Statistics for marine accidents in adverse weather conditions

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Statistics for marine accidents in adverse weather conditions

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ABSTRACT: This paper will be dealing with the statistical analysis of marine accidents in various heavy weather situations in relation to the sufficiency of the onboard installed power. The first step towards the analysis is the compilation of a database containing accidents in heavy weather conditions for different types of ships. The geographical scope is worldwide and the period of time investigated spans the years 1990 up to 2013. The relevance of each accident in the database was established after thorough examination of accident reports and information in various available sources. A timeline analysis of the number of accidents showed a statistically significant increasing trend in the examined time period for the accidents of interest. Furthermore, the statistical analysis produced a number of ships of interest for each ship type in order to better define the characteristics of the ships in greater risk. Finally, accident rates in relation to the Fleet at Risk were calculated and found to be in the order of magnitude of 10^{-4} to 10^{-3}.

1 INTRODUCTION

This paper deals with the compilation of a dedicated database and a statistical analysis of marine accidents in various heavy weather situations in relation to the sufficiency of the onboard installed power. The paper is divided in the following sections: Database, Statistical Analysis, Ships of Interest and Conclusions.

The Database section describes the compilation of the dedicated database containing cases under heavy weather conditions with the purpose of studying the adequacy of onboard installed power. The next section lays out the statistical analysis conducted on the collected sample of accidents, which includes a descriptive analysis, statistical percentiles as well as a timeline analysis of the number of accidents. Subsequently a description of the methodology used to extract the ships of interest per ship type and size class is given, as well as the relevant results and comparisons to the in service fleet data. In addition, accident rates will be presented and compared to similar results from Formal Safety Assessments. The paper ends with the most important concluding points and observations derived by the analysis.

2 DATABASE

The initial stage of the compilation of the accident database involved implementing inclusion/filtering criteria to the original/raw data collected from various sources. Consequently, a three stage screening process was used to filter out irrelevant incidents.

2.1 *Sources*

Two main sources were used for the collection of the necessary information, which are the following: the IHS Sea-Web marine casualty database and the database of the International Maritime Organization (IMO) Global Integrated Shipping Information System (GISIS).

The information collected from these sources was cross-referenced, whenever possible, from accident reports acquired from maritime safety Authorities and marine accident investigation boards. These sources indicatively include the Marine Accident Investigation Branch (MAIB) from the United Kingdom and the Federal Bureau of Maritime Casualty Investigation from Germany.

Another important source of information was Lloyd’s Casualty Week publication.

2.2 *Inclusion Criteria*

The initial criteria for including an accident in the database were based on type of ship, gross tonnage, date of build, date of accident occurrence and weather conditions (basic criterion). Specifically, the inclusion criteria were the following:

- The included ship types are: Container ships, Cruise ships, Ro-Ro ferries, Ro-Ro Cargo ships, Pure Car Carriers, Gas Carriers, Tankers, Bulk Carriers and General Cargo ships,
- Gross Tonnage greater than or equal to 400 GT,
- Date of build after and including Jan. 1980,
- Accident period from Jan. 1990 to Dec. 2013,
- Heavy weather conditions, as defined in the IHS Sea-Web database, for example winds exceeding 30 knots and waves higher than 2 meters etc. Poor visibility situations were excluded.

The number of accidents collected during the first stage of the data collection reaches 1666 cases.

2.3 *Screening Process*

After the initial data collection, the accidents were further filtered out through three stages. In the first stage, accidents were excluded based on the nature of incident. In the second stage, not serious accidents and those involving high speed craft were excluded. The third stage involved searching for accident details and causation factors from accident reports and web sources to determine the relevance of each incident to the scope of study.

2.3.1 *Stage I*

The types of accidents excluded from the database in this stage are the following:

- Hull and machinery damages, which include main engine or generator engine failures, blackouts, hull cracks and failure of bow thruster, propeller, rudder and stabilizer,
- Accidents that are caused by fire/explosion in machinery, cargo spaces or in the accommodation,
- Accidents that occurred under extreme weather conditions such as hurricanes/typhoons/cyclones, tsunami, freak seas or tropical storm,
- Any incident where the ship sank due to either ingress of water or cargo shift,
- Accidents that happened while the ship was in shipyard or dry dock.

2.3.2 *Stage II*

In this stage two additional exclusion criteria were used, namely severity and whether the ship involved in the accident is a High Speed Craft.

High Speed Crafts were determined as those ships that have a Froude Number greater than 0.5. This criterion is applicable to Cruise and Ro-Ro Ferries vessels.

A serious accident, as defined in (LRFP 1995), is one that results in one of the following:

- Structural damage, rendering the ship unseaworthy, such as penetration of hull underwater, immobilization of main engines, extensive damage, etc.
- Breakdown.
- Actual Total Loss.
- Any other undefined situation resulting in damage or financial loss which is considered to be serious (incl. fatalities, missing persons and environmental damage).

Every accident that does not fall in the serious category is classified as “Not Serious” and was excluded. In most cases not serious accidents suffer from under reporting, which makes it very difficult to establish relevance to the scope of the analysis. Furthermore, most not serious accidents are reports of minor damages to the hull or hull structures.

2.3.3 *Stage III*

Further analysis of the accident descriptions and the accident reports, where available, marked the exclusion of incidents based on the following criteria:

- Cases where the ship was either anchored or moored and either started to drag its anchor and drift or broke its moorings,
- Contacts with objects such as floating logs or containers that could not be seen and therefore could not have been avoided by the crew,
- Incidents that involved damage to the superstructures caused by weather conditions,
- Collisions that were caused by non-compliance of the crew to the international Collision Regulations (COLREGs) and could therefore have been avoided.

In the accident elimination process we took into account human factor as causation as well as accidents involving ships that were under tug assistance, based on the available information.

Table 1. Number of accidents per ship type at the end of the screening process.

Ship Type	Initial #	Excluded #	Retained #	[%]
Containers	136	127	9	7
Cruise	45	34	11	24
Ro-Ro Ferries	178	130	48	27
Ro-Ro Cargo	50	40	10	20
Pure Car Carriers	39	31	8	21
Gas Carriers	37	30	7	19
Tankers	183	160	23	13
Bulk Carriers	355	306	49	14
General Cargo	643	569	74	12
TOTAL	1666	1427	239	14

2.3.4 *Summary*

Table 1 summarily shows the results of the screening process by stage and ship type, as well as the number of the retained accidents.

Figure 1 shows the percentage of retained accidents per ship type after the screening process, in relation to the initial number of collected data.

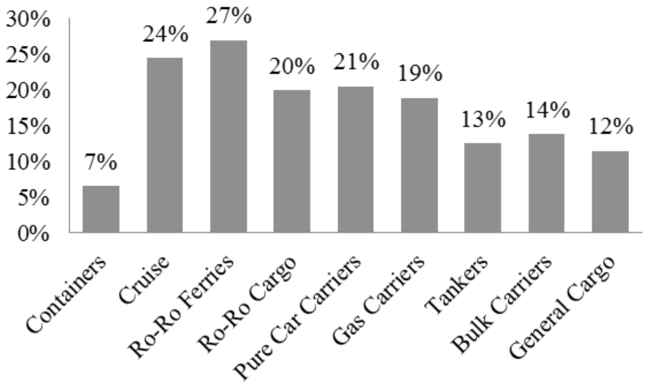

Figure 1. Percentages of retained accidents per ship type after the screening process.

3 STATISTICAL ANALYSIS

The analysis consists of descriptive statistics of the sample, percentiles for essential characteristics of each ship type, and finally a timeline analysis.

The statistical analysis is accompanied by direct comparisons to Fleet at Risk data, which have been acquired by the Clarkson's Shipping Intelligence Network as well as from data provided by the Laboratory for Ship Design of the School of Naval Architecture & Marine Engineering, NTUA.

3.1 *Descriptive Statistics*

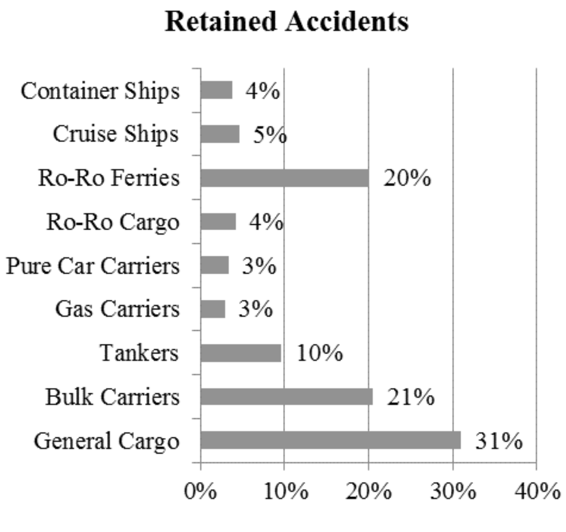

Figure 2. Distribution of ship types in the database.

Figure 2 shows the distribution, in percentages, by ship type in the database of accidents. 82% of the sample consists of General Cargo ships (31%), Bulk Carriers (21%), Ro-Ro Ferries (20%) and Tankers (10%). Additionally, the occurrence of General Cargo ships, Bulk Carriers, Tankers, Gas Carriers and Pure Car Carriers in the accident sample is as expected from the distribution of ship types in the Fleet at Risk (Fig. 3).

There are proportionately more accidents involving Ro-Ro ships (24% of accidents), which includes Ro-Ro Ferries and Ro-Ro Cargo, compared to the number of such ships in the Fleet at Risk (8%). Additionally, there are significantly less accidents involving Container ships (4% of accidents vs 12% of fleet).

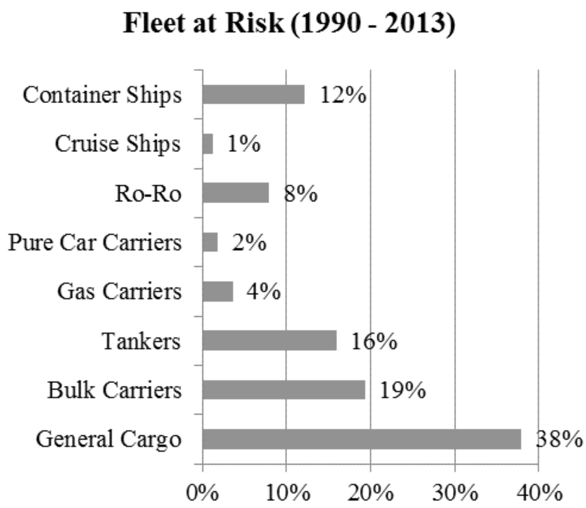

Figure 3. Distribution of ship type in Fleet at Risk.

Fleet at Risk data used in Figure 3 contain vessels built from 1980 onward and were in service in the time period from 1990 up to 2013 and totals 459,760 shipyears.

Figure 4 shows the distribution per accident type in the database. 50% of cases are groundings, while the other 50% is practically equally distributed between contacts (26%) and collisions (24%).

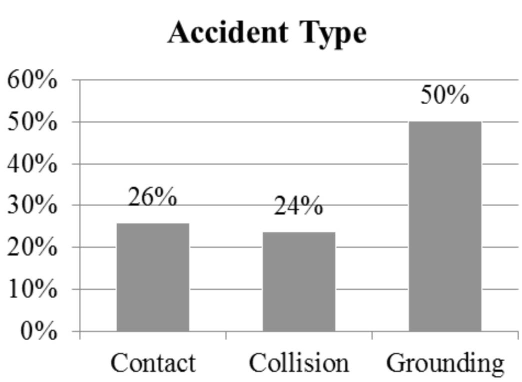

Figure 4. Distribution per accident type in the database.

Figure 5 shows the distribution of accidents per location; i.e. 57% of accidents happened within ports, 20% in restricted waters and the rest 23% while the ship was en route.

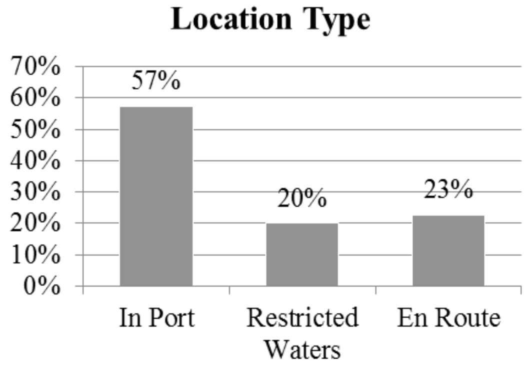

Figure 5. Distribution of location types in the database.

Figure 6 presents a cross tabulation between ship type and location type. Most accidents that happened while the ship was in port involve Ro-Ro Ferries (19%) and General Cargo Ships (14%). The high frequency of accidents for these types of ships can be explained by the routes they usually serve with frequent port calls. Furthermore, for Ro-Ro Ferries the high wind profile area plays a significant role in the hampering of the manoeuvring abilities of these ships under adverse weather conditions.

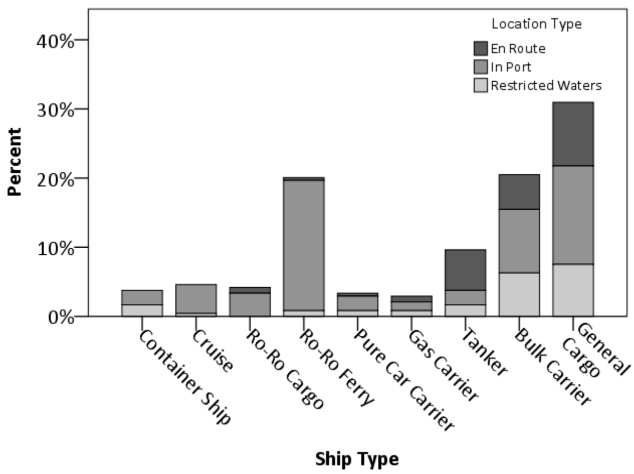

Figure 6. Percentages of ship types by location types.

3.2 *Percentiles*

The presented statistical percentiles compare a characteristic measure of size, i.e. Deadweight (DWT), Gross Tonnage (GRT) or TEU containers depending on ship type, to the Maximum Continuous Rating (MCR) between the accident sample and the fleet in service per ship type. The data for the fleet were taken from the IHS Sea-Web database and include the ships that were in service in November 2013.

The minimum and maximum values of each variable are marked in the percentiles on Figure 7 through Figure 9. The rectangle contains 50% of all values. The top line marks the 75th percentile, the bottom line the 25th and the line inside the rectangle the 50th percentile of the sample. These graphs visualize the dispersion of values in the accident sample against the dispersion of the fleet sample. Using this information we will estimate the ship size, by ship type, which is most often encountered in these accidents.

Regarding the ship types: Container, Cruise, Ro-Ro Ferries, Ro-Ro Cargo and Tankers, on average, the accident sample contains larger ships compared to the 2013 in service fleet. This is true both for the characteristic measure of size and the installed power, as shown in Figure 7 for Container ships.

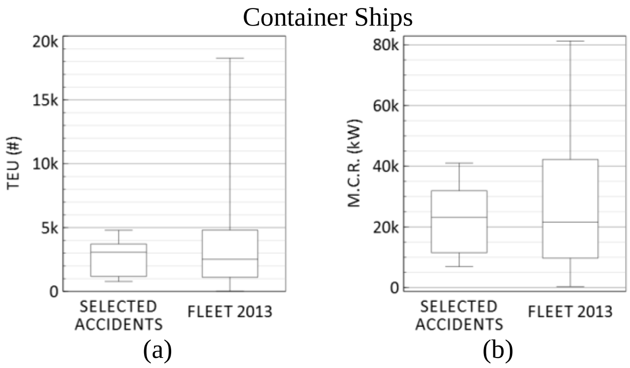

Figure 7. Comparison of percentiles for (a) TEU and (b) MCR between selected accidents and Fleet 2013 for container ships.

Regarding the ship types: Pure Car Carriers, Gas Carriers and Bulk Carriers, on average, the accident sample contains smaller ships compared to the 2013 in service fleet. This is true both for the characteristic measure of size as well as the installed power, as shown in Figure 8 for Bulk Carriers.

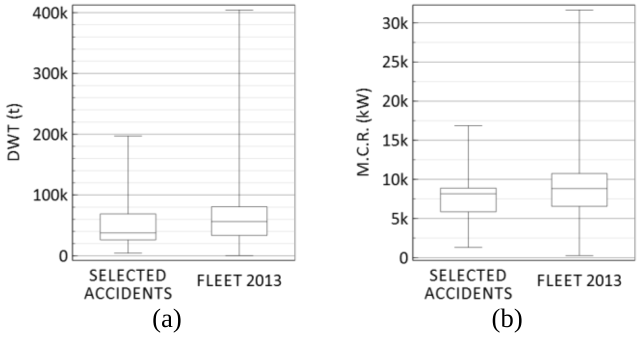

Figure 8. Comparison of percentiles for (a) DWT and (b) MCR between selected accidents and Fleet 2013 for bulk carriers.

For the General Cargo ships the distribution of values in the selected variables is similar to the respective metric of the 2013 fleet. In addition, the ship sizes in the selected accidents are on average the same compared to the 2013 fleet (Fig. 9).

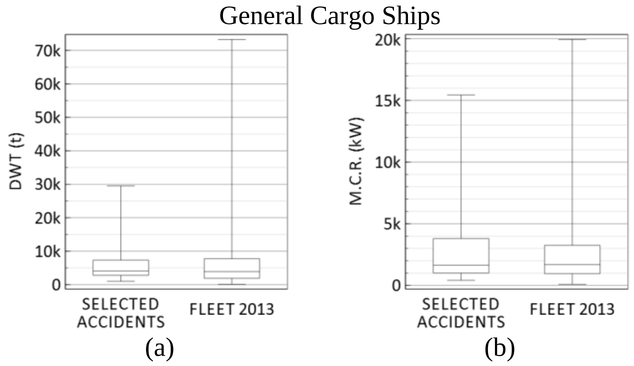

Figure 9. Comparison of percentiles for (a) DWT and (b) MCR between selected accidents and Fleet 2013 for general cargo vessels.

3.3 *Timeline Analysis*

For each ship type, a Kendall's Tau non-parametric test of statistical significance was conducted to determine any statistically significant increasing trend in the number of accidents. The results of the test are given in Table 2.

Table 2. Kendall's Tau test for accident timelines per ship type.

Ship Type	Kendall's Tau	p-value	Significance
Container Ships	0.125	0.1380	Not Sig.
Cruise Ships	0.370	0.0270	Sig. at 0.05 level
Ro-Ro Ferries	0.570	0.0001	Sig. at 0.01 level
Ro-Ro Cargo	0.203	0.2280	Not Sig.
Pure Car Carriers	0.243	0.1540	Not Sig.
Gas Carriers	0.292	0.0920	Not Sig.
Tankers	0.169	0.3040	Not Sig.
Bulk Carriers	0.527	0.0010	Sig. at 0.01 level
General Cargo	0.642	0.0001	Sig. at 0.01 level

There is a statistically significant increasing trend with high probability in the number of accidents for the following ship types: Ro-Ro Ferries, General Cargo and Bulk Carriers; Cruise ships also present an increasing trend. For the rest ship types, no significant trend can be concluded from the collected data.

Figure 10 gives the total number of accidents, for all ship types, per year. It is obvious that there is an increase in the total number of accidents after 2005, which peaks around 2007. From 2010 onwards there seems to be a decreasing trend; however the overall trend is positive as shown by Figure 10.

To validate the observed overall increasing trend a Kendall's Tau test was implemented and found equal to 0.662, with a p value less than 0.0001. This means that there is a statistically significant increasing trend in the total number of accidents.

The increasing trend in the number of accidents up to 2007 may be attributed to the booming of the shipping industry that started in 2003 and was mostly based on the increase of demand for cargoes for China's infrastructure development. This fact justifies the trend for Bulk Carriers and General Cargo Ships. Therefore, a major contributing factor to the observed increase is the greater number of ships that were in service during that period, which can be supported by the fact that the Bulk Carrier Fleet at Risk showed a 230% increase in the 2001-2010 period compared to the previous decade, while the increase in the General Cargo ships Fleet at Risk is estimated at 40%, respectively.

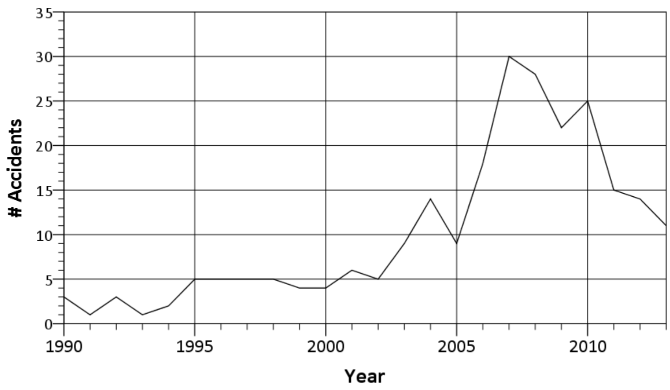

Figure 10. Timeline for the total number of accidents in the period 1990 - 2013.

Another important contributing factor for the apparent increasing trend in the number of accidents up to the year 2007 may be the improvement in accident reporting practices. This means that the increase in the number of accidents may be due to more cases being reported compared to the previous decade.

4 SHIPS OF INTEREST

This paper attempts to identify which size classes per ship type seem to be most vulnerable to the particular kind of accident.

The first step is to define the size classes for the various ship types. The next step is to examine the distributions per size and ship type in the accident sample. The ships of interest are defined for the size classes with the highest frequency, for each ship type.

The characteristics of the ships of interest were based on the following parameters: a measure of the size of the ship (DWT, GRT or number of TEU) and the MCR, which indicates the installed power. For ship types that exhibit high correlation between size and installed power, determined by appropriate correlation matrices, only one of the basic parameters was used. This is due to the fact that in such cases the two parameters offer the same pattern of information. In particular, when the two parameters are positively correlated and the values are narrowly dispersed only the size variable was used in defining the ships of interest. The data for the correlations came from the 2013 fleet sample also used in the statistical analysis.

The next step is to calculate the average value of the basic parameter in the accident sample and to round down the result in order to define the size class, i.e. a DWT, TEU or GRT class. Using the defined size class as a base point the Fleet 2013 sample was filtered to include ships of similar size. Finally, the average values for MCR and Length between perpendiculars (L_{BP}) were calculated from this dataset.

Therefore the ship of interest for each ship type and size class is defined by three variables: Size (DWT, TEU, or GRT), MCR and L_{BP}.

Additionally, we extracted an average ship for each ship type and size class, as defined above, from the Fleet 2013 sample, to be compared to the ships of interest of the accident sample. This was accomplished by calculating the average value of the size variable for each size class and following the same process as previously described.

Below is the examination of the accident sample in terms of distribution in size class per ship type.

Container ship accidents consist of 50% Panamax ships, 37.5% Handy and 12.5% Feedermax ships. In the accident sample there were no Feeder, Sub-Panamax or Post-Panamax vessels.

The majority of Cruise ships are middle sized vessels in the category of 10,000 – 60,000 GRT (63.6%). In the accident sample there are no small vessels up to 10,000 GRT. The rest of the sample consists of 27.3% 60,000 – 100,000 GRT and 9.1% > 100,000 GRT.

94% of Ro-Ro Ferries are in the size categories up to 7,500 t DWT. 40% of these are small vessels up to 2,000 t DWT.

Ro-Ro Cargo ships that are involved in accidents of interest are large vessels with DWT over of 15,000 t (37.5%). The other 25% of these accidents involve vessels from 10,000 to 15,000 t DWT while the remaining 37.5% involves vessels up to 10,000 t DWT.

A similar situation is observed for Pure Car Carriers, with the majority of vessels (37.5%) in the large sized class being over 17,500 t of DWT.

The 72% of the Gas Carriers involved in the retained accidents are small vessels with up to 40,000 m^3 of gas carrying capacity. The 28% of Gas Carriers are large vessels with carrying capacity between 100,000 and 140,000 m^3, while there are no retained accidents that involve Gas Carriers in the remaining size classes.

The distribution per size class for Tankers appears to be bimodal, with one peak in Small tankers (30.4%) and the other in Aframax tankers (39.1%). From examining Figure 11 it seems that large VLCC or ULCC tankers are not typically involved in the accidents of interest.

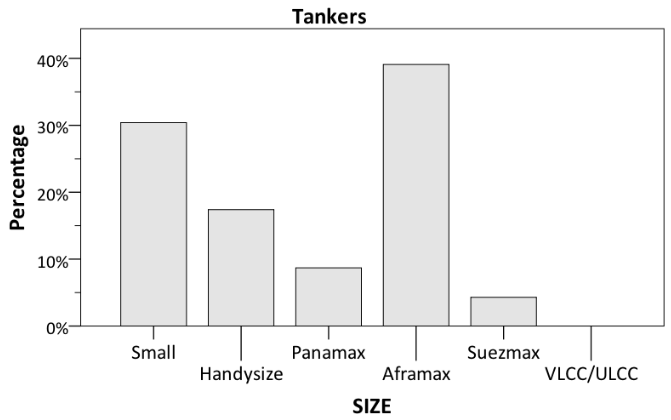

Figure 11. Distribution of accidents per size class - Tankers.

The accident sample involves Bulk Carriers that are mostly of average size totaling 80%, i.e. Handysize, Handymax, Panamax vessels. The 42.9% of the accidents involve Handysize Bulk Carriers (Fig. 12).

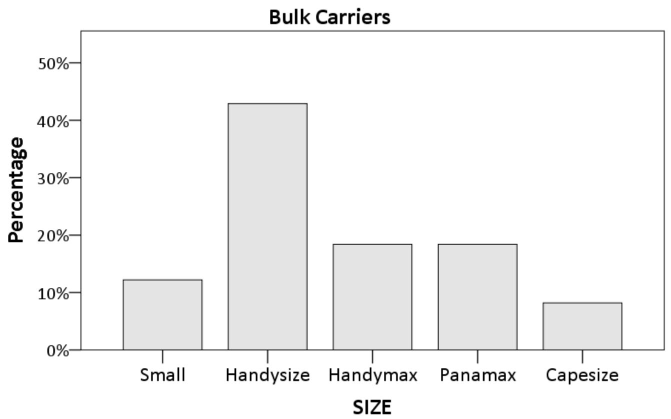

Figure 12. Distribution of accidents per size class - Bulk Carriers.

General Cargo ships are mostly small vessels of up to 5,000 t DWT, totaling about 62%, as is depicted by Figure 13.

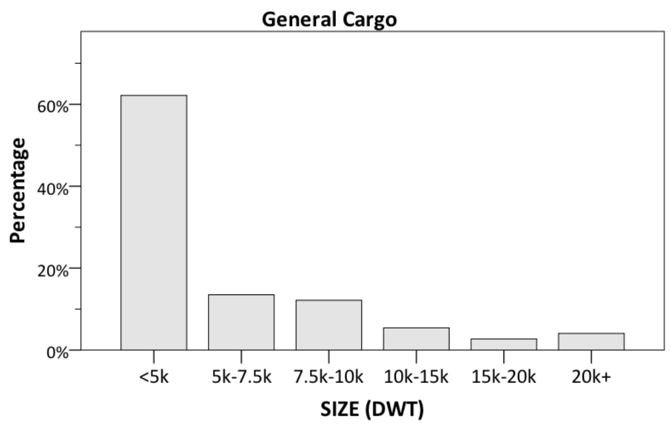

Figure 13. Distribution of accidents per size class - General Cargo Ships.

Below is a comparison of the ship of interest per ship type and size class to the Fleet 2013 average ship per size class. Figure 14 through Figure 16 cover Container ships, Tankers and Bulk Carriers, respectively.

In general the ships of interest are smaller than the average ships of the Fleet 2013 in the respective size categories.

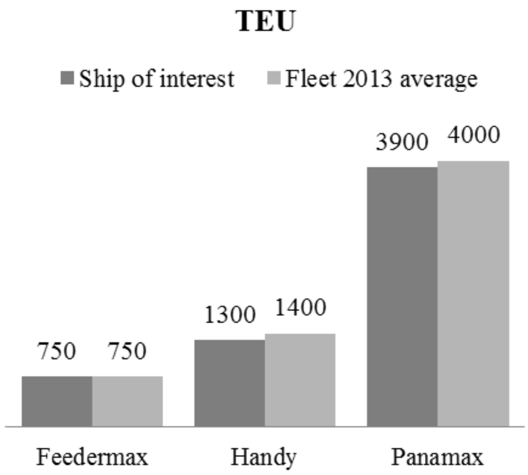

Figure 14. Comparing TEU between Ship of Interest and Fleet 2013 Average Ship – Container Ships.

On the other hand, for the following ship types: Ro-Ro Ferries, Ro-Ro Cargo Ships, Gas Carriers and Pure Car Carriers it appears that while the ship of interest in a particular size class is smaller than the average Fleet 2013 ship, the corresponding installed power is larger than the average installed power in the in service Fleet. The validity of the data used for the comparison has been ascertained in the maximum possible degree and therefore the disparity may be attributed to the characteristics of the particular ships that are included in the accident sample; hence this must be dealt with caution.

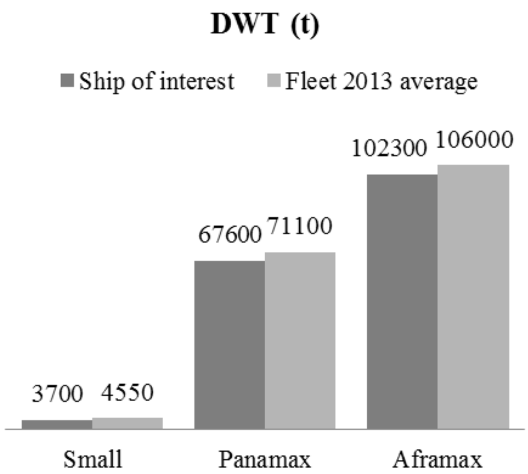

Figure 15. Comparing DWT between Ship of Interest and Fleet 2013 Average Ship – Tankers.

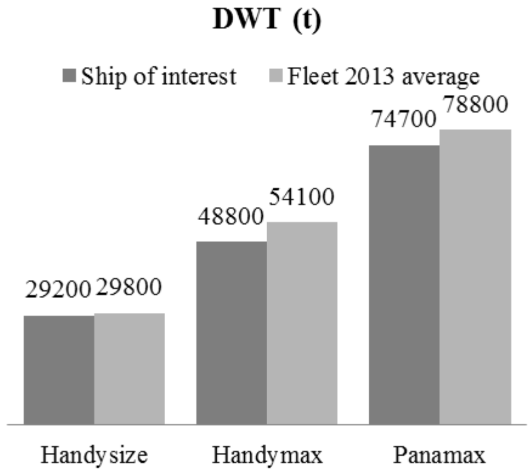

Figure 16. Comparing DWT between Ship of Interest and Fleet 2013 Average Ship – Bulk Carriers.

General Cargo ships of interest are above the Fleet average ship both in terms of DWT as well as MCR (Fig. 17).

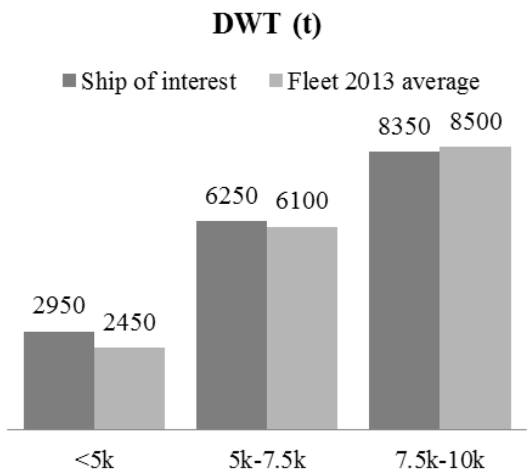

Figure 17. Comparing DWT between Ship of Interest and Fleet 2013 Average Ship – General Cargo Ships.

5 ACCIDENT RATES

The rates of accidents of interest were compared to the Fleet at Risk data, which have been acquired by the Clarkson's Shipping Intelligence Network, for the time periods as shown in Table 3.

Accident rates are in the order of 10^{-4} to 10^{-3}, which are comparable to results from Formal Safety Assessments (Wang & Foinikis 2001). Table 3 shows that the lowest calculated rate is for containerships, while the highest frequency is observed for General Cargo ships, which can be attributed to frequent port calls made by this type of vessels.

Furthermore, rates for collisions, contacts and groundings were compared to the respective results from Formal Safety Assessments.

Table 3. Accident frequencies per ship type.

Ship Type	Period	Fleet at Risk	Accidents	Rate
Containers	1996-2013	63594	8	$1.26 \cdot 10^{-4}$
Cruise Ships	1996-2013	5252	11	$2.09 \cdot 10^{-3}$
Ro-Ro Ships	1996-2013	19173	56	$2.92 \cdot 10^{-3}$
Pure Car Carriers	1996-2013	9814	8	$8.15 \cdot 10^{-4}$
Gas Carriers	1996-2013	22195	6	$2.70 \cdot 10^{-4}$
Tankers	1990-2013	145159	23	$1.58 \cdot 10^{-4}$
Bulk Carriers	1990-2013	143158	49	$3.42 \cdot 10^{-4}$
General Cargo	1996-2013	23462	74	$3.15 \cdot 10^{-3}$

Comparing the rates per accident type from the accident database to the IACS FSA Study (IMO 2010) for General Cargo Ships in Table 4, the former are smaller by one order of magnitude. This is to be expected because the accident database contains accidents only under heavy weather conditions.

Table 4. Comparison of accident rates per accident type for General Cargo Ships.

Accident Type	MSC 88/INF.8	Accident Database
Collision	$5.50 \cdot 10^{-3}$	$7.67 \cdot 10^{-4}$
Contact	$2.30 \cdot 10^{-3}$	$4.26 \cdot 10^{-4}$
Grounding	$7.40 \cdot 10^{-3}$	$1.83 \cdot 10^{-3}$

6 CONCLUSIONS

Groundings contacts, and/ collisions within ports are the most frequent accident type under heavy weather conditions with relation to the adequacy of the installed power.

Underreporting plays a significant role in the quality of the available information concerning accidents, especially for those marked as not serious. Taking this into consideration and after thoroughly examining the available information concerning the conditions of each case, it was decided to exclude the not serious accidents from the analysis.

Bulk Carriers are involved in 21% of the accidents in the developed database, while the respective figure for Tankers adds up to 10%. Taking into account the available Fleet at Risk data, it would have been expected that the involvement of these ship types in the retained accidents would be similar. The observed difference may be attributed to the operational differences between the two ship types, namely taking more precautions for Tankers in adverse weather conditions to prevent possible oil spills and likely the topology of relevant port facilities.

General Cargo Ships appear most frequently in the compiled accident database (31%). A contributing factor herein is the nature of the voyage scenarios of these ships, which include frequent calls at smaller ports. A similar conclusion can be reached for Ro-Ro Ferries, which relate to 20% of the database accidents.

The main contributing factor for the accidents involving Cruise Ships, Pure Car Carriers and Ro-Ro Ferries appears to be the large windage/profile area, which makes these types of ships susceptible to high winds and heavy weather conditions in general.

A statistically significant increasing trend is observed in the total number of captured accidents. The main contribution comes up to 2007 from increasing number of accidents for Bulk Carriers, General Cargo Ships, Cruise Ships and Ro-Ro Ferries.

After the extraction of the ships of interest per ship type and size class, it is concluded that on average the affected ships are smaller than those in the in service Fleet for 2013. The ships of interest, as defined in this paper, will help to further focus the study on particular size classes.

The calculation of rates for the accidents of interest indicate frequencies in the order of magnitude 10^{-4} to 10^{-3} for all ship types.

Finally, a main contributing factor that could determine the risk levels for this type of accidents is the operational/risk profiles of each ship type.

7 ACKNOWLEDGEMENTS

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