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Exploring Fire Incidents/Accidents Onboard Cruise and Passenger Ships

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Abstract

The aim of this paper is to present aspects of the implemented statistical analysis and patterns of the recorded maritime fire accidents. In this context, a focused database was created taking into account the specific sources for the data available; hence, the data was collected from selected cruise/passenger operators which provided information regarding the events of ignition, and generally smaller or bigger fires which took place onboard vessels. A key achievement of this effort is the healing of the usual problem of underreporting of fire accidents; in particular, underreporting small fires in relative (commercial) databases is a common problem in drawing reliable and usable risk related conclusions. However, the results presented in this paper are based upon a rather complete set of fire records providing this way for reality reflecting results and error free conclusions. Based on this database, the paper presents the results derived by statistical analysis which are able to provide patterns and trends of fires onboard passenger and cruise vessels. Furthermore, information about actually recorded occurrences/frequencies in relation to fire ignition and fire development is also included. This approach allows exploring, in a quantitative manner, the issue of fires for the examined fleet by giving specific figures regarding the frequency of events per ship-year, and the expected number of events per year. Finally, a series of tests is performed to identify whether the recorded patterns and relationships are statistically significant observations or whether they are solely attributable to chance. The paper concludes with insights drawn from the aforementioned topics.

JEL Classification: R41; L91; Y1.
Keywords: Maritime fire accidents; Cruise/passenger vessels; Ignition; Statistical analysis; Risk; Hypothesis tests.

1. Introduction

World trade undoubtedly owes a lot to the shipping industry; the sea and all activities associated with it, are vital to the entire planet. Maritime logistics and the transport chains of goods and passengers throughout the sea contribute to both the development and the economic prosperity of many countries worldwide.

Despite the significant and outstanding technological advances that have taken place and affected the marine industry, there are numerous problems and weaknesses to deal with in the effort to provide high quality marine transportation services. Among these, fire remains one of the main threats to ship safety.

In recent decades, lives are lost every year and millions of Euros worth of damage is caused, due to fires on ships. Fire hazards can lead to catastrophic consequences, not only to the ship and its cargo, but also to the environment. As a result, in the light of the trend for bigger, more complex and safer ships, fire safety is one of the main priorities in ship design and/or operation, particularly for passenger ships (Guarin *et al*., 2007; Nikolaou and Spyrou, 2010; Spyrou, 2010).

The aim of this paper is to provide an overview of relevant information about fire accidents onboard vessels and also to present statistical metrics capable to give the magnitude of the problem, such as average frequencies, numbers of expected events and statistical significance with relation to variables of interest. The research has taken account of historical fire accident data, from which a reliable and comprehensive database had been compiled. The results of a thorough and multi-faceted statistical approach are also presented, and patterns and trends are recorded in an effort to enhance marine safety and strengthen the overall performance of shipping.

The statistical (or similar) study of fires onboard vessels can be met in the international literature; indicatively, the work of Oikonomou and Ventikos (2010), Ventikos, Lambrinakis, Nitsopoulos and Lyridis (2007), Guarin *et al*. (2007), Soares and Teixeira (2001), and Da Veiga, Loggia and Segarra (1999) are referenced.

The rest of the paper is structured as follows: Section 2 gives details regarding the dedicated database developed in the context of this analysis. Section 3 presents indicative results from the statistical analysis conducted and provides also the framework and outcomes derived from the statistical inference. Finally, the paper closes with discussion and conclusions at Section 4.

2. Methodology: database and elements

A database for incidents of ignition and fires was developed from data provided by operators addressing incidents of fire ignition and fires that were recorded onboard cruise and passenger vessels; in particular, three different major operators of passenger/cruise ships provided access to their records of fire ignitions and developed fires from June 2003 to January 2010. This effort yielded a database of 1521 records. A short description is provided for each case which gives information about each fire incident. This way, the database manages to overcome a problem usually met in this type of research i.e. underreporting of low impact incidents. The database has provided coverage for fire events of the entire spectrum of magnitude: from incidents of ignition to developed fires (Ventikos, Lambrinakis, Nitsopoulos and Lyridis, 2007; Mendiola, Achutegui and De la Rosa, 2010; Joannovich *et al*., 1992; Darbra and Casal, 2004).

The ignition database comprises of several fields containing all the significant factors that affect a fire incident, hence the employed fields are:

- Incident Date: the date when the incident occurred;
- Time: the exact time when the incident took place;

- Location of the vessel: describes whether the vessel was at sea or in port when the incident happened;
- Weather situation: describes the prevailing weather conditions and whether they contributed to the incident or not;
- Onboard location: Each space onboard the vessel is given a number that corresponds to SOLAS space categories; in particular, there are 14 numbers/codes that define all onboard locations according to SOLAS Chapter II-2, regulation 9 (Table 1);
- Detection: refers to the effectiveness of the (installed) detection system;
- Adjacent detector activated: describes whether detectors of adjacent spaces were activated;
- Suppression means: the means that were used to confront the incident of fire;
- Time to extinguish (in mins): the elapsed time to extinguish the fire from the moment it was detected;
- Ventilation status: describes whether the ventilation system was closed or not;
- Fire door status: describes whether fire doors were closed or not;
- Space occupied: describes whether there were people on the location of the incident;
- Crew presence: describes whether crew members were located in the space of occurrence of the fire;
- Boundary cooling status: describes whether actions were performed to cool the boundaries (e.g. bulkheads, corridors etc.) of the spaces in which the fire initially outburst;
- Emergency response failure: describes whether emergency response action was executed or not;
- Containment failure: refers to the time at which the temperature at the unexposed side of the bulkhead exceeds certain value (i.e. 180^{o}C) in accordance to IMO (2001);
- Ignition in adjacent spaces: records the capability of the fire to spread to adjacent spaces (this means that the containment capability has failed) as shown by Hakkarainen *et al*. (2009);
- Severity: The severity scale adopts a five-step scale, namely negligible, minor, significant, severe, and catastrophic, based on the combination of the elapsed time from detection to extinguishment of the fire, with the elements of boundary cooling, emergency response failure, and ignition in adjacent space(s) as shown in IMO (2002);
- Source ignition: describes the cause of fire; this is a very important parameter in relation to the determination of the root cause of the incident (Gentile and Dickenson, 1995; Vlaun, Kirkbride, Pfister and Rosenblatt, 2001).
- Human factor contribution: describes the contribution of human element to the occurrence of the incident (Ventikos and Psaraftis, 2005).

Table 1. Definition of space categories according to SOLAS

SOLAS Space Categories	
Code	**Space defined**
1	Control station
2	Stairway
3	Corridors
4	Evacuation stations and external escape routes
5	Open deck spaces
6	Accommodation spaces for minor fire risk
7	Accommodation spaces for moderate fire risk
8	Accommodation spaces for greater fire risk
9	Sanitary, and similar spaces
10	Tanks, voids and auxiliary machinery spaces having little or no fire risk
11	Auxiliary machinery spaces, cargo spaces, cargo and other oil tanks and other similar spaces of moderate fire risk
12	Machinery spaces and main galleys
13	Store-rooms, workshops, pantries, etc.
14	Other spaces in which flammable liquids are stowed

3. Results

3.1 Location

Most of the incidents of fire onboard ships occurred when these were at sea (about 71% of the cases). Of the remainder, most cases occurred with the vessels in port (27%). Only 1% of the incidents occurred while the ship was approaching port and the same percentage when vessel was at anchorage. According to the values given in Table 2, the records for port approaching and at sea, as well as those for at anchor and in port, are statistically significant at a 0.05 level of significance.

Table 2. Analysis of vessel's location with regards to the occurrence of fire

Location of Vessel	n	%	P-value	
In port	410	26.96	At anchor / In port	0.003
At anchor	19	1.25		
At sea	1076	70.74	Port approaches / At sea	0.004
Port approaches	16	1.05		

3.2 Ignition source and onboard location of occurrence of ignition/fire

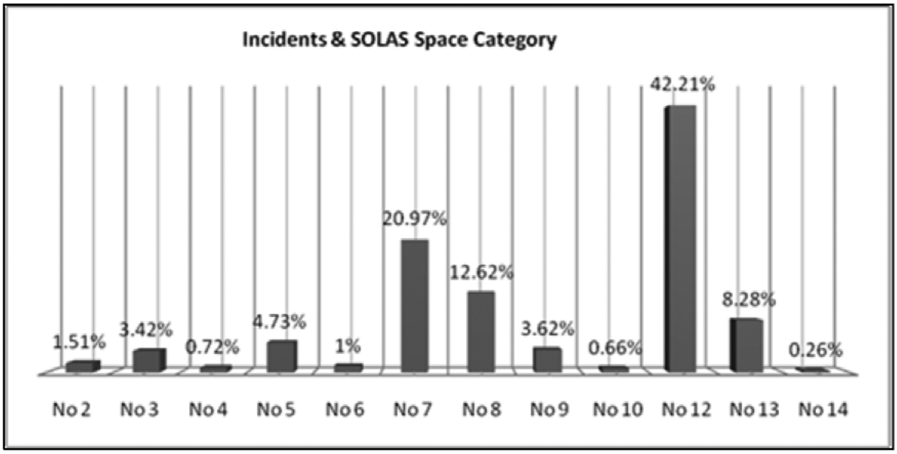
One of the most important aspects of a fire incident is its ignition source. Electricity is one of the main factors triggering the ignition process. Specifically, the option: "electrical other than static charges" is the major ignition source onboard cruise/passenger vessels with a frequency of 30% of the records. "Cigarettes, matches or similar smoking materials" follow with a frequency of 22% of the cases; this category is closely connected to the contribution of human factors to the occurrence of a fire incident. Apart from these two significant sources, the category of "hot surfaces (galley)" is also frequently visited with a percentage of 12%. Fire incidents in the galley of a vessel are a common phenomenon according to the descriptions given. Nevertheless, these seldom lead to severe incidents, as the crew is present; it remains vigilant in galleys and usually succeeds in extinguishing the fire before it becomes a real threat. In many of the cases, (219 incidents) a spontaneous combustion was to blame for the fire incident. According to the values from Table 3, combustion due to hot surfaces and electrical charges, as well as burning/welding/cutting and cigarettes, matches are statistically significant at a level of significance of 0.05.

Table 3. Analysis of ignition sources for fires on board cruise/passenger vessels

Vessel Location	n	%	P-value	
Electrical	458	30.11	Hot surface / Electrical other than static charges	0.039
Cigarettes	339	22.29		
Hot surface	187	12.29	Burning/Welding/ Cutting / Cigarettes, Matches etc.	0.007
Spontaneous Combustion	219	14.40		

The onboard location where the fire has originally outburst is a field that can define the subsequent escalation of the situation. All spaces onboard have been given a specific category number by SOLAS and are codified accordingly. In this outline, Figure 1 presents the metrics showing the majority and the most common of the locations onboard where a fire incident has occurred. Hence, the spaces of SOLAS category No 12 present the highest frequency regarding fire occurrence with 642 cases out of the 1521 incidents; the onboard locations that correspond to this SOLAS code number are galleys and machinery spaces. No 7 spaces follow with a record of 319 cases, whereas spaces with code numbers 8 (192 cases) and 13 (126 cases) show a lower but still significant frequency. SOLAS code number 7 represents accommodation spaces of moderate fire risk such as cabins, either crew/officer or passenger (interior and bathroom). Code number 8 stands for accommodation spaces of greater fire risk such as crew areas, casino, dining room, and number 13 corresponds to store rooms, laundry room, workshops, pantries etc.

Figure 1. Distribution of incidents against to SOLAS categorized on board locations



3.3 Statistical inference – Extracted frequencies

Using the above statistical analysis and the data obtained from operators, preliminary frequencies were obtained to show the significance of fire incidents and the factors that describe them. These frequencies can form a basis for further statistical analysis, comparisons, predictions as well as guidance for policy topics and practices regarding the significant task of fire safety (Soares and Teixeira, 2001). The employed fleet comprises 463 ship-years for the period of interest, i.e. from 12/6/2003 to 22/1/2010.

In Figure 2, the number of fires of all categories of severity for the timeline of the examined period is presented; it shows that the so called negligible fire incidents dominate the population of the elaborated database. This is an observation that faithfully reflects reality. The corresponding frequencies are given in Table 4. It shows that the average frequency of fires per ship-year equals 3.284. Taking into consideration that the database addresses mainly low severity incidents, i.e. negligible and minor incidents counts for 1507 out of a total of 1521 records, such a frequency is expected and justified.

Table 4. Frequency rates for the total number of fire incidents

Average Frequency / ship-year	3.284
Average fleet size / year	125
Expected number of events / year	410.52

Indicatively, a more focused statistical analysis on the frequencies and expected number of incidents leading to severe consequences is presented in Table 5. Hence, it shows that the average frequencies per ship-year for critical situations (i.e. severe incidents) are extremely low; in particular, the average frequency equals to $4x10^{-3}$ fires per ship-year, which corresponds to 0.54 events per year (or 0.0015 fires per day).

Figure 2. Distribution of total number of fire incidents and categories of severity against time

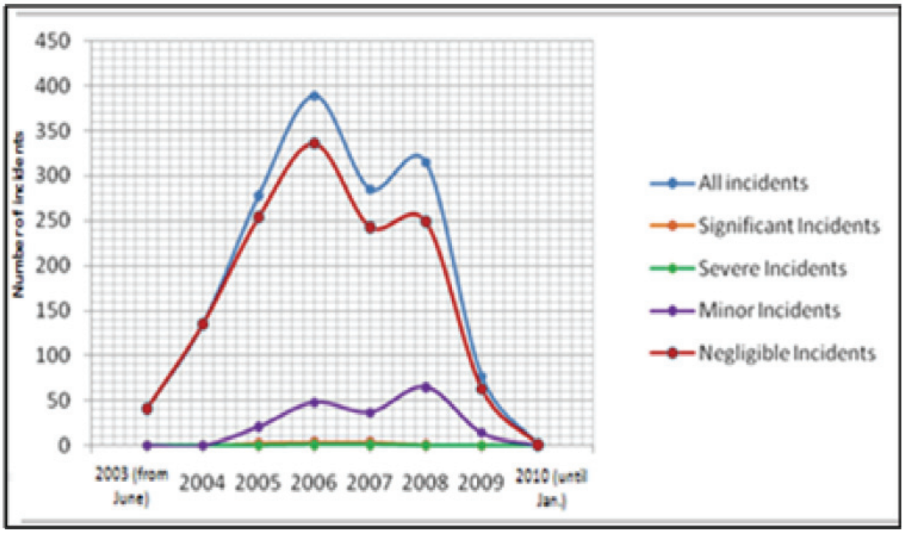


Table 5. Frequency rates for the elaborated fire incidents with severe consequences

Total number of Severe Incidents	2
Average Frequency / ship-year	$4x10^{-3}$
Average fleet size / year	125
Expected number of events / year	$5.4x10^{-1}$

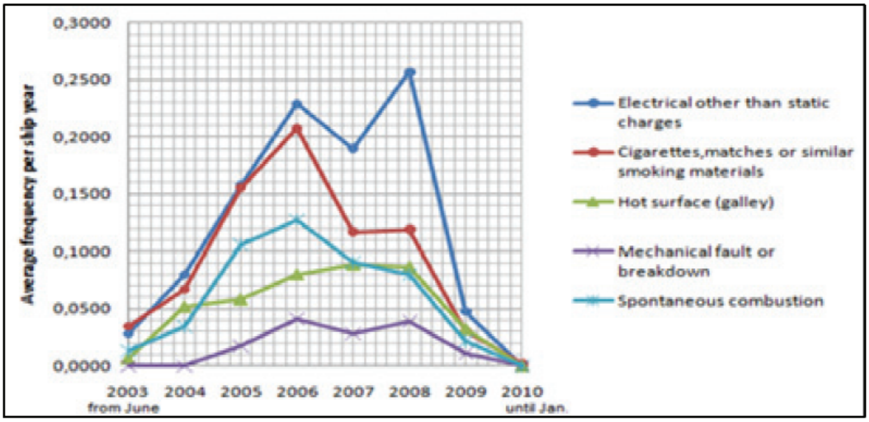
According to the SOLAS space categorization, the corresponding frequencies for each onboard location/space for fire incidents regardless their severity is presented in Table 6; it relates to the onboard spaces of passenger/cruise vessels where it is more likely for a fire accident to occur. Engine and machinery spaces (SOLAS spaces No 12) have the highest average frequency of 1.39 fires per ship-year.

Table 6. Frequency rate with regards to onboard locations (i.e. SOLAS space category) – total number of fire incidents

Fleet at risk = 463 ship-years						
SOLAS SPACE CATEGORY	SOLAS Space Category No 5	SOLAS Space Category No 7	SOLAS Space Category No 8	SOLAS Space Category No 9	SOLAS Space Category No 12	SOLAS Space Category No 13
Number of Fire Incidents (all incidents) for each SOLAS space category	72	319	192	55	642	126
Average Frequency / ship-year	$1.6x10^{-1}$	$6.9x10^{-1}$	$4.1x10^{-1}$	$1.2x10^{-1}$	1.39	$2.7x10^{-1}$
Average fleet size / year	125					
Expected number of events / year	19.43	86.10	51.82	14.84	173.28	34.01

In Figure 3, the number of fires of all main categories of ignition source for the timeline of the examined period is presented; this depicts the electrical related ignition sources for the majority of fire incidents recorded.

Figure 3. Time evolution of average frequency rate per ship-year for each ignition source



3.4 Hypothesis test analysis

The Chi-square test was employed to examine and define whether two variables are independent or not; for example, based on the available data, it can be investigated whether the relation and fluctuation of the SOLAS space category and fire severity independent variables is coincidental or not. Some of the implemented chi-square (non-parametric) tests are presented.

- SOLAS space category against severity

H_0: SOLAS space category and severity are independent events;
H_1: SOLAS space category and severity are not independent events.

In this case the level of significance is a=0.05 and the degrees of freedom are equal to 33. Using the relevant statistical tables the critical value was found equal to 47.367 (Ingster, 2000; Siskinda *et al.*, 2010) the probability of having this specific chi-square value is 0.064. The chi-square value for the records from the database equals $x^2 = 46.143$ and since $x^2 < 47.367$, then H_0 is not rejected and so SOLAS space category and severity seem to be independent events. This result is supported by the probability for the chi-square of 46.143 being 0.064 ($0.05 < p < 0.1$); however, in this case the results are marginal since the chi-square value is almost equal to the critical one. For example, it is possible that the addition of extra records in the database could reverse the independence of these two variables and therefore this result should be dealt with caution.

- Ignition source against SOLAS space category

H_0: Ignition source and SOLAS space category are independent events;
H_1: Ignition source and SOLAS space category are not independent events.

In this case the level of significance is a=0.05 and the degrees of freedom are equal to 143. Using the respective statistical tables the critical value was estimated to the order of 124.3 (x_{cr}). The probability of having this specific chi-square value is less than 0.001. The chi-square value for the records from the database equals $x^2 = 1306.688$ and since $x^2 > 124.3$, H_0 is rejected and therefore ignition source and SOLAS space category are not statistically independent variables. This result is further supported by the fact that the probability of a chi-square value of 1306.688 is less than the level of significance ($p < 0.05$).

- Ignition source against severity

H_0: Ignition source and severity are independent events;
H_1: Ignition source and severity are not independent events.

In this case the level of significance is a=0.05 and the degrees of freedom are equal to 39. Using the statistical tables the critical value was estimated equal to 44.538 with the respective probability being less than 0.001. The chi-square value of the specific data is equal to 159.094, hence since $x^2 > 44.538$ (critical value), H_0 is rejected and so ignition source and severity are not statistically independent parameters. This result is also supported by the fact that the probability of the estimated chi-square (i.e. 159.094) is less than the level of significance ($p < 0.05$).

4. Discussion

The descriptive statistical analysis provided certain conclusions with regards to the parameters employed; namely in many cases human negligence is to blame for the occurrence of onboard fire incidents. In particular, ignition source such as "cigarettes, matches or similar smoking materials" gives about 20% of the records. Electrical factors are also involved in the outburst of fires. Moreover, galleys and cabins (interior-exterior, either passenger cabin or crew cabin) are the most frequent spaces onboard where the ignition of a fire occurs adding up to a frequency of 19.7% and 21.4%, respectively; incinerator rooms follow with 15.1%.

Bearing in mind that nowadays more focus is given to the timely detection of fire and to the formulation of efficient procedures for its extinguishment, it is recorded that, for most cases included in the database, the fire was self-extinguished (21%); consequently, most of the database relates to low severity events. Water suppression (other than portable water extinguishers) reveals that when a fire occurs, the person who is currently at the scene tries to eliminate the threat by any means (e.g. a bucket of water) and also that the size of fire is rather small so a bucket of water can solve the problem. However, the most commonly used suppression method is CO^2 extinguishers with 16%. Fires are manually detected by crew although a detection system is installed in the specific space by 59%.

The scale for severity is similar to the one adopted by the FSA (IMO, 2002): Negligible, Minor, Significant, Severe, and Catastrophic. In 87% of the cases the incident was negligible with significant events below 1%. The significant and severe incidents totaled 14 out of 1521. This shows that this database contains a considerable (and representative) number of fire incidents onboard cruise/passenger fleet in the period under examination and therefore it does not just cover well developed fires; as such the conclusions drawn from this effort are deemed to be valuable to the shipping community.

Finally, it is important to observe the effect of the most significant issues (e.g. ignition source, onboard location of fire occurrence) to a specific average fleet size, according to the results of the average frequency of fire accident per ship-year and the expected number of fire incidents per year. Hence, the expected number of incidents due to electrical charges in a year is about 123 while the average frequency per ship-year is 0.98. "Cigarettes, matches or similar smoking materials" add up to 92 incidents per year (giving an average frequency of 732 fires per ship-year). For a mechanical fault or breakdown and a spontaneous combustion the corresponding values are 17 incidents per year, and 59 incidents per year, respectively. Most fire incidents occur in the engine/machinery/incinerator room, or the galley of the ship (173 expected incidents per year). High levels of fire risk are also calculated in cabins with about 85 incidents per year for the fleet of interest. For critical situations (i.e. severe incidents) the average frequency for fires per ship-year equals $4x10^{-3}$.

5. Conclusions

This paper focuses on fire accidents onboard cruise and passenger ships; the topic of fire safety is dominant in discussions at the IMO and within the whole international maritime community. Fire can be devastating on a ship – particularly on a passenger ship, where large number of people can be exposed to great danger. On July 1st, 2002, a comprehensive new set of requirements for fire protection, fire detection and fire extinction onboard vessels entered into force as a new revised Chapter II-2 of the International Convention for the Safety of Life at Sea (SOLAS).

However apart from the well documented technological advances in the fields of fire detection and extinction, it is the continuous study and implementation of the lessons learned from previous fire incidents that can aid the shipping industry to adopt a better perspective towards this problem and provide with practical, realistic solutions and ways out.

The database was developed using incident records provided by major operators in the cruise and passenger ship sectors. Most of the cases describe low severity situations. The large number of records examined (1521 records) offers reliability to the database and reduces significantly the usual weakness of the underreporting of small fires; hence it surpasses focusing on recorded developed fires.

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