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# Assessing the topicality of the problem related to the explosion of crankcases in marine main propulsion engines (1972–2018)

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**JEL Classification:** L62, L90, L92, R41

**Dataset:** https://zenodo.org/record/6586952 (DOI: 10.5281/zenodo.6586952)

**Abstract**

The purpose of this paper is to present the results of a query aimed at assessing the validity of the topic of crankcase explosions prevention in the main marine engines. The study takes into account the engine type, engine manufacturer, ship's age, accident severity, ship's location at the time of the incident, and the share of fatal accidents in the analyzed population of crankcase explosions. One of the primary hazards associated with offshore and deep-sea ship operations – and primarily ship power plants – are fires and explosions that result in accidents and incidents with an average frequency of 60 days. This paper discusses the actuality of crankcase explosion hazards in the main propulsion engines of various types of sea vessels. The assessment was made based on the results of a statistical analysis of historical data from 1972 to 2018. The methodology consisted of three stages: (1) a selection query to obtain the source data, (2) analysis of the obtained results (data separation, extraction of additional information, and statistical analysis), (3) synthesis of the obtained information, and drawing conclusions about the numerical indicators describing the statistical distribution of individual events for the given evaluation criteria. The analysis showed that the risk of crankcase explosions affects ships of all ages – both in crosshead (31%) and trunk piston engines (61%) – and that the number of serious incidents (67%) remained constant over the investigated period. Half of all incidents occurred on vessels younger than 15 years old. 58% of explosions took place in engines of the most popular prime movers manufacturers. The probability that a main engine crankcase explosion will result in injury or death is 17.34%.

## Introduction

Human civilization is increasingly dependent on a reliable supply of energy carriers and various types of products. This demand can be met with a reliable transport chain, of which ships are a key link. The share of maritime transport in the international trade of goods is estimated by various sources to be in the range of 80–90% (Allianz Global Corporate & Specialty, 2019; UNCTAD, 2020). Allianz Group estimates that ship capacity has increased by 1500% over the past 50 years (Allianz Global Corporate & Specialty AG, 2012). It is also estimated that 90–92% of modern ships in operation have propulsion systems that use diesel engines. Among the propulsion systems currently in use, there are three basic designs (Figure 1). There are also combination propulsion systems using different configurations of cooperating basic systems and/or simultaneously using prime movers of a different type than piston internal combustion engines.

Therefore, in practice, almost all ships are powered by internal combustion engines. The fact that these types of engines perform very well compared with ships with large cargo volumes (the total energy efficiency of modern engines exceeds 55%) suggests that this situation is unlikely to change in the coming years. Demands to carry increasingly higher cargo loads have resulted in the need to equip ships with engines with ever-higher horsepower (Piotrowski & Witkowski, 2013). The power rating of the largest slow-speed, crosshead engines exceeds 80 MW, which is sufficient to power a small town with electricity. These motors are very large. For example, the 14-cylinder Wärtsilä 14RT-Flex96C engine, rated at 81.3 MW, weighs over 2,300 tons and is 27.3 m long and 13.5 m high (Chybowski, 2019), and its crankcase has a volume exceeding 500 $m^3$ (Valčić, no date).

One of the primary hazards associated with ship operations – and primarily ship power plants – are fires and explosions, which cause accidents and incidents with an average frequency of 60 days (Allianz Global Corporate & Specialty, 2019). For example, accident statistics kept by Allianz Group in 2018 show that there were 174 reported incidents.

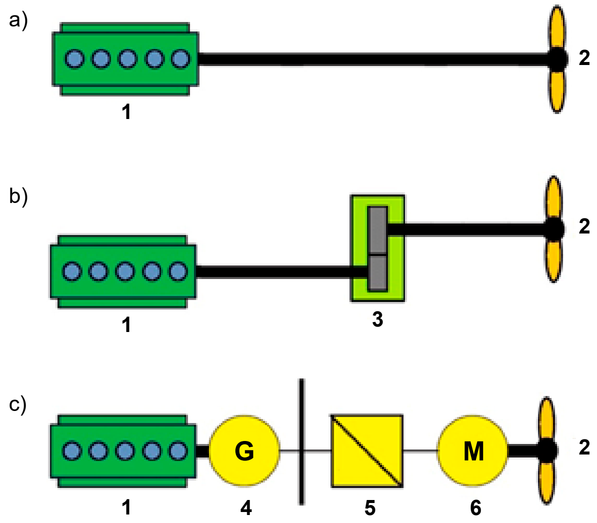


**Figure 1. The basic design of ship propulsion systems: a) direct propulsion, b) indirect propulsion, c) diesel-electric; 1 – diesel engine, 2 – propeller, 3 – gearbox, 4 – electric generator, 5 – electric converter, 6 – electric motor**

Between 2009 and 2018, Allianz Group also identified 103 cases of vessel loss related to fire or explosion out of 1,036 completely destroyed vessels. Thus, this represents about 10% of all losses. The statistics of fires and explosions resulting in the total loss of a vessel for the years 2009–2018 are shown in Figure 2.

The reliable and efficient operation of a ship's engine room plays an important role in ensuring vessel safety. Major engine failures of large and high-horsepower engines may be caused by fires or explosions in and around the engine spaces

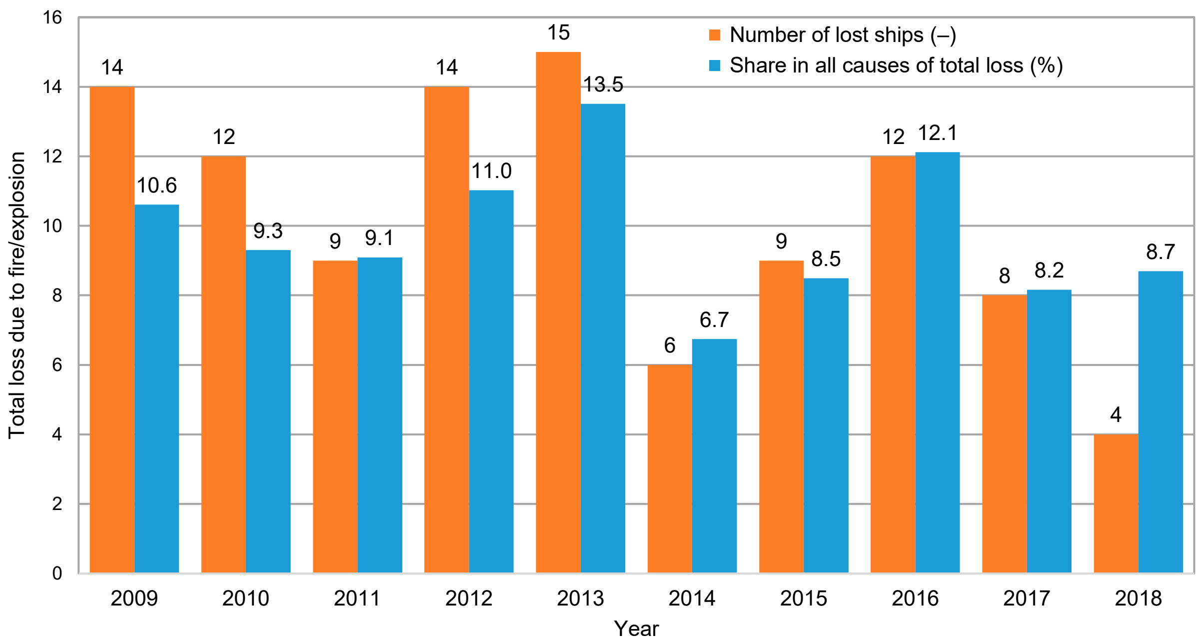


**Figure 2. Share of fires and explosions of total ship losses in 2009–2018 (source: the authors' elaboration based on (Allianz Global Corporate & Specialty, 2019))**

(Holness, 1995). The main subsystems of modern marine engines that generate fire and explosion hazards during operation are turbochargers, starting air manifolds, sub-piston spaces and scavenging air chambers, exhaust manifolds, fuel injection systems, and crankcases (Chybowski, 2022a, 2022b).

These engine subsystem failures or primary fires and explosions can also result in secondary fires and explosions in machinery spaces, cargo holds, tanks, and ship rooms (Włodarski, 1998; Piotrowski & Witkowski, 2005; Krystosik-Gromadzińska, 2020). Both primary and secondary failures, fires, and explosions often result in injuries or loss of life, damage to cargo, serious damage to the vessel, sinking of the vessel, and the release of toxic substances into the marine environment. Fires and explosions can also cause severe burns and mechanical injuries to the body.

Some of the most dangerous consequences are explosions in engine crankcases (Chybowski et al., 2015). While their causes and development may be different for crosshead and trunk piston engines, both the explosion itself and the accompanying secondary phenomena, such as a fire in the engine room, have very serious effects. They have repeatedly injured and killed crew members and caused serious ship failures.

The causes and analysis of explosions in crankcases have long been the focus of many researchers (Burgoyne & Newitt, 1956; Rickaby et al., 2002). Minkhorst was one of the first to analyze this topic (Minkhorst, 1957), who in 1957 made an in-depth literature analysis of the topic of crankcase explosions in the context of the August 11, 1947 explosion of four engines aboard the ocean liner m/v Reina del Pacifico (Eckhoff, 2005). This explosion killed 28 people and injured another 23 (Chybowski, 2022a). This event resulted in the development and widespread use of explosion valves and oil mist detectors (OMD) (Valčić, no date). However, crankcase explosions have continued to occur (CA69, 2001; Australian Transport Safety Bureau, 2004, 2005; The Hong Kong Special Administrative Region, 2009; Federal Bureau of Maritime Casualty Investigation, 2018; MAIB, 2018) and have been further studied (MAN B&W Diesel A/S, 2002; Eckhoff, 2005). This has resulted in a number of ever-improving regulations aimed at increasing the operational safety of marine engines (IACS, 2016; IMO, 2020; PRS, 2021). It should also be pointed out that the global literature does not present any up-to-date studies on this topic or basic statistical information on crankcase explosions, nor has there been a comparison of their numbers over the past several decades. This paper attempts to accomplish this task by answering the following questions: Did the number of explosions in crankcases vary significantly in particular years? What is the relation between ship age and the number of explosions? How many explosions occurred due to the consequences of particular events? Are machines of particular manufacturers dominant among the damaged main engines?

## Material and methods

Figure 3 shows the methodology adopted in this paper. The process consisted of three stages: (1) a selection query to obtain the source data, (2) analysis of the obtained results (data separation, extraction of additional information, and statistical analysis), (3) synthesis of the obtained information, and drawing conclusions about the numerical indicators describing the statistical distribution of individual events for the given evaluation criteria.

The query of crankcase explosions for raw data output was selected using the internationally-recognized *IHS Sea-web* tool (https://maritime.ihs.com). It is a set of databases that provides access to a range

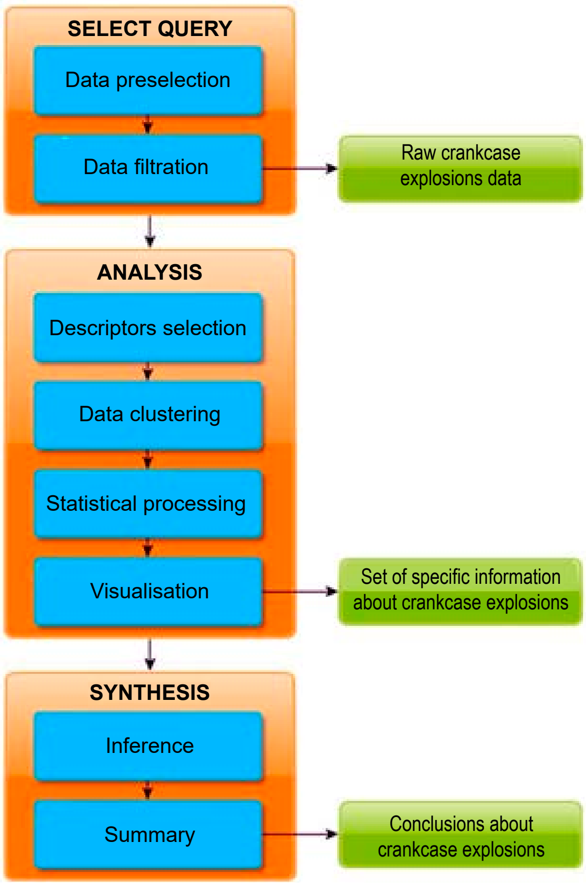


**Figure 3. Stages of the methodology adopted in the work and their results**

of information on ships, owners, shipbuilders, fixtures, casualties, port state control, ISM, real-time vessel movements, and port information using a single application. This tool contains detailed information on more than 200,000 ships (100 GT and above) and more than 240,000 company records, including owners, operators, managers, and builders. The characteristics of accidents officially reported to ship operating authorities are contained in the *Sea-web Casualty & Events* database (IHS Global Limited, 2022).

During analysis, of all accidents occurring onboard ships (99,119 events), the events with casualties caused by a fire/explosion (8844 events) were initially selected. Among them, 102 fires related to explosions in the crankcases of marine engines occurring between 1972 and 2018 were found, of which 98 explosions involved the main propulsion

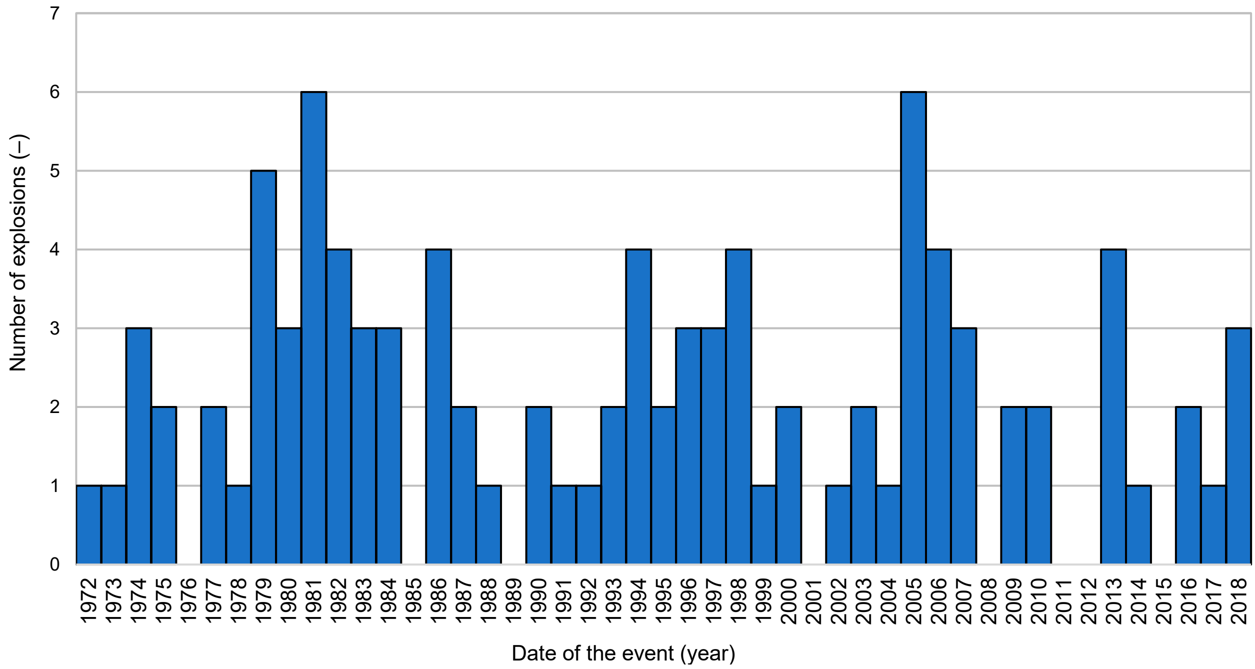


**Figure 4. Distribution of the analyzed main engine crankcase explosions from 1972 to 2018**

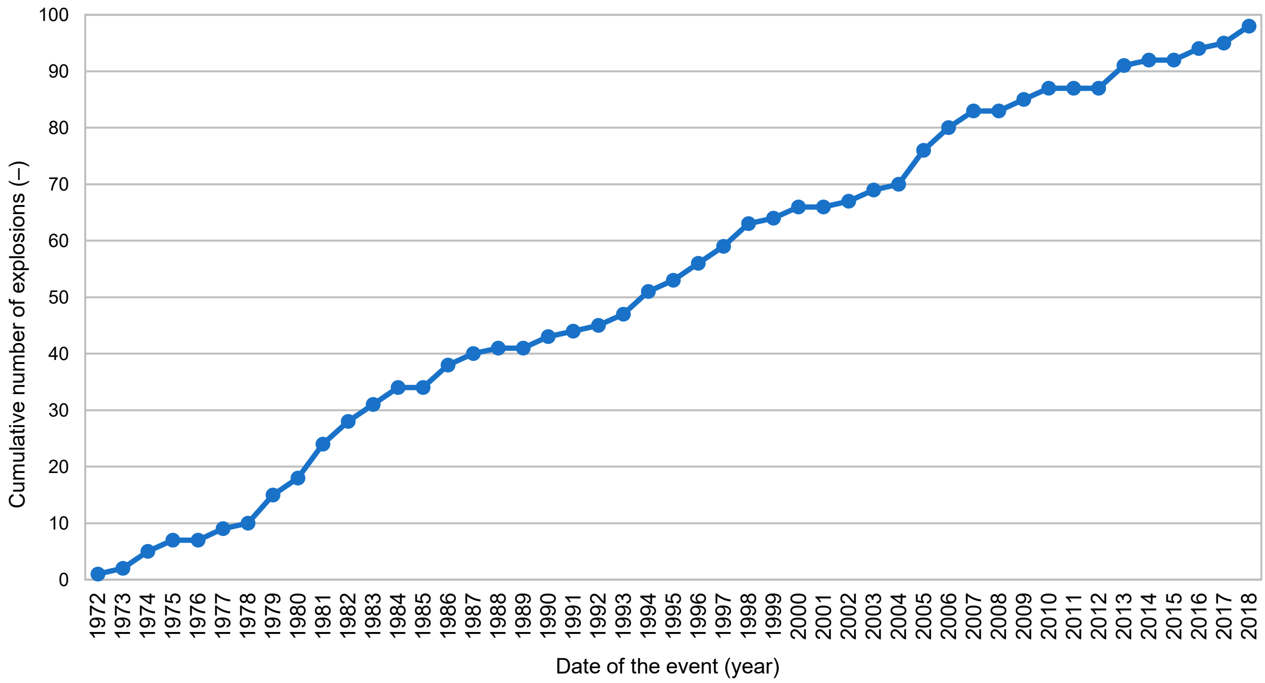


**Figure 5. Cumulative number of main engine crankcase explosions from 1972 to 2018**

engines. This gives an average of 2.13 explosions per year. The dataset of the analysed explosion population is available in the Zenodo repository (Chybowski, 2022c).

The low number of explosions in auxiliary engines is presumably due to the lack of accident reports when an accident did not injure or kill people. In the case of main propulsion engine failures, each event was associated with the temporary immobilization of a ship, which often also resulted in a fire in the engine room; thus, they were reported to the nautical supervision institutions and sea rescue units. Therefore, the adopted input data can be considered reliable.

Among the population of 98 crankcase explosions, 6 events resulted in the loss of life of crew members. A summary of the number of explosions in the main engine crankcases by year is shown in Figure 4, and the cumulative number of explosions is shown in Figure 5.

Based on the input data, detailed information was extracted as the number of explosions as a function of the age of the vessel on which the incident occurred, the main engine manufacturer, the location where the incident occurred, the severity of the incident, and human casualties.

## Results and discussion

Figure 6 shows the proportion of main engine crankcase explosions by vessel location. The overwhelming majority of these incidents occurred during sea travel (82%), followed by accidents when vessels were on rivers (10%).

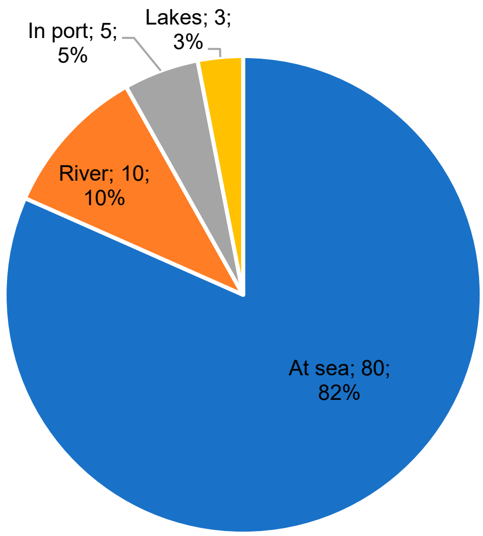


**Figure 6. Location of the vessel at the moment of a crankcase explosion**

The reported number of main engine crankcase explosions in relation to ship age is shown in Figure 7. The youngest vessel on which an explosion occurred was in service for less than 1 year, and the oldest was 63 years old. The largest number of explosions (8 events) was observed for vessels that were 14 years old, representing 8% of the analyzed population. More than half of all observed explosions

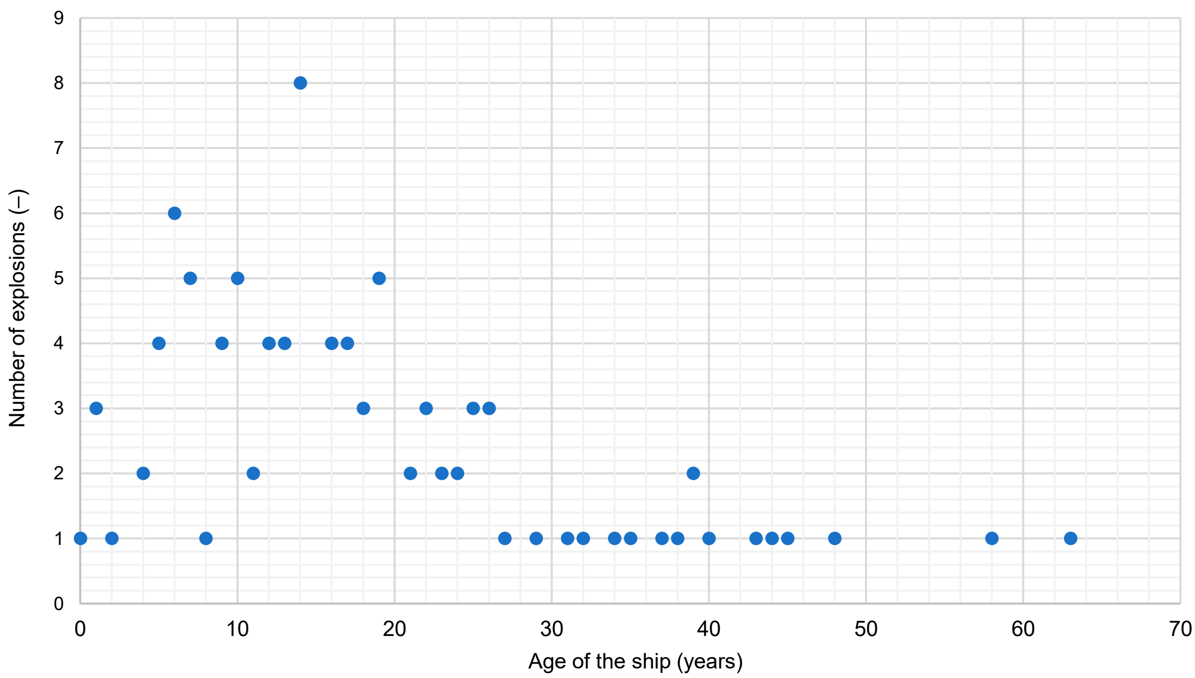


**Figure 7. Number of the main engine crankcase explosions as a function of the ship's age**

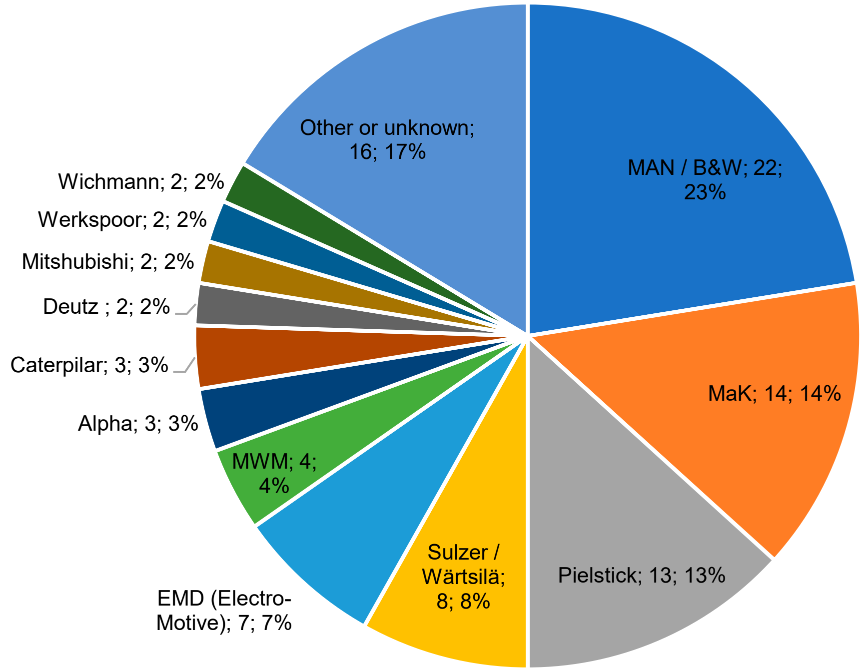


**Figure 8. Main engine manufacturer in which a crankcase explosion occurred**

involved vessels that were in service for fewer than 15 years.

The proportion of the analyzed engine population sorted by machine manufacturer is shown in Figure 8. This shows that main engines from various manufacturers are similarly susceptible to crankcase explosions. It can also be concluded that this share coincides with the popularity of engines from various manufacturers as prime movers for ships – 58% of all explosions occurred in engines from MAN/B&W, MaK, Pielstick, and Sulzer/Wärtsilä, i.e., the industrial barons in the production of marine main engines.

The severity classification of the analyzed population of crankcase explosions is shown in Figure 9, where 67% of all analyzed explosions were classified as serious events.

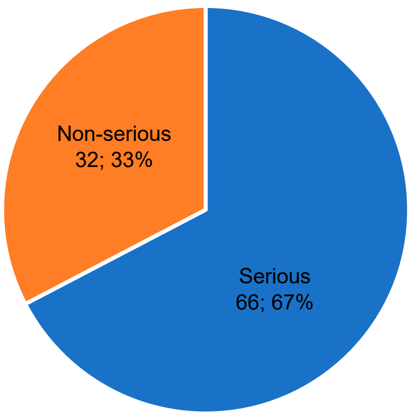


**Figure 9. Severity of the analyzed crankcase explosions**

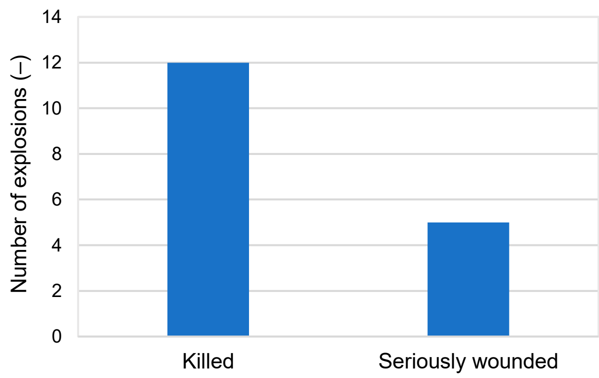


**Figure 10. Proportion of serious and fatal accidents in the analyzed population of crankcase explosions**

The proportion of explosions resulting in serious and fatal injuries is shown in Figure 10.

Among the incident population analyzed, 12 people were killed by explosions, and 5 were seriously injured. It follows that, statistically, about one-in-five explosions result in death or serious injury. The probability that a main engine crankcase explosion will result in injury or death is 17.34%. The above factors show the serious consequences of these accidents.

## Conclusions

The analyzed data show homogeneity and a similar level of decomposition of detailed information. The size of the initial population allows us to draw statistically reliable conclusions.

The prevention of explosions in the crankcases of marine main engines is always topical because the number of explosions remains constant (average of 2.13 explosions per year in the analysed population). Vessels of virtually all ages are affected, with half of all incidents occurring on vessels younger than 15 years old.

The topicality of this issue applies to both crosshead engines (MAN/B&W, Sulzer/Wärtsilä, Mitsubishi – 33 explosions; 31%) and trunk piston engines (MaK, Pielstik, EMD, and others – 60 explosions; 61%). Five engines in the analysed population were of an unknown type (5%). No manufacturer accounted for a significant proportion of engines in the analyzed population of explosions (58% of explosions took place in engines of the most popular prime mover manufacturers). These shares largely coincide with the share of engines of a given type in the total global population of marine main engines.

The overwhelming majority of incidents occurred during sea travel, and 67% of all incidents were classified as serious. The probability that a main engine crankcase explosion resulted in injury or death was 17.34%.

The presented results are only a small fragment of analogous accidents that have occurred in the global fleet, including some events that have occurred onboard ships without classification society supervision. Moreover, some events without injuries and some that were classified by the shipowner as less-significant may not have been included in the source material due to the failure to disclose them to the classification institutions. Nevertheless, the real number of explosions in crankcases is potentially higher than the number analyzed in the article with the simultaneous high size of the analyzed population. This confirms the validity of the topic of preventing this type of accident. According to the authors' best knowledge, this is probably the first paper that has analyzed such a large number of main engine crankcase explosions.

## Acknowledgments

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