's focus on detentions only. The number of detentions and deficiencies detected at previous inspections is used as proxy for future risk. Notwithstanding the importance of detentions and of solving deficiencies for preventing future accidents, the risk of accidents itself is also of importance for maritime safety. Perepelkin et al. (2010) and Ji et al. (2015) advocate using accident data besides detention data to evaluate safety performance of registries. The main message of this paper is that targeting risky vessels for inspection can be improved by combining detention risk derived from empirical inspection data with accident risk derived from empirical accident data. The ultimate goal of inspections and detentions is not so much to prevent future detentions but to increase maritime safety by preventing future accidents. By combining these two risk dimensions, PSC's can improve their chance to select those vessels for inspection that have highest risk of future very serious and serious (VSS) accidents.

The empirical analysis presented in this paper uses worldwide data of 158,187 inspections and 376,508 vessel-year observations on accidents from 2010 to 2014. Detention risk is found to be unrelated to past VSS accidents, to decrease with past inspections, and to increase with past detentions. The risk of VSS accidents is found to be unrelated to past inspections and past detentions and positively related with past VSS accidents. Estimated vessel-specific probabilities of detention and VSS accidents for 2017 for 71,655 vessels are nearly uncorrelated (correlation -0.03). These results indicate that current inspection and detention policies do not relate well to accident risk. The main contribution of this paper is to combine the two risk dimensions, detention risk and accident risk, to improve PSC policies for targeting risky vessels for inspection. The targeting performance of a benchmark policy based on detention risk alone is compared with four alternative risk classification methods, one of which is based on accident risk alone whereas the other three consist of various combinations (maximum, minimum, or average) of detention and accident risk. The predictive power for future detentions and VSS accidents is validated as follows. For each vessel, its five risk scores are estimated using data up to December 2017. Next, the empirical detention and accident rates from January to

March 2018 are compared across the various risk classes, with higher rates expected for higher risk classes. The outcomes show that the four alternative methods outperform the benchmark policy based on detentions alone. By incorporating accident risk in their targeting policies, PSC's can reduce their chance to miss vessels that have low detention risk but high accident risk.

Apart from providing new tools for selecting vessels for inspection, this paper also helps PSC's in prioritizing risk domains during their inspections. These domains are characterized in terms of eight accident types: collisions, drift grounding, powered grounding, main engine failure, hull failure, loss of life, fire and explosion, and pollution. For each vessel, the probabilities for these accident types are transformed into percentile rank scores, that is, probabilities relative to the fleet of all vessels. The employed data are described in Section 2, and the rest of the paper is structured as a sequence of four practical steps for industry or regulators to select the most risky vessels for inspection and to decide on inspection priorities. This quantitative inspection protocol consists of the following four steps:

Step 1. Obtain formulas that express probabilities of detention, VSS accidents, and eight accident types in terms of vessel-specific risk factors. Section 3.1 describes the methodology to derive these formulas from logit models estimated from historical inspection and accident data for 2010-2014. As these formulas are relatively stable over time, they can be updated at relatively low frequency, for example, once per five years.

Step 2. Obtain up-to-date information on current values of vessel-specific risk factors, and use these values to determine current probability scores by means of the formulas of Step 1. Section 3.2 describes how this is done for a set of 71,655 vessels in December 2017. These scores can be computed relatively easily and can in principle be updated frequently, for example, monthly, weekly, or even daily.

Step 3. Determine the set of vessels eligible for inspection, for example, vessels currently in port or also vessels expected to arrive shortly. Evaluate the relative detention and VSS accident risk scores of Step 2 for each of these vessels and rank their risk by one or several classification procedures, as described in Section 3.3 and illustrated in Section 4.3. Depending on available capacity and on extra expert information that the responsible industry or regulator may have, determine which vessels will be inspected. Sections 4.1 and 4.2 evaluate how well the five classification methods succeed in predicting future detentions and VSS accidents from January to March 2018.

Step 4. For each of the vessels selected for inspection in Step 3, use the probabilities for eight accident types determined in Step 1, combined with expert insights, to select priority areas for inspection. This is illustrated in Section 4.3, where the vessel risk for accident types is expressed by percentile rank scores relative to the fleet of all vessels.

2. Employed databases

The empirical analysis employs comprehensive databases on ship-particular characteristics, accidents, and inspections. These worldwide data are available from 2010 to 2014 and from January 2017 to March 2018 and were provided by LLI, IMO, and HIS Markit for accidents and by IHS Markit for ship-particulars and inspections. Since original data providers use different definitions for seriousness of accidents, these data have been reclassified according to definitions of IMO (2000) for very serious (including total loss), serious, and less serious. Besides this reclassification, accident initial events were identified when possible to classify the type of accident. The analysis is restricted to very serious (including total loss) and serious (VSS) accidents and excludes less serious accidents and near misses because the latter are relatively less relevant for maritime safety and may be less well reported (Hassel et al. 2011). Ship-particular data are available for over 500 variables and include standard particulars such as ship type, age, size, and flag, as well as owner, classification society, engine designer and builder, proxy variables for maritime expertise such as years in existence, previous inspection and accident histories, and changes of ship-particulars. The included ship types are general cargo, dry bulk, container, tanker, passenger, and other types excluding fishing and tugs.

The ship-particular and accident database for 2010-2014 contains 376,508 observations with (at most) one observation per vessel per year (75,302 vessels on average per year, around 80% of commercial vessels worldwide), with 8,874 VSS accidents. This database also contains information on the types of accident shown in Table 1. The most common accident types for VSS accidents are drift grounding (25%), collision (24%), powered grounding (20%), and main engine failure (20%), and less common are fire and explosion (11%), pollution (7%), hull failure (7%), and loss of life (4%). Table 1 also shows the risk domains associated with each accident type, which PSC's can use for selecting domains of special importance when inspecting a vessel. This database is used to estimate the probability of VSS accidents and associated accident types at the level of individual vessels, which corresponds to Step 1 of the inspection protocol described at the end of Section 1 and which will be explained in Section 3.1.

Table 1: Accident types and associated risk domains

Acronym	Meaning	Associated risk domains for inspection prioritization
VSS	Very serious (incl total loss) and serious	All of below
COL	Collision and grounding	Passage planning, bridge management, crew qualification
DGR	Drift grounding	Main engine, emergency procedures
ENG	Main engine failure	Maine engine, emergency procedures
FIR	Fire and explosion	Fire related aspects, emergency procedures
HUL	Hull failure	Maintenace related issues including tanks and water integrity
LIF	Loss of life	Occupational safety, safety management, life boats
PGR	Powered grounding	Passage planning, bridge management, crew qualification
POL	Pollution	Pollution prevention and emergency response

Table notes

* COL includes navigation and communication failures.
* DGR includes main engine failure, mobility related failure (propulsion, steering gear), anchor and mooring.
* ENG includes camshaft, crankshaft, turbo charger, and main engine stoppage or blackout.
* HUL includes rudder problems and tank problems.
* LIF is total number of lives lost.
* PGR includes wrecked, stranded, grounded, and navigation (compass, radar) and communication (AIS).

The inspection database for 2010-2014 contains 158,187 inspections with 6,458 detentions and can have multiple observations for the same vessel in the same year. This database contains on average 21,117 inspected vessels per year, which corresponds to a vessel coverage rate compared to the accident database of 30%. This database is used to estimate the probability of detention at the level of individual vessels, which corresponds again to Step 1 of the protocol.

The database for January 2017 to March 2018 concerns 71,655 vessels. Inspection, detention, and VSS accident outcomes for 2017 and for the first quarter of 2018 (2018Q1) are shown in Table 2. Yearly VSS accident rate has dropped considerably compared to 2010-2014. The much lower inspection and detention rates compared to 2010-2014 are caused by the fact that the inspection database concerns MoU's with relatively high inspection rates and covers only 30% of the accident database. This causes no analysis problems, however, as the inspection database is used only to relate inspection and detention probabilities to vessel-specific characteristics and not to predict inspection or detention rates. This database further contains estimated detention and VSS and associated accident type probabilities per vessel computed from information available in December 2017. This corresponds to Step 2 of the inspection protocol. The empirical data for 2018Q1 are reserved for policy evaluation purposes according to Step 3 of the protocol, as will be discussed in Section 4.

Table 2: Inspection, detention, and VSS accident rates in three periods

Period	2010-2014	2017	2018Q1 (quarter)	2018Q1 (year)
VSS accidents				
# Vessels	75,302 (A)	71,655	71,655	71,655
# VSS Accidents	1,775 (A)	1,178	174	696 (C)
% VSS accidents per vessel	2.36	1.64	0.24	0.97
Inspections				
# Vessels	21,117 (B)	71,655	71,655	71,655
# Inspections	31,637 (A)	81,085	15,868	63,472 (C)
% Inspections per vessel	149.82	113.16	22.15	88.58
# Detentions	1,292 (A)	1,977	480	1,920 (C)
% Detentions per vessel	6.12	2.76	0.67	2.68
% Detentions per inspection	4.08	2.44	3.02	3.02

Table notes

* The column 2018Q1 (quarter) shows the actual figures for this quarter, and 2018Q1 (year) inflates these figure to estimated yearly figures by multiplying the quarterly ones by 4, denoted by code (C).
* Code (A) means that 5-year total counts for 2010-2014 are divided by 5 to get average yearly ones.
* Code (B) gives the average of five yearly numbers of vessels in the inspection database.
* Code (C) means that the count for the first quarter of 2018 is multiplied by 4 to get an estimated yearly count for 2018.

3. Methodology

This section describes statistical methods to implement the four steps of the inspection protocol described in Section 1. Each subsection describes one step of this procedure.

3.1 *Risk formulas*

Step 1 requires formulas that express probabilities of detention, VSS accidents, and accident types in terms of vessel-specific risk factors. The accident and inspection databases for 2010-2014 are used to estimate logit models for each of these probabilities according to the methodology described in Knapp

(2006), Knapp and Franses (2007), and Heij and Knapp (2018). Knapp (2015) describes this method for the current database in more detail. The estimated logit models express the probability of an event (detention, VSS accident, or accident type) by means of the fraction exp(xb)/(1+exp(xb)), where ‘exp’ denotes the exponential function, ‘x’ is the set of vessel-specific risk factors such as age, size, flag, and so on, and ‘xb’ is a weighted average of these factors with estimated weights per factor. Initial models contain large sets of factors, which are down-tested by removing insignificant factors until all remaining factors are significant (at 5% level). All models are estimated by quasi-maximum likelihood (Greene 2000) to allow for possible misspecification of the assumed underlying distribution function for logit models.

Table A1 in the Appendix summarizes the ten obtained models. In general, models for more common events contain more risk factors because data on such events is more informative. The richest model is obtained for VSS accidents (8,874 events) and contains 15 scale variables such as age, size, and past accident history, and 172 dummy variables for factors like flag, engine designer and builder, and ship type. The smallest model is for loss of life (376 events) and contains 7 scale variables and 26 dummy variables. As accident types are restricted to VSS accidents, it is not surprising that past VSS accidents have positive effects on most accident type probabilities. Past inspections and detentions, however, are insignificant in most cases; the only exception, possibly by chance, is a positive effect of past inspections on powered grounding risk. This means that, given the other vessel specifics including past accident history, the past inspection and detention history of the vessel has no additional explanatory power for VSS accidents and associated accident types. Past inspections reduce detention risk and past detentions increase this risk, as expected. However, past accident history has no effect on detention risk. The effects of vessel age and size for VSS accident risk are opposite to those for detention risk, as detention risk is higher for older and smaller vessels whereas VSS accident risk is higher for newer and larger vessels. As the detention model reflects actual MoU decisions in practice, these outcomes indicate that inspection and detention policies in 2010-2014 did not incorporate accident information. This finding is directly related to the main message of this paper that past accident information is relevant for targeting vessels for inspection to reduce accident risk.

3.2 *Current vessel-specific risk scores*

Step 2 of the protocol is to compute up-to-date probabilities for detention and VSS accidents and associated accident types using current information on vessel-specific risk factors. These probabilities are obtained by substituting the current data into the logit probability formulas of Step 1, which requires data on the current age of the vessel, its current flag and owner, its recent history of inspections, detentions, and VSS accidents, and so on. These probabilities are computed from information up to December 2017 by specialized software, including filtering of vessels in service at that time and resulting in 71,655 vessels.

The computed model-based probabilities can be interpreted as yearly probabilities only after calibration to correct for sample selection effects in the underlying databases. As the vessel database covers about 80% of the world commercial fleet and VSS accidents may be under-reported, this means that the accident database is incomplete with respect to both non-accident and accident observations. Let the database contain fractions ‘fna’ of all non-accidents and ‘fa’ of all VSS accidents worldwide. Then correct levels of VSS accident probabilities are obtained from estimated logit probabilities exp(xb)/(1+exp(xb)) by adding the calibration factor a = ln(fna/fa) to xb, i.e., by using the formula exp(a+xb)/(1+exp(a+xb)), where 'ln' denotes the natural logarithm. This result is shown in Franses and Paap (2010, pp. 73-75) for fa = 1 and is easily extended to the case fa < 1. This calibration effect is not uniform over all vessels, as it is largest for probabilities near 0.5 and smallest near 0 and 1. Comparison of estimated VSS accident probabilities with empirically observed VSS accident rates shows that sample selection effects differ per ship type. The resulting calibration factors for VSS accidents and associated accident types are (rounded to two decimals) 0.96 for general cargo, 0.80 for dry bulk, 0.99 for container, 0.97 for tanker, 0.92 for passenger, and 0.99 for other ship types.

Calibration along similar lines of estimated detention probabilities to yearly probabilities is hard because the inspection database covers only a limited part of the global fleet and contains multiple inspections of the same vessel in the same year. Estimated detention probabilities for 71,655 vessels in December 2017 are 6.45% on average, whereas the empirical detention rate for this set of vessels over 2017 is 2.76%. The logit detention probabilities are divided by 2 to match them roughly to empirical rates. This crude procedure does not affect the analysis, which is based on percentile ranks and not on numerical levels of probabilities.

3.3 *Combining detention and accident risk*

In step 3 of the protocol, vessels are ranked according to their risk scores computed in Step 2. In practice this ranking can be done for any subset of vessels of interest, but here this is done for the full set of vessels. To prevent difficulties in interpretation of numerical levels of probabilities, they are transformed into relative scores by means of percentile rank scores. If, for example, a vessel has rank score 83 for VSS accident risk, this means that 83% of the vessels have lower risk and 17% have higher risk for a VSS accident. Rank scores are computed for the full set of 71,655 vessels and rank from 0 for the least risky vessel to 100 for the most risky one.

The rank scores of each vessel are denoted by RDET for detention and by RVSS for VSS accidents. Two simple ranking methods are to rank vessel risk by RDET neglecting accident risk or by RVSS neglecting detention risk. Figure 1 shows three methods to combine these two risk dimensions, where the combined detention and accident risk is ranked according to the highest of the two ranks (method A), the lowest (method B), or their average (method C). Percentile ranks of vessels are distributed uniformly across both axes. The figure also shows five quintile areas for each method, where each quintile contains 20% of all vessels if the two risk dimensions are independent. The fraction of the (100×100) square occupied by area 1A, for example, is 0.447×0.447 = 0.2, that of area 1B is 0.632×0.632 – 0.2 = 0.2, and that of area 1C is 0.632×0.632/2 = 0.2. RDET and RVSS computed in December 2017 for the set of 71,655 vessels are nearly completely uncorrelated (correlation 0.002) and the percentage of vessels in the areas of Figure 1 ranges from 19.5-20.2% for method A, 19.6-20.3% for method B, and 19.1-21.0% for method C. The empirical analysis in Section 4 will use exact quintiles with boundaries that differ slightly from those in Figure 1.

As method C uses the average of rank scores of detention and VSS accidents, this corresponds to assigning equal weights to these two risk dimensions. Another option is to leave selection of weights to regulators, see also Ji et al. (2015). One can also follow an empirical approach. For example, a logit model for VSS accidents in 2017 assigns weights of about 2 for RVSS and -1 for RDET, a rather peculiar outcome that indicates once again that past inspection policies do not succeed well in targeting accident risk. This method is infeasible in real time, however, because the rank scores RVSS and RDET are computed with information of December 2017 and can hence not be used to predict VSS accidents in 2017. Estimation of weights based on past predictive performance may be a realistic option when longer evaluation periods become available.

Figure 1: Three risk classification methods for combining the risk of detention and the risk of a VSS accident

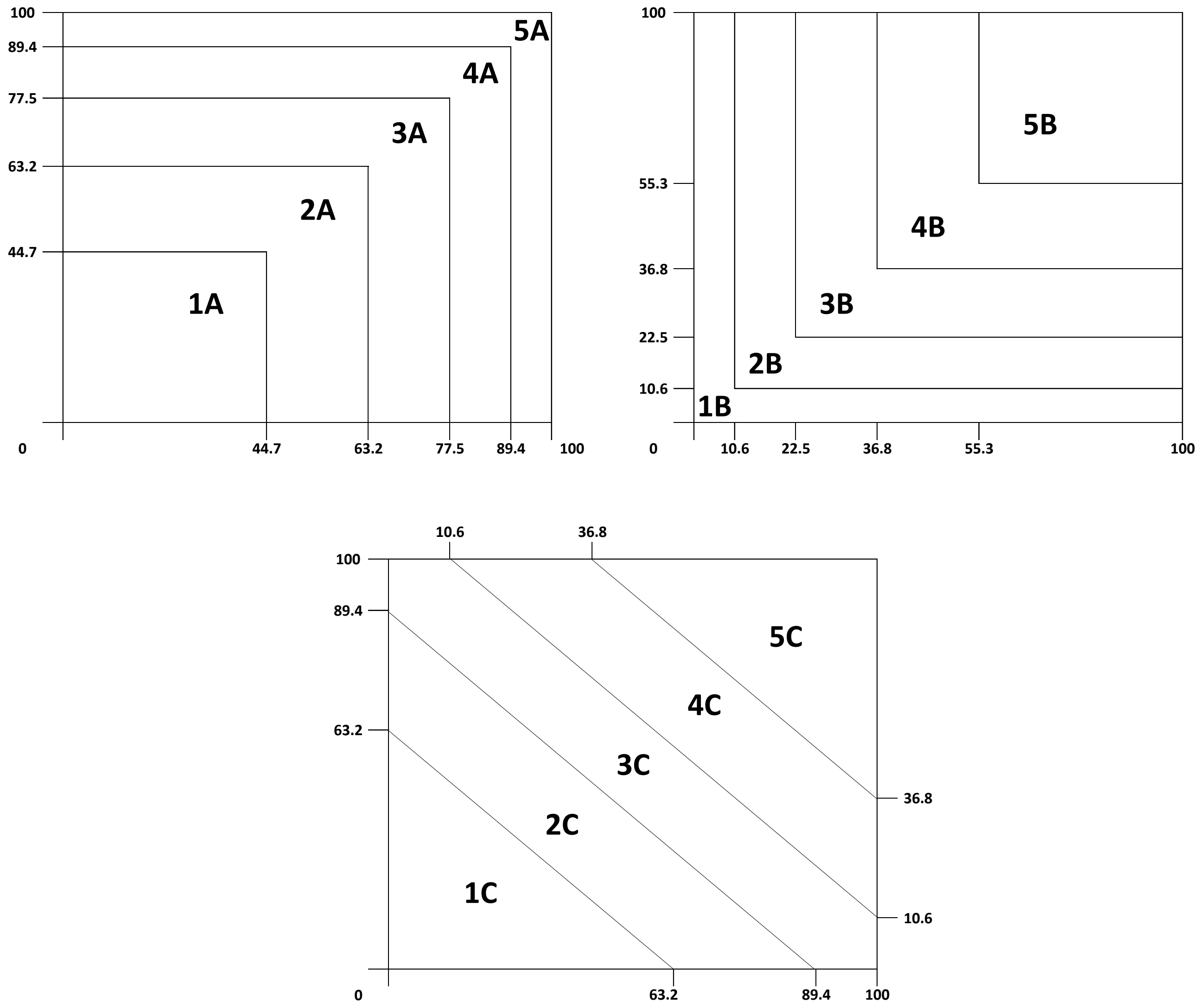


Figure notes

* The axes show the rank (scale from 0 for lowest till 100 for highest) of two risk indicators: VSS accident probability and detention probability.
* Method A classifies the combined risk according to the maximum of the two risk ranks, B according to their minimum, and C according to their average; if the risk rank of a vessel is RDET for detention and RVSS for VSS accident, then method A classifies the combined risk by max(RDET, RVSS), method B by min(RDET, RVSS), and method C by (RDET + RVSS)/2.
* Quintiles rank from 1 for least to 5 for most risky, and the areas 1-5 all cover 20% of the total area if the two risk indicators are independent.
* For the empirical dataset of 71,655 vessels, the correlation between RDET and RVSS is 0.002 and area 5A contains 20.2% of all vessels, 5B 20.1%, and 5C 19.6%.

3.4 *Inspection priorities*

If inspection capacity is limited, then inspection efforts can be focused mostly on vessels in the highest risk quintiles. For example, if 20% of all vessels can be inspected, then vessels in the top quintiles 5A, 5B, or 5C are prime targets.

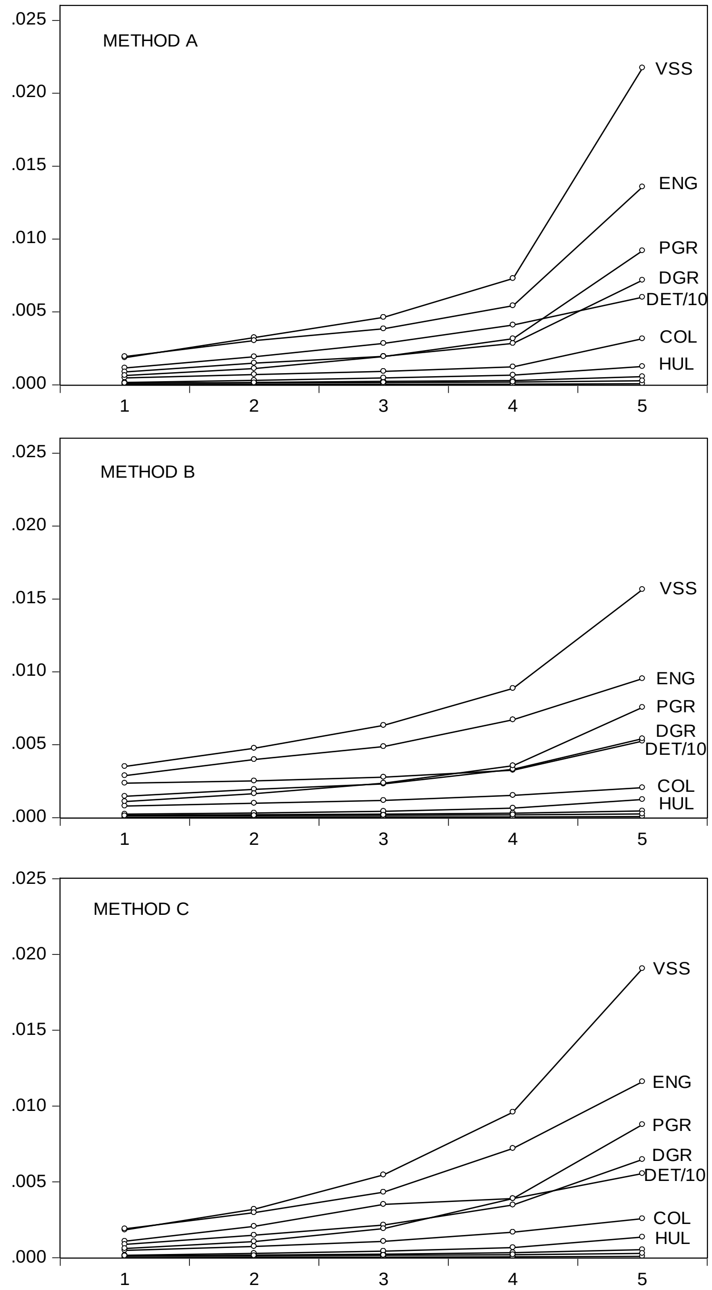
In step 4 of the protocol, for a given set of vessels selected for inspection, risk domains deserving special attention can be determined per vessel based on probabilities for the eight accident types of Table 1. For each vessel, inspectors can check percentile rank scores per risk domain and decide which domains get inspection priority. The risk domains listed in Table 1 include bridge management, passage planning, crew quality, maintenance issues related to engine and hull, occupational safety, emergency procedures, and pollution prevention. In principle, these risk domains can be extended and refined if more detailed accident type information becomes available with sufficient number of events to construct reliable probability models.

As the eight accident types of Table 1 are analysed for VSS accidents, it is not surprising that the risk for each type increases per risk quintile. Figure 2 shows average yearly probabilities for each accident type, computed in December 2017, per quintile for each of the three risk combination methods. It also shows average yearly detention probabilities per quintile, which are divided by 10 to get comparable vertical axis scales. All eight accident types have highest average probability in the top quintiles (5A, 5B, 5C), with roughly 2-3 times larger risk than average. Method A is more successful than method B in classifying vessels with highest accident type risks in its top quintile, whereas method C takes a kind of middle position. The table in Figure 2 shows that engine failures and powered and drift groundings are expected to occur most frequently for future VSS accidents. Although the expected frequencies of loss of life, pollution, and fire and explosion are relatively small, these types of accident have of course serious consequences. The analysis in this paper will therefore transform probabilities into percentile rank scores that show the risk position of a vessel relative to the global fleet.

4. Results

This section investigates predictive out-of-sample performance of the five risk classification methods of Section 3.3 in detecting future risk for VSS accidents. The risk scores of each vessel are determined from logit formulas with weights of risk factors estimated for 2010-2014 (see Section 3.1) and by substituting up-to-date values of these risk factors that apply for December 2017 (see Section 3.2). Performance of the five methods is evaluated for inspections, detentions, and VSS accidents in the forecast period January to March 2018 (2018Q1). It is shown that the four methods that include VSS accident risk (RVSS and methods A, B, and C) provide significant information for future VSS accidents, whereas the method based on detention risk alone (RDET) has no predictive value. This finding is confirmed by comparing the number of VSS accidents in high risk classes with those in low risk classes (Section 4.1) and by determining hit rates of vessels with future VSS accidents when each method is used to target vessels for inspections (Section 4.2). A small management example with 12 vessels illustrates how the proposed methods can be applied in practice to select vessels for inspection and to determine domains of attention during inspections (Section 4.3).

Figure 2: Means of accident type probabilities per risk quintile for three risk classification methods



Quintile	VSS	DET	ENG	PGR	DGR	COL	HUL	FIR	POL	LIF
All (1-5)	0.78	3.22	0.56	0.32	0.29	0.13	0.06	0.03	0.02	0.00
5A	2.17	6.01	1.36	0.92	0.72	0.32	0.13	0.06	0.01	0.03
5B	1.57	5.25	0.95	0.76	0.54	0.21	0.12	0.05	0.01	0.03
5C	1.91	5.55	1.16	0.88	0.65	0.26	0.14	0.05	0.03	0.01
Highest	A	A	A	A	A	A	C	A	C	A
Lowest	B	B	B	B	B	B	B	B	B	C

Figure notes

* The results apply for the set of 71,655 vessels for 2017 and 2018Q1, with 14,331 vessels per risk quintile, with probabilities computed with information up to December 2017.
* The figures show the mean values of the yearly accident probabilities of vessels in risk quintiles 1-5 (on the horizontal axis), with quintiles based on each of the combined risk classification methods A, B, and C.
* For reasons explained in the text, logit model detention probabilities are downscaled by a factor 2, and for ease of readability of the figures the resulting percentage for detentions is divided by 10.
* In each figure, the bottom three curves below "HUL" are (from top to bottom) for FIR, POL, and LIF.
* The table shows the mean percentage risk (probability times 100) for vessels in the top quintile (top 20%) for each method (5A, 5B, and 5C), as well as the gross mean percentage over all vessels (all quintiles 1-5).

4.1 *Predictive power of risk classification methods*

To assist inspection decisions, the risk of each vessel is ranked relative to a reference group of vessels. In this application the reference group consists of 71,655 vessels distributed as follows over vessel types: 26% general cargo, 22% tanker, 16% dry bulk, 9% passenger, 7% container, and 20% other excluding fishing and tugs. For each vessel, its probabilities of detention and VSS accidents are determined from data up to December 2017 (see Sections 3.1 and 3.2). These probabilities are transformed into percentile rank scores RDET for detention and RVSS for VSS accidents and five vessel risk ranking methods are compared: RDET and RVSS that consider only a single risk dimension, and methods A, B, and C that combine these two dimensions (see Section 3.3 and Figure 1). For each method, vessels are classified in five risk groups, that is, five quintiles that each contain 20% of all vessels (14,331). The bottom quintile contains the 20% of vessels with lowest risk and the top quintile contains the 20% with highest risk.

Figure 3 shows empirical rates of inspections, detentions, and VSS accidents in 2018Q1 within each quintile (on the horizontal axis) and for each method. These event rates are shown as percentages on the vertical axis, so that a value of 1 means that 1% of the vessels in this quintile had this type of event in 2018Q1. These percentages are most precise for inspections (12,791 vessels, 2,558 per quintile), followed by detentions (462 vessels, 92 per quintile), and they are least precise for VSS accidents (173 vessels, 35 per quintile). These vessel counts differ from the counts for 2018Q1 in Table 2 because vessels can have multiple events. For example, one vessel had two VSS accidents and 172 vessels had one such accident, so the total number of VSS accidents is 174 and the number of involved vessels is 173.

The graph for detentions shows that actual detention rates during the forecast period increase for higher quintiles. This agrees with the idea that the chance of detention should be higher for riskier vessels. Methods B and C have the highest detention rate in their top quintile, so these two methods are most successful in predicting high detention risk.

The graph for inspections shows that inspection rates increase per risk class for methods RVSS and B, fluctuate for method C, and decline for methods RDET and A. The results for RVSS and B are rather weak, as inspection rates are flat across the highest three quintiles. The results for A and especially for RDET indicate that these methods do not correspond with actual inspections in 2018Q1. Stated otherwise, inspections in 2018Q1 were only weakly related to VSS accident risk and even negatively to detention risk. The actual inspection rate in the highest detention risk quintile for RDET is only 8.6%, less than half of the average inspection rate of 21.7% in the three lowest detention risk quintiles.

The graph for VSS accidents shows haphazard patterns due to the relatively small number of VSS accidents in 2018Q1. However, method RVSS shows a clear upward trend and all methods except RDET have clearly higher VSS accident rates in the top quintile compared to the bottom quintile. Accident rates for RDET are rather flat or even declining for higher risk, showing that detention risk alone is not well related to future VSS accident risk.

The visual comparisons in Figure 3 are supported by statistical tests on the research hypothesis that future inspection, detention, and VSS accident rates are higher for vessels falling in higher risk classes. Note that these risk classes have been determined ‘ex ante’, that is, from past data up to

December 2017 and prior to the events in the evaluation period 2018Q1. The test outcomes are shown in Table 3. Outcomes under ‘Event yes / no’ compare median risk in two groups of vessels, those with the event of interest (inspection, detention, or VSS accident) and those without. A standard test for rank comparison between two groups is the rank sum test of Wilcoxon (1945) for equal medians. The table shows the difference between the median rank score in the group with events from that without events, so that positive values are expected. The reported p-values are for the two-sided alternative that median ranks differ in the two groups.

Figure 3: Rates of inspections, detentions, and VSS accidents in 2018Q1 for five risk classification methods

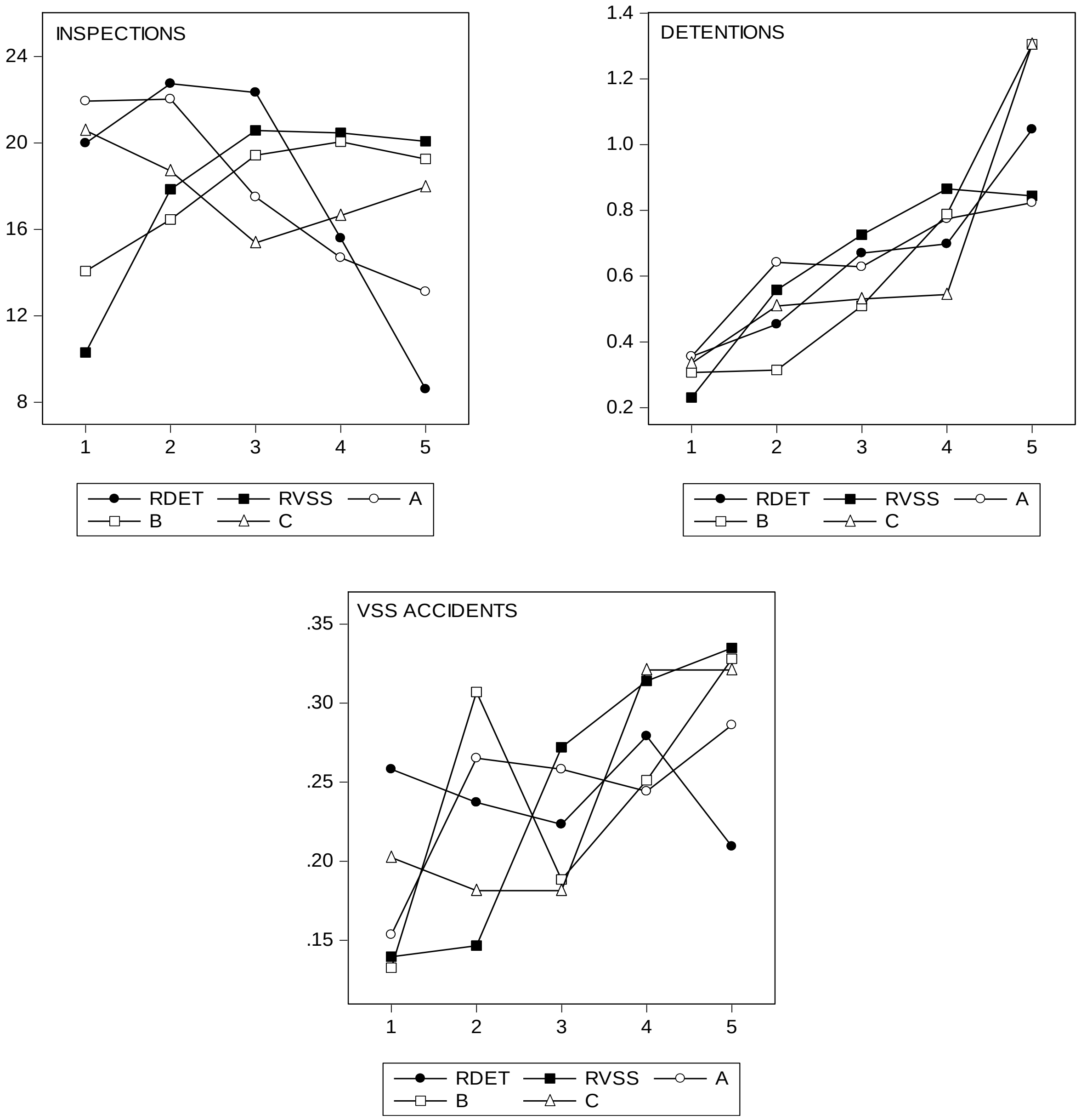


Figure notes

- * The figure for inspections shows the percentage of vessels with at least one inspection in the first quarter of 2018 per risk quintile (on the horizontal axis) for five risk classification methods based on the probability of detention (RDET, denoted by curves with closed dots), on the probability of a VSS accident (RVSS, closed blocks), and on each of three risk combination methods A (open dots), B (open blocks), and C (open triangles).
- * The figures for detentions and VSS accidents show similar percentages of respectively detentions and VSS accidents per risk quintile.

The results for detentions are as expected, with higher risk for detained vessels compared to non-detained ones. For all five methods, ‘ex ante’ detention risk signals future detention risk. This signal is strongest for method B, followed by C, RDET, RVSS, and finally A. The results for VSS accidents are also as expected, except for RDET. The strongest signal for future VSS accidents is provided by methods RVSS and C, followed by B, and that of A is small and only marginally significant. Method RDET is not successful, as the median risk rank for vessels with VSS accident is even slightly lower than that of vessels without accident. Finally, the results for inspections are mixed because inspections in 2018Q1 were more likely for vessels with higher accident risk but less likely for vessels with higher detention risk. The median ‘ex ante’ VSS accident risk rank of inspected vessels (56.21) is higher than that of non-inspected ones (48.46), but the median detention risk rank of inspected vessels (41.61) is lower than that of non-inspected ones (52.48).

Table 3: Ex ante risk classifications and event outcomes for inspections, detentions, and accidents during 2018Q1

		INS (12,791 = 17.85%)		DET (462 = 0.64%)		VSS (173 = 0.24%)	
Risk method	Test	Diff	P-value	Diff	P-value	Diff	P-value
Event yes / no							
RDET	W	-10.87	0.000	14.71	0.000	-0.27	0.826
RVSS	W	**7.74**	0.000	12.19	0.000	**12.61**	0.000
A	W	-11.41	0.000	9.55	0.000	2.12	0.066
B	W	5.39	0.000	**21.67**	0.000	8.48	0.004
C	W	-3.85	0.000	18.66	0.000	12.43	0.005
Quintile 5 / 1							
RDET	T	-11.39	0.000	0.69	0.000	-0.05	0.392
RVSS	T	**9.78**	0.000	0.61	0.000	**0.20**	0.001
A	T	-8.81	0.000	0.47	0.000	0.13	0.017
B	T	5.18	0.000	**1.00**	0.000	**0.20**	0.001
C	T	-2.62	0.000	0.97	0.000	0.12	0.049
Quintile 4-5 / 1-2							
RDET	T	0.69	0.000	0.47	0.000	0.00	0.933
RVSS	T	**6.20**	0.000	0.46	0.000	**0.18**	0.000
A	T	-8.07	0.000	0.30	0.000	0.06	0.170
B	T	4.39	0.000	**0.74**	0.000	0.07	0.098
C	T	-2.34	0.000	0.50	0.000	0.13	0.002

Table notes

* Risk classifications are determined with data up to December 2017, and events (inspections, detentions, and VSS accidents) are for the first quarter (January-March) of 2018. The total number of vessels is 71,655, and the number and percentage of vessels is shown at the top of the table; here an event like inspection means that the vessel has been inspected at least once during the first quarter of 2018.
* For "Event yes / no", the risk percentile ranks of vessels are compared between two groups of vessels, those with an event and those without an event. Test W is the Wilcoxon rank sum test for equal median rank scores for the two groups of vessels.
* For "Quintile 5 / 1", the event percentages are compared between two risk groups of vessels, those with highest 20% risk (quintile 5) and those with lowest 20% risk (quintile 1). Test T is the Satterthwaite t-test for equal event percentages for the two groups of vessels.
* "Quintile 4-5 / 1-2" compares in a similar way the event percentage for the 40% vessels with highest risk (quintiles 4 and 5) with that of the 40% of vessels with lowest risk (quintiles 1 and 2).
* For "Event yes / no", "Diff" shows by how much the median percentile rank score of vessels with event exceeds that of vessels without event, and for the two quintile comparisons "Diff" shows by how much the percentage of events of vessels in the higher risk class exceeds that of vessels in the lower risk class.
* Bold numbers are for the classification method providing the sharpest contrast.

Another way to test predictive power of risk classification methods is to compare event rates (of inspections, detentions, and VSS accidents) in high risk classes with those in low risk classes. The research hypothesis is that the event rate, measured as the percentage of vessels that has the event in 2018Q1, is higher for higher risk classes. Table 3 shows the difference of event percentages between the highest and lowest risk class, so that positive values are expected. A standard test for the comparison of percentages in two groups is the t-test of Satterthwaite (1946), and p-values reported in Table 3 are for the two-sided alternative that event percentages differ between the two groups. This test is implemented in two ways, one comparing the 20% most risky vessels (quintile 5) with the 20% least risky ones (quintile 1) and another comparing the 40% most risky vessels (quintiles 4 and 5) with the 40% least risky ones (quintiles 1 and 2).

The outcomes support earlier findings. For all five risk classification methods, detention rates are higher in the higher risk group with largest difference for method B. As expected, the difference for quintile 5 compared to 1 is sharper than that for quintiles 4 and 5 compared to 1 and 2. For method B, for example, the detention rate, which is 0.64% for all vessels, is 1.30% in quintile 5 against 0.31% in quintile 1, and 1.05% in quintiles 4 and 5 against 0.31% in quintiles 1 and 2. The results for inspection rates are again rather mixed. The overall vessel inspection percentage in 2018Q1 is 17.85%, but only 8.60% of vessels in the highest detention risk quintile is inspected compared to 19.99% in the lowest one. Inspection rates are higher for vessels with higher VSS accident risk, 20.07% in quintile 1 against 10.29% in quintile 5 and 20.27% in quintiles 4 and 5 against 14.07% in quintiles 1 and 2. Finally, VSS accident rates are significantly higher for higher risk classes except for method RDET. At an overall accident rate of 0.24%, the rate in the highest (lowest) quintile is 0.33% (0.14%) for RVSS, 0.33% (0.13%) for method B, 0.29% (0.15%) for method A, 0.32% (0.20%) for method C, and 0.21% (0.26%) for RDET. This shows that all methods except RDET succeed rather well in signalling future risk for serious and very serious accidents, as this risk is about twice as large for vessels in the top quintile compared to the bottom quintile.

4.2 *Hit rates for VSS accidents at various inspection rates*

The main purpose of inspections is to prevent future accidents. The success of inspection strategies to target vessels with future VSS accidents can be measured in terms of the hit rate, defined as the targeted percentage of vessels with future VSS accidents relative to the overall percentage of vessels targeted for inspection. For example, if 50 out of 1,000 vessels have an accident and a strategy selects 200 vessels for inspection 30 of which have an accident, then the hit rate is equal to (30/50) divided by (200/1000), that is, 3. Random strategies unrelated to accidents are expected to have a hit rate of 1, and hit rates above 1 indicate successful targeting.

The five risk classification methods are applied on the set of 71,655 vessels with risk scores computed from information up to December 2017 (see Section 3.2). Now suppose that R% of these vessels can be inspected, then the best way to do this from a risk perspective point of view is to select the vessels with highest R% of risk scores. The hit rates for VSS accidents in 2018Q1 are shown in Table 4 for each method and for quarterly inspection rates ranging from 5-100%. For a quarterly inspection rate of 20%, for example, all vessels are inspected that fall in the highest risk quintile. The table shows how many of the 173 vessels with a VSS accident in 2018Q1 are selected for inspection in this way, together with the corresponding hit rates. For a quarterly inspection rate of 20%, methods

RVSS, B, and C have hit rates above 1.3, meaning they do more than 30% better than random. Methods B and C perform best for smaller inspection rates, with hit rates up to 50% better than random. Method RDET does not perform well and does not outperform a random strategy, whereas methods RVSS, B, and C increase the hit rate by 30-50% for yearly inspection rates of about 20-60%. Method A is also better than random but performs less well than RVSS, B, and C.

Table 4: VSS accident hit rates during 2018Q1 for various risk-based inspection methods

Inspection rate (%)		Expected inspections		Risk ranking method					
Quarterly	Yearly	Quarterly	Yearly	Random	RDET	RVSS	A	B	C
				Number of vessel hits					
5	18.5	0.05	0.2	8.65	10	10	11	12	13
10	34.4	0.1	0.4	17.3	17	23	19	25	26
20	59.0	0.2	0.8	34.6	30	48	41	47	46
40	87.0	0.4	1.6	69.2	70	93	76	83	92
60	97.4	0.6	2.4	103.8	102	132	113	110	118
80	99.8	0.8	3.2	138.4	136	153	151	154	144
100	100.0	1.0	4.0	173	173	173	173	173	173
				Hit rate					
5	18.5	0.1	0.2	1.00	1.16	1.16	1.27	1.39	1.50
10	34.4	0.1	0.4	1.00	0.98	1.33	1.10	1.45	1.50
20	59.0	0.2	0.8	1.00	0.87	1.39	1.18	1.36	1.33
40	87.0	0.4	1.6	1.00	1.01	1.34	1.10	1.20	1.33
60	97.4	0.6	2.4	1.00	0.98	1.27	1.09	1.06	1.14
80	99.8	0.8	3.2	1.00	0.98	1.11	1.09	1.11	1.04
100	100.0	1.0	4.0	1.00	1.00	1.00	1.00	1.00	1.00

Table notes

* For quarterly inspection percentage R, the inspection method consists of selecting for inspection those vessels with percentile above rank (100-R); for example, for rate R = 20% and method A, inspect all vessels with risk A percentile above 80.
* The yearly inspection rate is derived from the quarterly one with the assumption that selection for inspection is independent across quarters; for quarterly inspection rate r = R/100, the probability to be inspected at least once in a year is 1 - (1-r)^4.
* "Expected inspections" is the expected number of inspections for each vessel.
* Method "Random" is a benchmark rule that selects vessels arbitrarily for inspection, and the numbers for this method in the table are expected outcomes.
* "Number of vessel hits" shows the number of vessels with a VSS accident in 2018Q1 (173 in total) that would have been inspected for each risk method and inspection rate.
* "Hit rate" is defined as the percentage of vessels with VSS accident that is inspected divided by the percentage of all vessels that is inspected.

These results confirm earlier findings that inspection policies based on detention risk alone are not successful in targeting risky vessels, whereas incorporation of VSS accident risk improves this targeting considerably. The above risk-based strategies depend solely on quantitative information, and the involved set of risk factors consists of all factors incorporated in the logit risk formulas described in Section 3.1 (see also Table A.1 in the Appendix). In practice, inspection decisions involve an interplay of such quantitative information with qualitative expert knowledge and local considerations. The above analysis considers a simplified situation where inspections are based only on quantitative risk information and shows the potential power for improved inspection strategies apart from the evident importance of other information and considerations in the ultimate decision process.

The results in this and the previous subsection indicate that RDET does not perform well and that methods B and RVSS perform best on average, followed by C and A. It is therefore recommended to include accident risk in making inspection decisions and, if also detention risk is included, to focus on vessels where both risks are relatively high (method B).

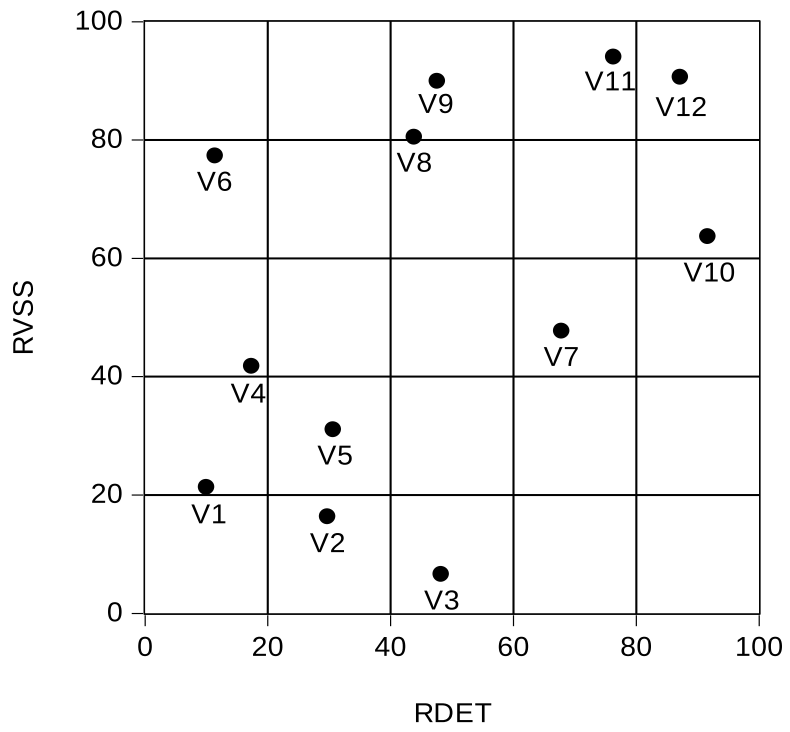
4.3 *Application example for inspection management*

A small example with 12 real-world vessels is used to illustrate the proposed methods as quantitative ingredient of the wider decision process which vessels to inspect. Steps 1 and 2 of the inspection protocol described in Section 1 result in percentile rank scores RDET for detention and RVSS for accidents, and Figure 4 depicts the rank scores of the 12 vessels. The table shows for each vessel its two rank scores, whether it had an inspection, detention, or VSS accident in 2018Q1, the risk quintiles of five classification methods, and the percentile scores on eight accident types. It is now shown how this information can be used for steps 3 and 4 of the inspection protocol to identify high-risk vessels and inspection domains of interest to prevent future accidents.

Vessels 1 and 3 to 6 (two tankers, two dry bulk vessels, and a general cargo vessel) were in fact inspected in 2018Q1 and vessel 6 (general cargo) was detained, but none of these vessels had a VSS accident (‘false positives’). The risk classification methods assign low risk quintiles to these five vessels, suggesting that these inspections had low priority. However, vessel 6 has high risk for some accident types, especially for powered grounding, engine failure, and pollution, which may justify its inspection and detention. Vessels 2 (dry bulk), 7 (passenger ship), and 12 (general cargo) were not inspected, and the classification methods agree with this decision for vessel 2 but not for vessel 12 and, to a lesser degree, also not for vessel 7 which has high risk for loss of life. The decision not to inspect vessel 2 is correct in the sense that it had no VSS accident (‘correct negative’), but vessels 7 and 12 did have such an accident in 2018Q1 (‘false negatives’). Vessel 12 has top priority for each of the five risk classification methods, and it would not have been missed for an inspection rate of 20% which is comparable to the actual inspection rate during 2018Q1, which is 22.15% on average and involves 17.85% of all vessels. Vessels 8 to 11 (two container ships, a tanker, and a general cargo vessel) were inspected but not detained and all of these vessels had a VSS accident in 2018Q1 (‘correct positives’). For an inspection rate of 20%, four of the five risk classification methods would have selected vessels 10 and 11 for inspection, three for vessel 9, and one for vessel 8. For this inspection rate, methods RVSS, A, and C succeed in selecting four of the six vessels with a VSS accident, B selects three of them, and RDET two. Again, the incorporation of VSS accident risk helps in signalling vessels with high future accident risk.

Once vessels have been selected for inspection, the percentile scores of accident types can be used to identify inspection domains of special interest. Vessels 9-12 have top risk and would be selected for inspection by almost all classification methods. The accident type risk of vessel 9, a container ship, belongs to the top 20% of all vessels in the following five risk domains (see Table 1): collision, engine failure, powered and drift grounding, and fire and explosion. Inspection of this vessel can put priority on these domains. Vessel 10 is a tanker and has high detention risk and quite high VSS accident risk, but accident type risks are quite flat across the eight domains so it is not easy to set priorities for this vessel. Vessel 11 is a general cargo vessel and has top risk for pollution and quite evenly spread moderately high risk for all other accident types, which makes it hard to set inspection priorities apart from pollution. Vessel 12 is also a general cargo vessel with high risk in nearly all domains except pollution, with highest risks for collision, powered and drift grounding, and engine failure.

Figure 4: Risk indicators, inspections, and targeting strategies for a set of 12 vessels



	Percentile		Event			Quintile					Percentile							
	RDET	RVSS	VSS	INS	DET	RDET	RVSS	A	B	C	COL	DGR	ENG	FIR	HUL	LIF	PGR	POL
Scale	(0-100)		(1 = yes, 0 = no)			(1 = lowest to 5 = highest)					(0 = lowest to 100 = highest)							
V1	10	21	0	1	0	1	2	1	1	1	36	40	53	47	10	61	14	48
V2	30	16	0	0	0	2	1	1	2	1	16	26	45	4	4	34	14	39
V3	48	7	0	1	0	3	1	2	1	1	2	35	28	0	41	31	1	51
V4	17	42	0	1	0	1	3	1	2	1	62	58	60	30	9	45	16	45
V5	31	31	0	1	0	2	2	1	3	1	39	38	58	14	11	32	50	39
V6	11	77	0	1	1	1	4	3	2	2	66	59	86	40	41	59	89	81
V7	68	48	1	0	0	4	3	3	4	4	11	17	4	58	69	89	42	40
V8	44	80	1	1	0	3	5	4	4	4	80	53	62	35	25	37	83	30
V9	48	90	1	1	0	3	5	5	4	5	90	86	90	82	64	49	85	39
V10	92	64	1	1	0	5	4	5	5	5	40	30	41	67	67	59	47	73
V11	76	94	1	1	0	4	5	5	5	5	78	58	68	76	71	67	73	93
V12	87	91	1	0	0	5	5	5	5	5	93	95	95	67	59	55	92	34

Figure notes

- * The figure shows the scores of two risk indicators, the percentile rank of the probability of detention (RDET) and that of a VSS accident (RVSS), for a set of 12 vessels.
- * The table shows for each vessel which events (VSS accident, inspection, detention) took place in 2018Q1, the quintile risk scores for five ranking methods, and the percentile rank scores of 8 accident type probabilities.

5. Conclusion

Inspections play a key role in protecting maritime safety. This paper proposes a four-step protocol for quantitative support of inspection decisions. The first two steps consist of using rich information sets to identify risk on the level of individual vessels for various risk dimensions, with risk of detention and of accidents as two primary dimensions and that of eight accident types as secondary dimensions. The last two steps consist of ranking vessels according to the first two dimensions to select vessels for inspection and of determining risk domains deserving special attention during inspections. This protocol is applied with three databases on vessel-specifics, inspections and detentions, and accident types. The first database for 2010-2014 provides the risk formulas for step 1 of the protocol, the second one for 2017 gives up-to-date risk values for step 2, and the third one for the first quarter of 2018 evaluates out-of-sample predictive performance of five risk classification methods for steps 3 and 4. The outcomes show that current inspection strategies that are based mainly on detention risk can be considerably improved by also incorporating accident risk. Such extended methods produce significant signals for future risk of serious and very serious accidents, as the out-of-sample frequency of these accidents is twice as large for vessels with large (top 20%) risk compared to those with small (bottom 20%) risk. These extended methods also increase the hit rate of vessels with future VSS accidents, which for detention-based inspection methods are no better than random but which increase by 30-50% by incorporating accident risk for yearly inspection rates of 20-60%. The general recommendation is to include accident risk in making inspection decisions and, if also detention risk is included, to focus on vessels where both risks are relatively high (risk classification method B).

The methodology and empirical analysis presented in this paper can be extended in several ways if more data become available. In the application of the inspection protocol for the first quarter of 2018, the risk scores of each vessel stay fixed as determined in step 2 for December 2017. This can be improved by repeating step 2 more frequently, for example, monthly, weekly or even daily to incorporate the most recent vessel information, in particular on recent inspections, detentions, and accidents. Further, the presented analysis is based on percentile ranks relating to the full set of vessels. It may be of interest to apply some or all steps of the protocol for smaller subsets of vessels, for example, per ship type or per inspection region, to tune inspection priorities more closely to the vessels of prime interest. No information on the accident types of Table 1 was available for the application in the first quarter of 2018, and it is of interest to add this information to evaluate how well the proposed methods succeed in signalling specific accident type risk. Another extension of interest is to refine the accident types and risk domains to deliver more detailed targeting suggestions for inspections, which would require more refined information on the precise causes of each accident.

Acknowledgment

We thank IMO, AMSA, LLI, and IHS Markit for providing their data to us for 2010-2014 and for January 2017 to March 2018.

References

Cariou, P., M.Q. Mejia, and F.C. Wolff. 2007. "An Econometric Analysis of Deficiencies noted in Port State Control Inspections." *Maritime Policy & Management* 34 (3): 243-258.

Cariou, P., M. Q. Mejia, and F. C. Wolff. 2008. "On the Effectiveness of Port State Control Inspections." *Transportation Research Part E* 44 (3): 491-503.

Franses, P.H., and R. Paap. 2010. *Quantitative Models in Marketing Research*. Cambridge: Cambridge University Press.

Greene, H.W. 2008. *Econometric Analysis*, 6-th Edition. New Jersey: Pearson Prentice Hall.

Hassel, M., B.E. Asbjørnslett, and L.P. Hole. 2011. "Underreporting of Maritime Accidents to Vessel Accident Databases." *Accident Analysis and Prevention* 43: 2053-2063.

Heij, C., G. Bijwaard and S. Knapp. 2011. "Ship Inspection Strategies: Effects on Maritime Safety and Environmental Protection." *Transportation Research Part D* 16: 42-48.

Heij, C., and S. Knapp. 2018. "Predictive Power of Inspection Outcomes for Future Shipping Accidents – An Empirical Appraisal with Special Attention for Human Factor Aspects." *Maritime Policy & Management* 45 (5): 604-621.

IMO. 2000. "Reports on Marine Casualties and Incidents - Revised Harmonized Reporting Procedures." IMO Document MSC/Circ. 953, MEPC/Circ. 372. Dated December 14, 2000. London: IMO.

Ji, X., J. Brinkhuis, and S. Knapp. 2015. "A Method to Measure Enforcement Effort in Shipping with Incomplete Information." Marine Policy 60: 162-170

Knapp, S. 2006. *The Econometrics of Maritime Safety – Recommendations to Improve Safety at Sea*. Rotterdam: ERIM Ph.D. Series Research in Management.

Knapp, S. 2015. "Methodology and Implementation Aspects for Risk Formulas at Ship Level." Technical Report for AMSA, Contract 15AMSA116, November 24, 2015.

Knapp, S., and P.H. Franses. 2007. "A Global View on Port State Control - Econometric Analysis of the Differences across Port State Control Regimes." *Maritime Policy and Management* 34 (5): 453-483.

Li, K.X., J. Yin, and L. Fan. 2014. "Ship Safety Index." *Transportation Research Part A* 66: 75-87.

Luo, M., and S.H. Shin. 2016. "Half-century Research Developments in Maritime Accidents: Future Directions." Accident Analysis and Prevention, in press. doi: 10.1016/j.aap.2016.04.010.

Perepelkin, M., S. Knapp, G. Perepelkin, and M. De Pooter. 2010. "An Improved Methodology to measure Flag Performance for the Shipping Industry." Marine Policy 34(3): 395-405.

Satterthwaite, F. E. 1946. "An Approximate Distribution of Estimates of Variance Components." *Biometrics Bulletin* 2 (6): 110–114,

Wilcoxon, F. 1945. "Individual Comparisons by Ranking Methods." *Biometrics* 1 (6): 80-83.

Yang, Z.L., J. Wang, and K.X. Li. 2013. "Maritime Safety Analysis in Retrospect." *Maritime Policy & Management* 40 (3): 261-277.

Yang, Z., Z. Yang, and J. Yin. 2018. "Realising Advanced Risk-based Port State Control Inspection using Data-driven Bayesian Networks." *Transportation Research Part A* 110: 38-56.

Appendix

Table A1: Logit model summaries

Dependent variable		Number of Observations	Events	Variables	Dummies	McFadden R-squared	Past information Inspections	Detentions	VSS Accidents VS	S	Ship particulars Age	Size
DET	Detention	158,187	6,458	16	42	0.106	--	+	0	0	+	--
VSS	VSS accident	376,508	8,874	15	172	0.232	0	0	+	+	--	+
COL	Collision	376,508	2,109	12	97	0.165	0	0	0	+	--	+
DGR	Drift grounding	376,508	2,192	9	120	0.211	0	0	0	+	0	0
ENG	Main engine failure	376,508	1,773	8	74	0.198	0	0	0	+	0	0
FIR	Fire & explosion	376,508	965	11	16	0.159	0	0	+	+	0	+
HUL	Hull failure	376,508	600	10	17	0.217	0	0	+	+	0	+
LIF	Loss of life	376,508	376	7	26	0.164	0	0	0	0	+	+
PGR	Powered grounding	376,508	1,803	13	111	0.196	+	0	0	+	--	+
POL	Pollution	376,508	609	10	23	0.142	0	0	0	+	0	+

Table notes

- The column "Dependent variable" shows the explained binary variable of the logit model, and "Events" shows the number of observations of this variable with such an event (detention, VSS accident, or accident of given type).
- The logit models for accidents are estimated for data with one observation per vessel per year for 2010-2014 with six ship types: general cargo, dry bulk, container, tanker, passenger, and other ship types excluding fishing and tugs.
- The logit model for detentions is estimated on a sub-sample of vessels for 2010-2014 and can have multiple observations per vessel per year if the vessel was inspected multiple times in that year.
- The columns "Variables" and "Dummies" show the number of scale variables and the number of dummy variables in the final logit model after reduction by omitting insignificant variables (at 5% level).
- The four "Past information" columns show the effects of some past information variables in the logit models, where + denotes a positive effect, -- a negative effect, and 0 means the effect is not significant (at 5% level) and is hence omitted from the model; VS denotes very serious past accidents and S denotes serious past accidents.
- The two "Ship particulars" columns show the effect of age and size of the vessel, measured in logarithms with variables ln(1+AGE) and ln(GRT), where AGE is the age of the vessel in years and GRT is its gross tonnage.