Ship Inspection Strategies:
Effects on Maritime Safety and Environmental Protection

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Abstract

Global trade depends for a large part on maritime transport, and safe ships are needed not only to protect precious cargo but also to prevent environmental damage. Flag state and port state authorities spend much effort in ship safety inspections to ensure a minimum safety level and to prevent casualties. This paper investigates the safety gains of current inspection rules as well as options for further improvement. The analysis is based on a dataset of over four hundred thousand ship arrivals originating from some important trading nations between 2002 and 2007, complemented with data on port state control and industry inspections and casualties. The results indicate considerable potential safety gains of incorporating estimated future casualty risks more explicitly in port state control strategies to select ships for safety inspection.

Keywords

maritime safety; inspection strategy; risk factor; hazard rate; port state control

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1. Introduction

Economic development and trade depend crucially on an efficient shipping industry, which carries a high percentage of traded resources and manufactured goods. In 2008, international seaborne trade reached over eight billion tons of goods loaded and a total of 32.7 trillion ton-miles (i.e., tons of cargo multiplied by the average transport distance).[4] Crude oil and oil products account for about two-thirds of the total cargo carried, and other important cargoes are dry bulk and containers. Maritime transport is relatively safe, but the personal, economic, and environmental costs of accidents can be huge. Loss of passenger ships at sea may involve a high death toll, and tanker accidents may cause severe and extensive oil pollution.[5]

The shipping industry's main regulatory bodies are the International Maritime Organization (IMO) and the International Labor Organization (ILO), which are responsible for more than fifty international conventions regulating all aspects of ship operations and measures to protect the marine environment, including recent regulations for emissions from ships. Knapp and Franses (2009) analyze the effectiveness of these conventions and note a change of emphasis over time, as the focus of attention for technical safety measures in earlier times has been shifted nowadays towards environmental aspects and the human factor of ship operations. For example, the International Convention for the Prevention of Pollution from Ships (MARPOL) now covers a wide range of environmental areas, such as prevention of pollution from oil chemicals and other hazardous substances, ballast water treatment, the reduction of harmful paints, the reduction of emissions from ships, and ship recycling.

Because of the very high costs of accidents, flag state authorities and coastal states try to follow preventive strategies. Changes to the legislative framework in shipping have been characterized by reactive rather than preventive actions, as they tend to follow major incidents. Further, flag states differ in their enforcement of minimum safety standards, which has led to loopholes in the regulatory system. This lack of harmonized efforts to enforce safety standards has created substandard shipping, estimated as about five to ten percent of the world fleet.[6] Prompted by a series of tanker accidents in the 1970's, and to improve the enforcement of international conventions, the concept of port state control (PSC) emerged.

The effectiveness of PSC inspections has been studied in the literature for some time.[7] This paper adds a new dimension to this analysis, by expressing the effect of PSC inspections on safety in terms of reduced casualty risk. By combining casualty and inspection data, the risk reducing effect of PSC inspections is estimated by means of duration analysis. The paper further investigates the potential safety gains that can be obtained by incorporating the ship-specific risk of future accidents explicitly in designing ship inspection strategies. Fixing inspection rates at their historical levels, a risk-driven inspection strategy aiming to maximize survival gains is compared to currently operating strategies in terms of the achieved reductions in casualty risk. The innovative aspect of this paper lies in its unique combination of inspection and casualty data, which allows the evaluation of inspections in terms of survival gains. The empirical analysis covers general cargo vessels, dry bulk carriers, container vessels, tankers, and passenger ships; it excludes other ship types, like offshore supply vessels and fish factories.

The paper has the following structure. Section 2 provides information on current PSC inspections. Section 3 discusses the data and the method to estimate the survival gains of

[4] See UNCTAD (2009).
[5] See, for instance, Talley, Din, and Kite-Powell (2001, 2008).
[6] Peijs (2003): Ménage a trios (speech at Mare Forum, Amsterdam).
[7] See, for instance, Payoyo (1994), Knapp and Franses (2007a-c, 2008), and Carriou, Mejia, and Wolff (2008).

inspections. These gains are evaluated in Section 4, for both the currently employed strategies and an alternative, risk-based strategy. Section 5 concludes.

2. Ship inspections

Port state control (PSC) is the right of a port or coastal state to conduct safety inspections and to enforce the international measures on ships that visit its port. An inspected ship that is found to fail the minimum standards is detained, and the deficiencies have to be rectified before the ship is released. In some cases, a ship can even be banned from re-entering ports if it has been detained several times. Ship owners wish to avoid detention, as it bears high economic costs and it may increase future inspections rates. PSC inspections are focused not only on safety measures, but progressively also on environmental protection.

Today, there are ten PSC regimes operative that cover all coastal states and that enforce international standards. The regimes are grouped by regions and countries which have agreed to conduct inspections in a harmonized way, based on so-called Memoranda of Understanding. All regimes use the same kind of information to decide, with varying levels of sophistication, whether a ship should be inspected or not. Each regime uses only its own past inspection data to target ships for inspections, thereby ignoring not only the inspection outcomes of other regimes but also industry vetting inspections, which are primarily performed on dry bulk carriers and tankers.

Apart from previous inspection results in the same region, other risk factors include ship particular data like the type, age, and size of the vessel, its flag state, its classification society, and sometimes its Document of Compliance company[8]. In all regimes, high risk vessels are tankers and passenger vessels, due to the potentially high costs in case of an incident. We refer to Knapp and Franses (2007b) for an in-depth comparison of PSC inspection regimes and target factors.[9]

As will be discussed in the next section, our dataset is obtained by combining data from a subset of the ten PSC regimes, corresponding to some major trading nations. The regimes in this subset provide a good reflection of the selection strategies that are used throughout the industry. Further, as will also be described in the next section, we consider an alternative selection strategy for inspections that amounts to a refined version of the current targeting strategies. This alternative strategy is based on survival gains, obtained from the duration analysis of Bijwaard and Knapp (2009) to estimate the risk of total loss accidents in terms of ship particulars, economic indices, and event history including past inspections, industry inspections, accidents, and changes of flag state and classification society. This means that a wider information set is employed as compared to current strategies, which may help to improve the estimated risk profiles of ships as a tool in making inspection decisions.

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[8] The DoC company is the designated company for the safety management of the vessel. It is still difficult to obtain adequate data on DoC companies, and there are many companies in operation (about five thousand).

[9] See Talley, Din, and Kite-Powell (2005) for a more detailed analysis of the inspection program of one of the regimes.

3. Data and methods

3.1. Arrival and inspection data

The arrival dataset consists of daily arrival information of 14,115 individual ships over the period 2002 till 2007, and it contains over 400,000 arrivals in total. These data are obtained from a number of port states that cover a considerable portion of world seaborne trade, amounting (in 2008) to 17% of goods loaded, 15% of goods unloaded, and 12.5% of the world merchant trade value.[10] The dataset provides a representative spread of all trade segments and of all ship types.

For each ship arrival, the information consists of the arrival date of the vessel in the respective port state, together with some basic ship particulars that apply at the time of arrival (ship type, age, gross tonnage, flag state, classification society, Document of Compliance company, country of location, changes of ship particulars over time), and the decision whether or not the ship is inspected. This information is complemented by port state control inspection data from various other PSC regimes as well as industry inspections,[11] see Bijwaard and Knapp (2009) for a more detailed description of these additional data. The combined inspection data show which arrivals result in inspections and detentions, together with the number of deficiencies found at each inspection.

Table 1 shows summary statistics of the data, differentiated for the five considered ship types, that is, general cargo, dry bulk, container, tanker, and passenger. General cargo, tanker, and container vessels have the largest number of ships, arrivals, and inspections. The total number of inspections is 61,010, and the overall inspection rate (that is, the total number of inspections divided by the total number of arrivals) is about 15%, with relatively the highest rates occurring for dry bulk carriers and general cargo vessels.

For the purpose of our analysis later in this paper, it is relevant to distinguish between arrivals that occur within the same PSC region in the twelve different half-year periods from 2002 to 2007. The reason for this distinction is the following. A PSC inspection reduces the risk of a casualty later on, but inspections of the same ship that follow each other too fast will not all lead to the same survival gain. Shipping experts differ in their opinion on how long the effect of PSC inspections last, but it is generally agreed that all effect is lost after a period of one year. Industry vetting inspections are performed more frequently on tankers and dry bulk carriers, and depending on the PSC regime, high-risk vessels can become eligible for inspections after a period of six months (in the case of passenger ships three months).[12] We will assume that the effect lasts sufficiently strongly for half a year, after which a new inspection is assumed to produce a survival gain that does not depend on previous inspections.

For every given PSC region and every half-year, the set of arrivals of a ship is compressed into a single arrival that we call the eligible arrival of this ship in this region for this half-year, in the sense that this arrival is the single candidate for inspection of the ship. By construction, subsequent inspections of eligible arrivals of the same ship in the same PSC region always

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[10] The data providing regimes wish to remain anonymous for the purposes of this paper. Readers interested in more details can contact the authors; provision of additional details depends on approval of the data providers.
[11] These industry inspections include vetting inspections of RightShip for dry bulk carriers, of the Chemical Distribution Institute (CDI) for chemical tankers, and of the Oil Companies International Marine Forum (OCIMF) for oil and chemical tankers.
[12] See Knapp and Franses (2007b) for further details.

occur in different half-years.[13] It may, however, be that ships that enter various regions in the same half-year are inspected more than once. We will allow this to happen, in order to respect the current practice that PSC regimes disregard inspections of the other regimes. Evidently, the effectiveness of PSC inspections could be enhanced by following an integrated approach covering all regimes, but the coordination of inspections between all the regimes falls outside the scope of this paper.

Table 1: Arrivals and inspections (per regime and per half year)

	Gen.Cargo	Dry Bulk	Container	Tanker	Passenger	Total
Total number of ships	3267	1447	2136	3604	197	14,115
Inspections per ship						
None (number of ships)	15,723	10,401	6380	10,171	251	42,926
idem (% of ships)	46.2	48.8	42.4	49.2	38.9	46.8
One (number)	15,300	10,686	5916	8305	232	40,439
idem (% of ships)	44.9	50.2	39.4	40.2	36.0	44.1
Two or more (number)	3046	206	2735	2199	162	8348
idem (% of ships)	8.9	1.0	18.2	10.6	25.1	9.1
Arrivals						
All (number)	122,808	52,496	117,012	107,658	8716	408,690
Eligible (number)	34,069	21,293	15,031	20,675	645	91,713
idem (% of all arrivals)	27.7	40.6	12.8	19.2	7.4	22.4
Inspections per arrival type						
Inspections of all arrivals (number)	22,330	11,141	12,889	13,791	859	61,010
idem (% of all arrivals)	18.2	21.2	11.0	12.8	9.9	14.9
idem (% of eligible arrivals)	65.5	52.3	85.7	66.7	133.2	66.5
Inspections of eligible arrivals (number)	18,266	10,822	8586	10,434	392	48,500
idem (% of eligible arrivals)	53.6	50.8	57.1	50.5	60.8	52.9
idem (% of all inspections)	81.8	97.1	66.6	75.7	45.6	79.5

In the far majority of cases, ships are inspected at most once per half year. Table 1 shows that, on average, only 9% of the ships encounter more than one inspection per half year, whereas 44% of the ships are inspected once and 47% are not inspected. The compression of multiple arrivals within a half-year leads to a total number of 91,713 eligible arrivals. When restricted to eligible arrivals, the total number of inspections is 48,500, and this amounts to 79.5% of all inspections in the full database. This means that we exclude 20.5% of the inspections by omitting multiple inspections. As such multiple inspections occur most frequently for passenger and container ships, the inspection omission rates for these two ship types are higher (respectively 54.4% and 34.4%). For eligible arrivals, the inspection rate per half-year ranges between 50% and 60% for all five ship types.

[13] The precise selection of the eligible arrival of a given ship in a given region and half-year is made as follows. If the ship was actually inspected exactly once during the half-year, then the arrival where this inspection occurred is the eligible arrival. If the ship was actually not inspected in the half-year, the arrival with the largest survival gain is the eligible arrival. Finally, if the ship was actually inspected more than once during the half-year, the arrival with inspection with the largest survival gain is the eligible arrival. The calculation of the survival gain of an inspection is explained in Section 3.3. In case of multiple arrivals of the same ship, the survival gains at different arrivals are commonly very close together, in which case the eligible arrival can be considered as a randomly chosen arrival of the ship in the considered half-year.

The restriction to eligible arrivals is essential for the evaluation of the survival gain strategy analyzed later in this paper. Without this restriction, the same ship could in principle be selected many times within the same half-year, and it would be unrealistic to assume that the same survival gain is realized at all these inspections. As we will see in Section 4, the average survival gain of the actual inspections on all (eligible and non-eligible) arrivals is about the same as that on the subset of eligible arrivals, so that eligible arrivals are representative in this respect. This result holds true because multiple inspections are relatively rare.

3.2. Casualty data and risk factors

Casualty data were obtained from Lloyd's Register Fairplay. The severity of casualties has been classified according to IMO definitions, ranging from 'less serious' to 'very serious' and 'total loss'. The risk analysis is restricted to total loss accidents, because of their large impact in terms of economic and environmental costs. The main determinants of total loss risk identified by Bijwaard and Knapp (2009) are past incidents, past PSC and industry inspection outcomes, ship economic cycles,[14] and ship particulars: age, size, flag, classification society, country of location of the DoC company, and changes of ship particulars over time.

The effect of the risk factors on total loss casualty risk is modelled by means of a hazard rate. Let $S(t)$ be the survival function, that is, the probability that the ship will survive for at least t periods from its creation. The hazard rate, denoted by $\lambda(t)$, is defined by $\lambda(t) = -d\ln(S(t))/dt$.[15] A large hazard rate corresponds to a large risk that the ship will not survive for long. Our hazard rate model has the form

$$\lambda(t) = \lambda_b(t) \times \exp(\beta_1 X_1(t)) \times \ldots \times \exp(\beta_k X_k(t)),$$

where the baseline hazard $\lambda_b(t)$ models the age effect[16] and where $(X_1, \ldots, X_k)$ denote the other risk factors. This is called a proportional hazard model, as each risk factor has a proportional effect on the hazard rate. Of particular interest for our analysis is the effect of a PSC inspection (measured by, say, X_1, with $X_1 = 1$ in case of an inspection and $X_1 = 0$ if no inspection is performed). Let λ_1 (λ_0) be the hazard rate after (without) an inspection, then $\lambda_1 = \exp(\beta_1)\times\lambda_0$, and the risk reduction factor of an inspection is $(\lambda_0 - \lambda_1)/\lambda_0 = 1 - \exp(\beta_1)$.

Separate hazard models for total loss accidents are estimated for each ship type and for each year from 2003 to 2007, using an expanding estimation window that stretches up to the year of arrival. Table 2 summarizes the estimation results of main importance for our analysis.[17] The risk reduction factors are considerable and differ per ship type. The largest reductions (corresponding to the largest risk reduction factors) are realized for passenger vessels and dry bulk carriers, and the reductions for containers are large in initial years but become smaller later on. The table shows also the effects of other risk factors for the model of the final year 2007. Industry vetting inspections reduce the casualty risk. Past casualties, detentions, and

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[14] Monthly average earnings data per ship type (except passenger vessels) are obtained from the Shipping Intelligence Network from Clarksons.

[15] Here, 'ln' denotes the natural logarithm, and the survival function is obtained by $S(t) = \exp(-\int_0^t \lambda(s)ds)$. We refer to Van den Berg (2001) for further explanation of hazard rates and duration models.

[16] We use a piecewise constant specification with six age groups, and $\lambda_b(t) = \exp(\alpha_j)$ in age group j ($j = 1, \ldots, 6$).

[17] The hazard models contain more factors than are shown in Table 2, including indicators for accidents in the previous half-year, flag, classification society, DoC company, and earnings. For passenger ships, the model could not be estimated with sufficient accuracy for 2003 and 2004, because of data limitations. Full details of the estimated hazard models per ship type and per year are presented in Knapp, Bijwaard and Heij (2010).

deficiencies increase the risk, although not all of these effects are significant for all ship types. Further, on average, larger ships carry higher risk, and the same applies for new ships (less than five years old) and for relatively old ships (more than twenty years old).

Table 2: Summary of hazard models

	Gen. Cargo	Dry Bulk	Container	Tanker	Passenger
Risk reduction factor of PSC					
2003	0.16 (a)	0.65	0.67	0.32	n/a
2004	0.28	0.63	0.50	0.30	n/a
2005	0.38	0.64	0.53	0.34	0.71
2006	0.34	0.53	0.38	0.24	0.67
2007	0.31	0.51	0.33	0.08 (a)	0.73
Some other risk factors (results for 2007)					
Vetting inspection (b)	n/a	-	n/a	-	n/a
Serious casualty (b)			+	+	
Very serious casualty (b)	+			+	
PSC detention (b)		+			+
PSC deficiencies (c)	+				
Gross tonnage (log)	+	+	+	+	
Age 0-4 years	BM	BM	BM	BM	BM
Age 5-10 years	-	-		-	-
Age 11-15 years	-	-			
Age 16-20 years					
Age 21-25 years	+	+	+	+	
Age above 25 years	+	+	+	+	+

Notes: + (-) denotes a risk increasing (decreasing) effect that is significant at 5%; BM denotes the benchmark age class; "n/a" denotes that the variable does not apply for the ship type; (a) denotes an effect that is not significant at 5%;(b) is for indicator variables that take the value 1 (0) if the mentioned event did (not) occur within one year before arrival; (c) is the number of deficiencies found at PSC inspections in a period of one year before arrival.

3.3. Calculation of survival gains and the survival gain strategy

The hazard model for total loss accidents forms our basis for the evaluation of the benefits of inspections in terms of reduced casualty risk. As discussed in Section 3.1, because the beneficial effects of an inspection fade out over time, we take the effect over a period of half a year into account. Now, consider a ship that at the current time (t) is in port. Using the hazard model that applies for the current year and the ship's data on all the risk factors of the model, we calculate the hazard rate λ_0 (λ_1) that applies without (with) an inspection, where $\lambda_1 = \exp(\beta_1)\times\lambda_0$. We denote the associated conditional survival probability of this ship for the next half-year by S_0 (S_1), where

$$S_0 = \text{Prob(survival till } t + 1/2) / \text{Prob(survival till } t)$$
$$= \exp\left(-\int_0^{t+1/2} \lambda_0(s)\,ds\right) / \exp\left(-\int_0^{t} \lambda_0(s)\,ds\right) = \exp\left(-\int_t^{t+1/2} \lambda_0(s)\,ds\right).$$

If we use the notation $\alpha = \exp(\beta_1)$, then $\lambda_1 = \alpha\lambda_0$; as $\beta_1 < 0$, it follows that $0 < \alpha < 1$, and

$$S_1 = \exp\left(-\int_t^{t+1/2} \lambda_1(s)\,ds\right) = \exp\left(-\alpha \int_t^{t+1/2} \lambda_0(s)\,ds\right) = S_0^{\alpha}.$$

Because shipping is not a very risky industry, survival probabilities are large. Knapp, Bijwaard and Heij (2010) find base risks of total loss ($1 - S_0$) that range roughly between 1-4% per year, so about 0.5-2% per half-year, so that S_0 will mostly be larger than 98%. Because S_0 is close to

1, the first order Taylor expansion $S_0^{\alpha} = (1 + (S_0 - 1))^{\alpha} \approx 1 + \alpha(S_0 - 1)$ provides an accurate approximation of S_1. The survival gain for the next half-year, caused by inspecting the ship now, is

$$S_1 - S_0 = S_0^{\alpha} - S_0 \approx (1 - \alpha)(1 - S_0) = (1 - \exp(\beta_1))(1 - S_0).$$

The relative survival gain, as compared to the probability $(1 - S_0)$ of a total loss accident in the next half-year if the ship is not inspected, is therefore $(S_1 - S_0) / (1 - S_0) \approx 1 - \exp(\beta_1)$. This means that the risk reduction factors in Table 2 can also be interpreted, to a high degree of accuracy, as the factors by which the probability of a total loss accident in the next half-year is reduced by means of an inspection.

The survival gains form the basis of our alternative inspection strategy, which we call the survival gain strategy (abbreviated henceforth by SGS). For every given PSC regime, ship type, and half-year, we determine the actual number of inspections, restricted to the set of eligible arrivals defined in Section 3.1. SGS selects an equal number of ships for inspection, but it selects the ships with the largest survival gains for the given PSC regime, ship type, and half-year. As we found above that $S_1 - S_0 \approx (1 - \alpha)(1 - S_0)$, the survival gain is almost proportional to the half-yearly casualty risk $(1 - S_0)$, so that SGS tends to select the highest risk vessels for inspection.

4. Survival gains of inspection strategies

The effect of PSC inspections can now be evaluated in terms of the resulting reduction of total loss casualty risk. To prevent over-estimation of the realized survival gains obtained by multiple inspections of the same ship within a brief period of time, the attention is restricted to eligible arrivals. This guarantees that successive inspections of the same ship in the same PSC regime never occur within the same half-year. For each regime, ship type, and half-year, the inspection rate is fixed at the historical rate that applied for the set of eligible arrivals for this regime, ship type, and half-year. For each ship type and each year, the average survival gain per inspection is obtained by dividing the sum total of survival gains of all inspections by the number of inspections. This average provides an indication of the survival gain that has actually been achieved by current inspection strategies. As an alternative, the average survival gain is also computed for SGS. SGS applies the same inspection rates as the actual strategies per regime, ship type, and half-year, but it selects those of the eligible arrivals for inspection that have the largest survival gains.

Table 3 summarizes the results of the actual inspection strategies and of SGS. The main conclusion is that there exist good opportunities for improving the effect of inspections in terms of gained safety. The average survival gain of SGS is a factor of about 1.7 higher than that of current strategies, except for passenger vessels where this factor is about 1.3. In absolute terms, the improvement of SGS over current strategies consists, per inspection, of a further reduction of total loss risk of 0.18% for general cargo, of about 0.10% for dry bulk, container, and tanker, and of 0.07% for passenger vessels. It is also of interest to compare the survival gains $(S_1 - S_0)$ in Table 3 with the un-inspected casualty risk $(1 - S_0)$, which is, on average, 1.88% for general cargo, 1.47% for dry bulk, 0.76% for container, 1.23% for tanker, and 0.48% for passenger vessels.[18] For example, inspections of general cargo vessels reduce the total loss risk within a half-year on average from 1.88% to 1.63%, whereas SGS inspections achieve a further reduction to 1.45%.

[18] These un-inspected casualty risks are obtained from Knapp, Bijwaard and Heij (2010), by transforming yearly risks for 2003-2007 into average half-yearly risks.

Table 3: Descriptive statistics of inspected ships (subset of half-yearly eligible arrivals)

	General Cargo		Dry Bulk		Container		Tanker		Passenger	
	Actual	SGS	Actual	SGS	Actual	SGS	Actual	SGS	Actual	SGS
Results of inspections										
Number of inspections	18,266	18,266	10,822	10,822	8586	8586	10,434	10,434	392	392
Overlap of actual and SGS inspections (%)	56		54		57		51		67	
Survival gain (half year; average %)	0.25	0.43	0.14	0.24	0.14	0.24	0.15	0.26	0.22	0.29
Detained (%) (a)	1.42	1.79	4.19	4.91	1.08	1.38	0.93	1.10	0.51	0.76
Total deficiencies (average) (a)	0.71	0.81	2.10	2.39	0.50	0.55	0.56	0.64	0.56	0.61
Zero deficiencies (%) (a)	78	76	54	51	83	83	81	79	81	80
Future risk of inspected ships										
Total loss (within one year, %)	0.08	0.13	0.04	0.05	0.01	0.00	0.04	0.07	0.00	0.00
Very serious accident (within one year, %)	0.04	0.03	0.05	0.05	0.05	0.05	0.12	0.12	0.00	0.00
Total loss (total number) (b)	32	32	7	7	2	2	7	7	0	0
inspected (total number)	15	23	4	5	1	0	4	7	n/a	n/a
Very serious casualty (total number) (b)	13	13	12	12	6	6	24	24	0	0
Inspected (total number)	7	5	5	5	4	4	13	13	n/a	n/a
Characteristics of inspected ships										
Size (gross tonnage / 1000; average)	25.47	26.16	43.43	45.55	34.57	34.96	40.34	51.10	48.46	45.31
Age group (average)	3.07	3.72	2.72	2.90	2.49	2.76	2.49	2.82	2.71	3.15
Age (average)	13.06	16.58	11.29	12.23	9.96	11.39	9.89	11.69	12.49	15.68
Flag black (%)	45.78	45.62	49.71	51.08	31.35	28.97	23.39	21.31	10.71	9.44
Flag grey (%)	9.15	9.78	12.26	12.77	4.82	5.03	7.68	6.03	5.36	5.87
Flag white (%)	43.87	42.28	37.28	34.01	63.50	65.54	67.60	71.44	82.14	82.40
Flag undefined (%)	1.20	2.33	0.75	2.13	0.33	0.47	1.33	1.23	1.79	2.30
Class IACS (%)	89.74	88.80	95.37	95.08	88.11	85.46	85.05	84.31	85.71	85.97
Class non IACS (%)	9.96	10.63	4.54	4.79	11.68	14.15	14.50	14.91	13.52	12.76
Class unknown (%)	0.31	0.57	0.09	0.13	0.21	0.38	0.45	0.78	0.77	1.28

Notes: (a): For SGS, this is computed for the subset of SGS inspections that are also an actual inspection, because the relevant information is missing for ships that were not actually inspected; (b): total number over all considered years and for the subset of half-yearly eligible arrivals.

Even though the risks and risk reductions may seem to be small in absolute terms, the achieved benefits of inspections in terms of saved potential accident costs are huge. Total loss accidents do not only involve the loss of ship and cargo, but they may also cause additional costs in terms of loss of life, environmental damage, and damage to third parties. It is not easy to quantify the monetary value involved in total loss accidents, but using results in Knapp, Bijwaard and Heij (2010), we obtain the following median values (in 2008 USD): 6.3 million for general cargo, 3.8 million for dry bulk, 4.4 million for container, 9.7 million for tanker, and 16.4 million for passenger ships.[19] For example, the extra survival gain of 0.18% of SGS as compared to current inspections of general cargo vessels amounts to an estimated extra saved value of about 11 thousand USD per inspection.

Whereas Table 3 shows average survival gains, these gains are split up over the years in Figure 1. Apart from the actual strategy for eligible arrivals (denoted by ‘Elig’ in Figure 1) and SGS, both shown in Table 3, the figure contains also the survival gains for the actual strategy for all arrivals in the database, including multiple inspections of the same ship within the same regime and half-year (denoted by ‘All’ in Figure 1). The figure indicates that the restriction to eligible arrivals is not a severe one for the current strategies, although in most cases, the overall average gains are somewhat larger than those of the subset of eligible arrivals are. This means that the multiple inspections of current strategies may be well motivated, as they often involve ships with relatively high risks. SGS outperforms both versions of the current strategies by a considerable margin. The gains show time patterns that differ between the ship types. The trend is steadily upwards for general cargo and passenger vessels, it is quite fluctuating for container ships, whereas an initial rise is followed by a decline for dry bulk carriers and tankers.

To conclude our comparison of inspection strategies, we return to the discussion of further results in Table 3. For each ship type, SGS inspections coincide with actual inspections in slightly more than half of all cases. As compared to current inspection strategies, SGS inspections are somewhat more successful in targeting ships that will be detained. Further, the average number of deficiencies is somewhat larger and the percentage of inspections finding no deficiencies is slightly smaller. In most cases, the future total loss accident rate of ships that would have been selected by SGS is higher than that of the actually inspected ships. All these results show that the information present in the hazard rate factors does indeed help to select ships that have a high risk (in terms of detention, deficiencies, and future casualties). Finally, the bottom part of Table 3 provides an indication of the average characteristics of inspected ships. As compared to current inspection strategies, SGS tends to select ships that are somewhat larger in size and somewhat older. The distribution over flags and classification societies is roughly similar to current practice.

5. Conclusions

Maritime safety can be improved by well-targeted ship inspections. The current practice of port state control inspections is that the various regimes share the same objectives and employ the same type of information, with varying levels of sophistication. However, information is not yet shared between regimes, and the regimes disregard each other’s inspections as well as inspections performed by the industry, such as vetting inspections.

[19] These values (say, V) are obtained from Knapp, Bijwaard and Heij (2010), using the (conservative) lower bound median values for expected cost savings in their Table 6 (say L) and the average of the yearly gains in their Table 5 (say G). As L = V×G, it follows that V = L/G. For example, for general cargo vessels, L = 21.0 thousand USD and G = 0.0167/5 = 0.00334, so that V = L/G is about 6.3 million USD.

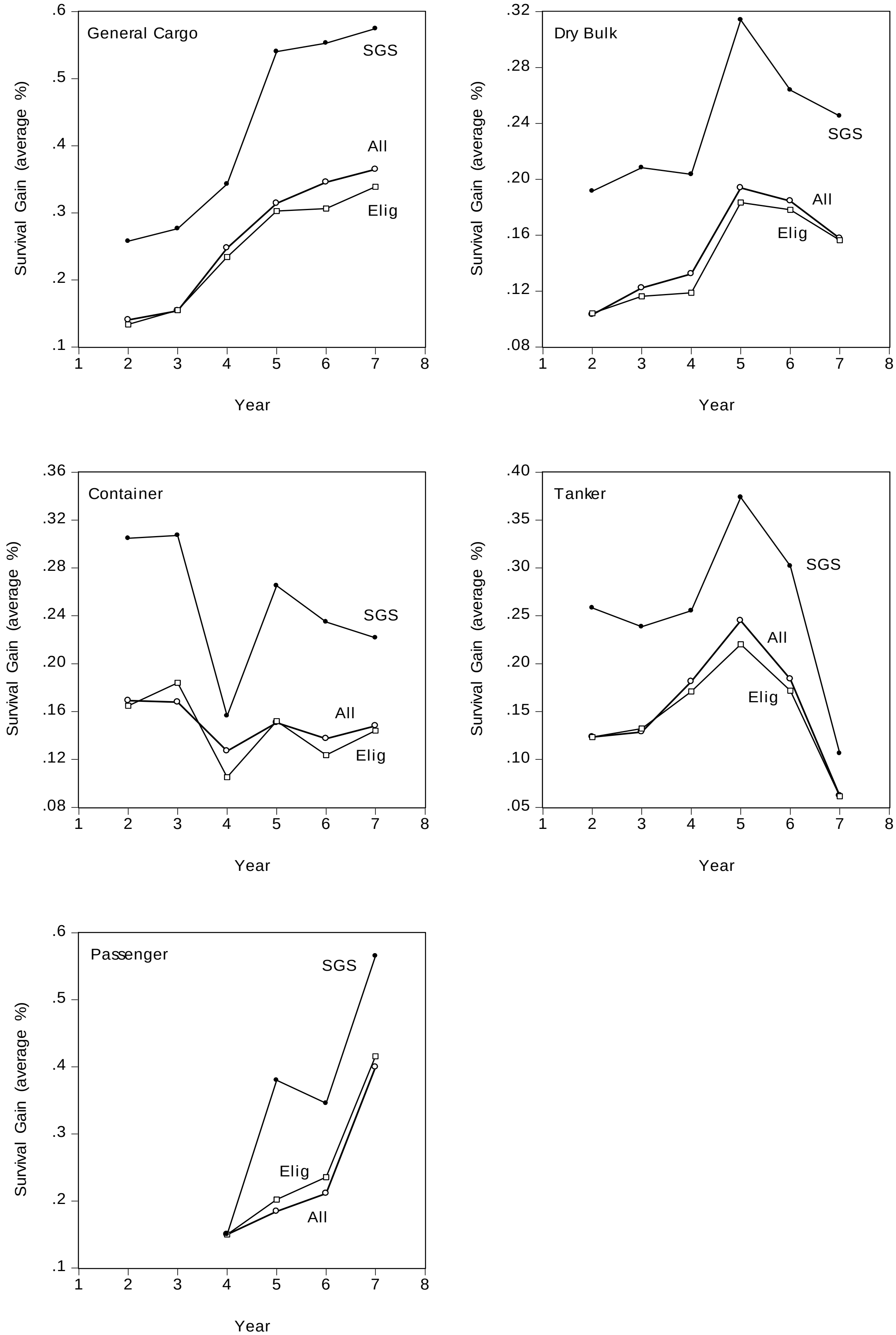

Figure 1: Average survival gain (in %) for the six months following an inspection, for "All" (all actual inspections for all arrivals), "Elig" (all actual inspections for eligible arrivals), and "SGS" (for eligible arrivals). The years run from 2002 to 2007 (for passenger ships from 2004 to 2007).

Based on a rich combined dataset, consisting of arrivals and inspections from several port state control regimes, industry inspections, and casualties, this paper investigates the effectiveness of currently employed inspection strategies in terms of reducing casualty risks. The central tool to transform relevant ship particular information into an inspection decision is the hazard rate, which expresses casualty risk in terms of a set of risk factors. The hazard rate model is estimated using data from all regimes, and it is used to compute the survival gains associated with inspections. These gains form the basis for an inspection strategy that is explicitly risk-driven, by selecting the ships for inspection that have the largest survival gain. This survival gain strategy (SGS) is found to improve considerably upon current practice, with survivals gains that are a factor of about 1.7 (1.3 for passenger ships) larger than the gains that are currently achieved. In absolute terms, and as compared to current strategies, the risk of total loss accidents within half a year after inspection is reduced by 0.18% for general cargo, 0.10% for dry bulk, container, and tanker, and 0.07% for passenger vessels. The corresponding potential savings in monetary terms are considerable, because total loss accidents involve very high costs.

The reported SGS results are only indicative, as the historical inspection and casualty data are obtained under the prevailing PSC regimes and the SGS rule has not been operative in practice. Nonetheless, the estimated gains are considerable and indicate that the incorporation of future casualty risk in making inspection decisions deserves the attention of port authorities, who share responsibility for selecting ships for inspections and for enforcing minimum international safety standards. The effectiveness of the selection of ships for inspection can be enhanced by integrating other inspection information, that is, the inspections made in other regimes as well as industry vetting inspections, in addition to casualty data. In the future, IMO's planned port state control module of the Global Integrated Ship Information System (GISIS) should preferably contain port state control inspections from all regimes, which can be linked to the existing GISIS module on casualties to provide an integrated database to target ships for inspections.

For practical implementation purposes, SGS can be complemented with easy-to-use selection rules. For example, one of the PSC regimes currently classifies ships into a number of risk groups and applies target inspection rates that increase per risk group. In a similar way, the expected gained lifetimes due to an inspection can be classified into a limited number of groups, with higher inspection rates for groups with larger expected gains. Although this leads to some loss in gained survival rate, the advantage is that an element of non-predictability of inspections (for low-hazard ships) acts as an incentive for ship owners to maintain high safety levels. Another possible refinement consists of incorporating cost considerations. SGS evaluates all gains in survival probability on an equal footing. However, the costs involved in losing a ship depend on the value of the ship and its lost cargo and on the associated environmental costs. Such cost information can be combined with casualty risks to refine inspection rules and to modify inspection rates.

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