Investigating the Human Factor in Maritime Accidents: A Focus on Compass-Related Incidents

Tanja Brcko[a], Ivica Pavić[b], Jakša Mišković[b], Andrej Androjna[a]

Accidents at sea can have devastating consequences, and investigating their causes is a complex and rigorous process. One of the most important factors contributing towards these accidents is the human factor, which has received considerable attention from researchers in recent years. This paper examines the role of the human factor in marine accidents, focusing on the use and maintenance of compasses. Using data from scientific journals and safety analysis reports, the frequency and focus of research on this topic are analysed and areas for further investigation are identified. International regulations, performance standards, and handling requirements relating to compasses are also discussed, and an analysis of compass-related accidents is presented. The survey conducted among seafarers indicates that they are satisfied with the performance of their compass, but there is a need for more advanced compass technologies and training on the proper use and maintenance of compasses. The survey shows that routine maintenance and calibration of compasses is crucial to minimise the possibility of human error and to prevent maritime accidents. In conclusion, the importance of conducting further studies in this area should be emphasised, taking into account the human factor, with a view to improving maritime safety measures.

KEY WORDS

~ Maritime accidents analysis
~ Ship compasses
~ Human performance
~ Survey

a. University of Ljubljana, Faculty of Maritime Studies and Transport, Slovenia
e-mail: tanja.brcko@fpp.uni-lj.si
b. University of Split, Faculty of Maritime Studies, Croatia

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1. INTRODUCTION

Marine accident investigations are complex and rigorous processes conducted to determine the causes of accidents. These investigations are important for a variety of reasons, including improving safety measures, preventing similar accidents in the future, and assigning liability for damage and loss. One of the main objectives of marine accident investigations is to determine the root cause of the accident, which often involves identifying a chain of events or a series of factors that led to the accident. Statistics show that between 2012 and 2021 there were a total of 26,707 accidents/incidents worldwide, taking into account only ships with a gross tonnage (GT) of 100 or more. According to Allianz (2022), most accidents were caused by engine damage or failure (9,968), followed by collisions (3,134), contact (2,029), piracy (1,995), and fire/explosion (1,747). In turn, the European Maritime Safety Agency (EMSA) reported that nearly 8,800 maritime incidents occurred between 2011 and 2021, involving 10,500 ships[1]. Most of these ships were cargo ships, accounting for 61.5% of incidents. Broken down by type of accident, collisions and groundings, each accounted for about 30%, while contacts between ships accounted for the remaining 40%. Navigation

1. *Applies to accidents involving ships flying the flag of an EU member state; or which have occurred in the territorial and internal waters of a member state; or which affect other essential interests of the Member States (EMSA, 2022).*

problems were responsible for 573 of these marine casualties, with the human factor accounting for 78%. System or equipment failures contributed to only 7.7% of the reported accidents (EMSA, 2022).

To reduce the number of accidents at sea, the factors causing these incidents need to be identified and addressed. According to data from the Web of Science, maritime accidents are a frequent topic of scientific research. In the period between 2000 and 2023, almost 4,100 publications were published on marine casualties, of which 212 included the topic of human factor/error, which is an interesting area of research. The software "VOSviewer"[2] was used to analyse the titles and summaries of the collected literature to gain a better understanding of the development and focus of research on marine casualties and human error. Figure 1 shows the network of research focused upon over the last 20 years, through differently coloured words indicating theoretical research keywords such as "human factor," "probability," "collision," "human error assessment," and more.

The size of the bubbles in Fgure 1 reflects the number of occurrences of the keywords in the literature, while the lines indicate the correlation between them, and the colour is determined by the cluster to which the topic belongs (Van Eck, 2022).

In marine accidents, human error is a crucial factor that researchers around the world are paying close attention to. There is a clear focus on studying the causal links between human actions and accidents, and on developing models to assess the likelihood and potential consequences of human error. The topic is currently the subject of intensive scientific research. Figure 2 shows the correlation between the research keyword "human factor" and other focal points. There are strong links to probabilistic models, the study of human performance, the assessment of reliability and error, etc. Looking more closely at the connections, one finds that human factor is closely linked to collisions and groundings, which is due to the fact that these two types of accidents are among the most common accidents at sea. According to the Safety Analysis Report (EMSA, 2022), the cause of the problem can be traced to the use of critical tools that support nautical behaviour, such as the use of compasses to determine visual bearing as additional sources for risk assessment. The authors have conducted an accident analysis, which has revealed that approximately 10% of collisions were caused by improper operation or use of the compass. This resulted in inaccurate readings on other navigation devices, such as Automatic Radar Plotting Aid (ARPA) radar, Electronic Chart Display and Information Systems (ECDIS), autopilot, ultimately influencing

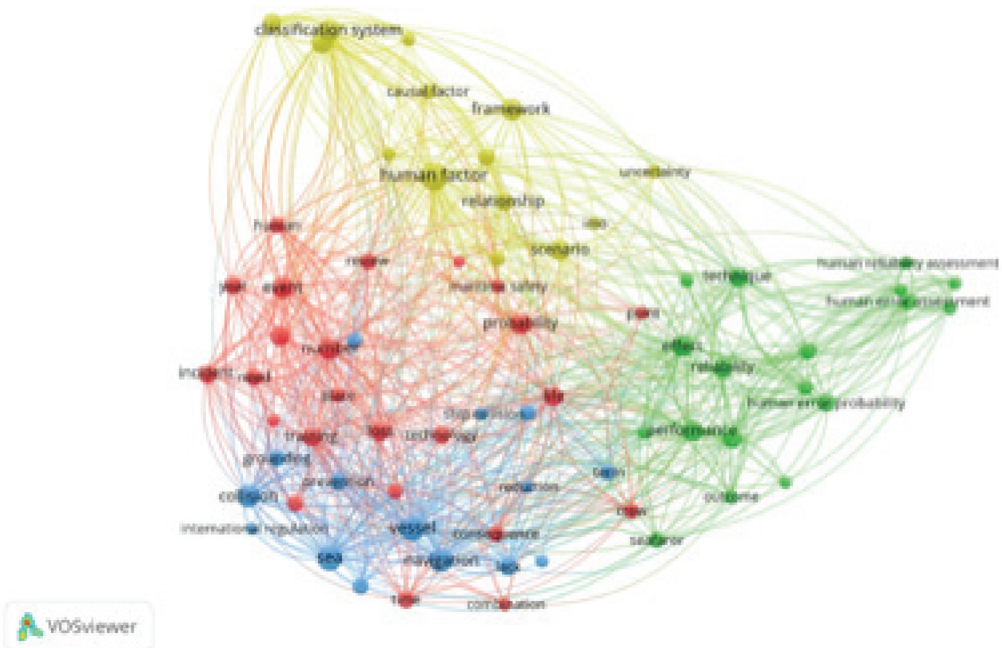

Figure 1.
Map of key words clustered for the human factor/error in maritime accidents (WoS database).

2. *VOSviewer is a software tool for creating and visualising bibliometric maps of the scientific literature (available at: https://www.vosviewer.com/)*

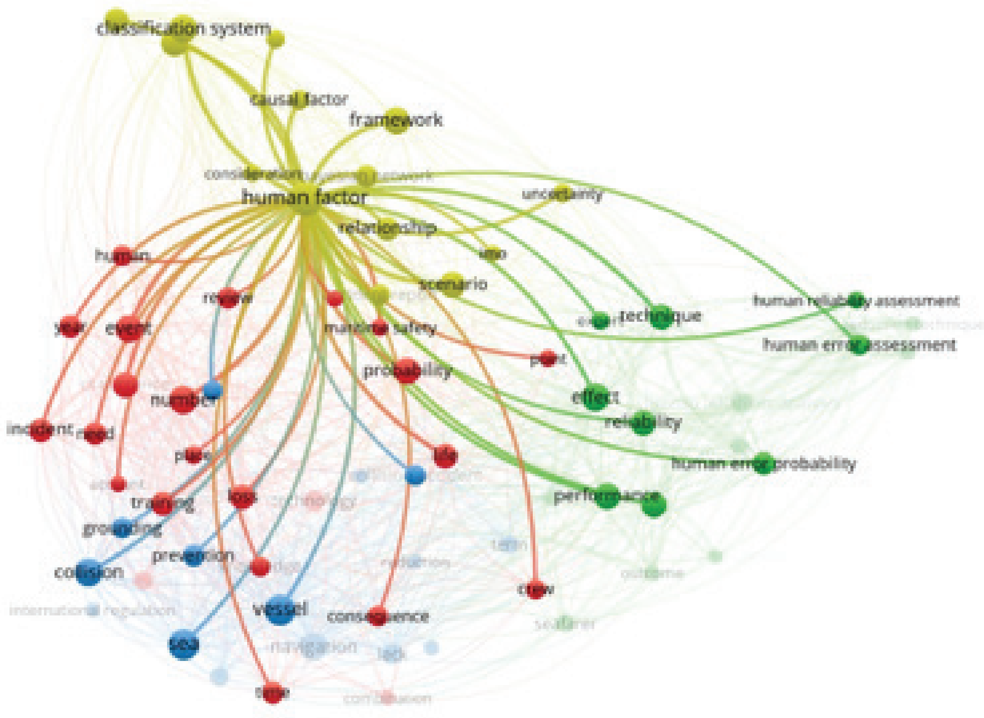

Figure 2.
Correlation between research keyword "human factor" and other focal points (WoS database).

the decisions of the Officer of the Watch (OOW) or pilot. The latter is also a leading factor in grounding accidents, although in smaller numbers than collisions. This is particularly problematic in areas where ships have to navigate through narrow channels or around obstacles, as even a small deviation from the course can cause a ship to run aground. It is therefore important that compasses be regularly maintained and calibrated to reduce the risk of compass errors. The results of the analysis are presented in more detail in the following sections.

This paper deals with one aspect of maritime accidents in which the handling or operation of a ship's compass played a role. The analysis of the accidents is used to determine the extent of human factors and technical errors of the compass or its connection to other navigational instruments. Also presented are the results of a survey conducted among seafarers on the use of ship compasses. Essentially, the purpose is to determine the extent to which seafarers are familiar with the operation and errors of marine compasses and which compasses are most commonly used on ships.

The paper consists of six sections, the first of which familiarises the reader with the topic of human factors in marine accidents and how it is presented in the scientific literature. The second section explains the methodology used in the study. The third section provides an analysis of the requirements for the carriage and handling of marine compasses and discusses both traditional and modern compass types to gain a better understanding of the navigational devices in question. The fourth section summarises the results of a survey of professional mariners, whereas the fifth section analyses and discusses compass-related accidents. Conclusions and suggestions for future research are presented in the sixth section.

2. METHODOLOGY

Three different methodological approaches have been used to conduct the study, including a literature review, an analysis of accidents and incidents, and a survey.

The systematic literature review focuses on the analysis of relevant sources related to the topic of the paper. These include international and national technical and training requirements, recommendations from professional authorities on accident investigation and data collection, compass manufacturers' manuals and catalogues, and scientific and professional papers on the subject of human error and accidents at sea. Relevant research databases and open sources have been used to collect the literature. The selected documents have then been analysed and merged, based on their contents and findings.

The following methodological approach has been employed to analyse accidents (and incidents) caused by or related to ship compasses. Data on accidents have been collected from various publicly available sources from 2000 to 2022. The data was analysed in two steps. In the first step, databases of investigation reports have been searched for evidence of groundings and collisions, as these two accidents at sea can be caused by problems with the ship's compass(es). In the second step, a thorough investigation of marine accidents related to ship compasses has been carried out. A total of 544 accidents have been analysed, of which 266 were groundings and 278 were collisions. Although these are a relatively small number of incidents, their significance and applicability to this research is paramount.

The third approach used in the study is the survey method. The purpose of the survey has been to collect information on the current use of marine compasses on ships and the extent of seafarers' knowledge at the working and management levels. It consists of three parts, with the first part containing an introduction and notes on the survey. The second part contains general questions about certificates of competency, seafaring experience, and shipboard duties to categorise respondents. The third part contains specific questions divided into two groups. The first group focuses on the use of compasses to determine the level of knowledge of the seafarers. Closed-ended questions with single or multiple-choice answers have been used for the second part and the first group of the third part of the questionnaire. The second group of questions focuses on the frequency and importance of using the compass for steering. A series of questions have been asked using a five-point Likert scale, including numerical values from 1 to 5. The numerical values indicate the degree of importance and frequency of performing the task, allowing a relationship to be established between the responses. The survey was conducted between December 2020 and February 2023. During this period, 193 responses were received and analysed. The authors administered the survey and interviewed 10% of the respondents in person or online to verify the results and ensure a clear interpretation. Discrepancies in some responses were also verified in subsequent interviews.

Some components of the survey have already been discussed in the paper "Comparison of the different compass types used in navigation" (Brcko, 2023). Moreover, the articles titled "Determining residual deviation and analysis of current magnetic compass usage" and "A review of magnetic compass usage in navigation" have also covered the survey components, although these articles only cover the fundamental requirements for accurate magnetic compass utilisation, as explained by Androjna (2021) and Pavić (2022).

3. NAVIGATIONAL COMPASSES

Throughout the history of seafaring, many different types of compasses have been developed and used. All these compasses have their advantages and disadvantages. Therefore, they are more or less reliable for use on ships, depending on the navigational area. The requirements for carrying compasses on ships are governed by various regulations and are defined in the International Convention for the Safety of Life at Sea (SOLAS).

3.1. Compass Carriage and Handling Requirements in Maritime Navigation

The carriage requirements for compasses are set out in SOLAS regulation V/19. Regulation V/19.2.1.1 requires all ships, regardless of size, to have a properly adjusted standard magnetic compass, while regulation V/19.2.2.1 requires ships of 150 gross tonnage (GT) or more, as well as passenger ships, regardless of size, to be equipped with a spare magnetic compass. In addition, Regulation V/19.2.5.1 requires all vessels of 500 GT or more to have on board a gyrocompass or other means of determining and indicating the course by non-magnetic means (IMO, 2020). The Maritime Administration may grant an exemption from SOLAS regulation V/19.2.1.1. for vessels equipped with two independent gyro compasses connected to the dual power supply system. This means that each compass must have an emergency power supply for 30 minutes. This is usually the case on dynamic positioning (DP) vessels Class 2 and 3 (Kjerstad, 2016).

International Maritime Organization (IMO) Resolution A.382(X) requires ships to carry magnetic compasses and undergo regular compensation processes, including the use of compass cards (IMO, 1977). IMO Resolution A.424 (XI) outlines the requirements for gyro compasses in terms of accuracy, settle point errors and their operation under varying conditions, such as rapid alterations of speed and course (IMO, 1979). Taking into account the particularities of High-Speed Craft (HSC), IMO Resolution A.821(19) sets out the performance standards for gyro compasses of such ships, specifying accuracy, static and operational (dynamic) performance (IMO, 1995). Therefore, all vessels must be equipped with a magnetic compass and, depending on the size, a gyro compass or some other kind of non-magnetic compass. It is essential that the magnetic compass be adjusted and a deviation table or curve provided.

The requirements for handling compasses are contained in the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW). According to the STCW Code (A-II/1), operational-level navigation requires that officers in charge of a navigational watch have knowledge of the principles of magnetic and gyro compasses and be able to determine compass errors. According to the STCW Code (A-II/2), navigation at the management level requires that masters and chief mates understand the systems under the control of master gyro and have knowledge of the operation and maintenance of the main types of gyro compasses (IMO, 2017). In addition, the STCW Convention, in the Principles for Keeping Navigational Watch, requires periodic checks and determination of the standard compass error at least once per watch and, if possible, after each major alteration of course. It also requires regular comparison of the readings of the standard compass and the gyro compass and synchronisation of the repeating compasses with master compass (IMO, 2017).

3.2. An Overview of Traditional and Modern Technologies of Ship's Compasses

One of the earliest navigation tools was the astronomical compass, which utilised the positions of celestial objects, such as stars or the sun, to ascertain true north. This device operated by aligning a sighting mechanism with a celestial body and gauging the angle between the body and the horizon. This angle is used to calculate the observer's latitude and longitude and determine the direction of true north. Astronomical compasses have been used for centuries by mariners and explorers in the polar regions, and are still an important tool for scientists and researchers working in these areas, as conventional compasses are less reliable due to their proximity to the Earth's magnetic poles. Therefore, an astronomical compass is often used instead to navigate and determine direction (Linton, 2013).

The magnetic compass, and later the gyrocompass, have played an important role in navigation, enabling navigators to determine the ship's heading instantly without additional calculations. These two types of compasses have long been the most important devices on the bridge. Despite technological advances, the magnetic compass has been used as a substitute for modern compasses because it does not require a power source. Due to its simple design, relatively small size, and low cost, the magnetic compass is considered basic equipment and often the only compass on ships not under the SOLAS Convention. The accuracy of these compasses depends on the magnetic field of the Earth and the ship. In order to function accurately, they must be compensated, adjusted, and calibrated in accordance with the IMO regulations (IMO, 1977). Traditionally, compensation is performed by determining the deviation coefficients and creating a deviation table or curve. However, alternative methods have been developed, such as Łushnikow's (2018) technique, that utilises the compass's directional force to minimize deviations and increase guiding force. However, this method requires modifying the current compass design. In addition to the above-mentioned techniques, it is important to acknowledge other methods for calculating coefficients of deviation on each course. These include the last-square method proposed by Nguyen (2019), the use of a device that automatically collects deviation information suggested by Felski (1999), and an algorithm for estimating latitude error presented by Basterretxea (2016). However, it is crucial to note that these proposals require practical validation and are based on either the existing deviation tables or technical adjustments to the already existing compasses.

Nowadays the gyro compass is most commonly used on SOLAS ships[3]. The gyro compass is known for its high accuracy and precision compared to the magnetic compass. Therefore, it is often used as the primary compass on ships for regular navigation, while the magnetic compass is reserved for emergency situations (Łushnikow, 2015). There are two main types of gyroscopes, namely top-heavy and bottom-heavy gyroscopes, which influence the technical performance of gyroscopes (Kjerstad, 2016). This, in turn, influences the design of the gyrocompass, with leading manufacturers, like Raytheon Anschütz, to utilise a bottom-heavy gyroscope, while others prefer top-heavy gyroscopes (Anschütz, 2005; Kjerstad, 2016). According to Škrobonja (2020), gyrocompasses exhibit both static and dynamic errors. Structural measures can help to address some of the dynamic errors, but the speed/latitude error is particularly noteworthy as it can be automatically corrected through the use of position and velocity sensors (Škrobonja, 2020; Kjerstad, 2016; Anschütz, 2015). The gyro errors tend to increase with higher latitudes, which can pose limitations on the use of gyrocompasses in these regions.

To overcome the limitations of conventional magnetic and electromechanical compasses, electronic compasses have been developed using technologies, such as fluxgate compasses, optical and hemispherical resonator gyroscopes (Bowditch, 2017). Fluxgate compasses utilise a fluxgate magnetometer sensor, consisting of coils that detect changes in the magnetic field induced by the earth's magnetic field (Baschirotto, 2006). Although still affected by large changes in the ship's magnetic field, fluxgate compasses offer advantages in terms of reliability and maintenance over traditional magnetic compasses, and do not require classical compensation (Bowditch, 2017; Makar, 2022). Optical compasses are classified into two types: Ring Laser Gyroscopes (RLG) and Fiber Optic Gyroscopes (FOG) based on the structure of the gyroscope. They are based on the Sagnac effect, in which the rotation of a medium results in a phase shift of counter-propagating electromagnetic waves. RLG utilises a fiber optic ring to measure laser-generated light waves travelling in opposite directions. FOG, on the other hand, uses a coiled optical fiber system to detect the intensity of light beams based on the

3. A SOLAS ship is a vessel that complies with the safety requirements and regulations set out by the SOLAS convention. These requirements cover a wide range of aspects related to ship safety, such as ship construction, fire protection, lifesaving appliances, communication equipment, and navigation equipment. The aim of the SOLAS convention is to ensure that all ships, regardless of their flag or nationality, meet a consistent set of safety standards to protect human life at sea.

phase difference and gyroscope's angular velocity (Kjerstad, 2016; Bowditch, 2017; Škrobonja, 2020; El-Sheimy, 2020).

The development of modern marine compasses has also used Hemispherical Resonator Gyro (HRG) technology, which has proved to be extremely reliable when used in space (Bowditch, 2017). The HRG is based on the Coriolis effect in measuring the input velocity (El-Sheimy, 2020). The principle of this technology is that the gyroscope (resonator) changes its shape under the influence of the Coriolis acceleration that occurs when the sensitive element is excited to vibrate and is simultaneously rotated (Felski, 2008). Therefore, the technology of vibrating resonator gyroscopes is used, where angular rate sensors and accelerometers measure rotation rates and accelerations. Heading, rotation, and inclination are calculated based on these measurements (El-Sheimy, 2020; Anschütz, 2016; Anschütz, 2023). Subsequently, these compasses can also measure the pitch and roll of the ship, in addition to heading (Felski, 2008).

Optical compasses offer numerous advantages over gyro compasses. These include the absence of any mechanical components, faster settling time, no maintenance requirements, and unrestricted use in polar regions. However, they come at a higher cost compared to gyro compasses (Škrobonja, 2020; Sperrymarine, 2022; Tokyo Keiki, 2022). A viable alternative to optical compasses is a satellite compass, which serves as a heading sensor for various ship technologies, such as ARPA radar, Automatic Identification System (AIS), ECDIS, and sonar. The function of the satellite compass is to acquire signals from a Global Positioning System (GPS) satellite network and use complex algorithms to calculate the user's exact position and orientation in three dimensions. The compass has a great advantage of having no mechanical components, requiring no routine maintenance, and not being affected by ship speed or geomagnetism (Furuno, 2022). However, as the accident analysis has shown, navigating a ship with a satellite compass also has a disadvantage. The helmsman, who is inexperienced in steering solely with the digital compass, has difficulty in maintaining a stable course. Also, unlike the gyro and magnetic compasses, it cannot measure azimuths. Regardless of the type of compass, the ship's compass must provide the data on the ship's course necessary for safe navigation to keep the ship on the indicated course, while also providing reliable data for other navigation sensors.

4. SURVEY ON THE USE OF COMPASSES ON SHIPS

In order to gain an understanding of how ship compasses are used today, a survey was conducted among seafarers. Once responses were received, the data was processed using a statistical, descriptive, and comparative methods. The initial stage of data processing involved identifying the sample of respondents, which was determined by considering three key questions: Certificate of Competency (CoC), seagoing experience, and current (or last) assignment on board. Out of the total number of seafarers (193) that responded to survey, 79 (40.9 %) hold the CoC for Officers in charge of a navigational watch on ships of 500 GT or above, 24 (12,4 %) officers hold the CoC of Chief mate on ships of 3,000 GT or more, and 71 (36.8 %) hold Master mariner unlimited certificates. Other officers, 19 (9.9 %), who responded to the survey, hold the CoC for Master on ships between 500 and 3,000 GT, or naval and other national certificates.

In terms of seafaring experience 37 (19.2 %) respondents have 1 - 4 years of sea service, 61 (31.6%) have 4 - 10 years of sea service, 41 (21.2 %) have 10 – 15 years of sea service, while 54 (28%) have more than 15 years of sea service. The total number of respondents, their qualifications, and seagoing experience provide a relevant sample to draw reasonable conclusions about the knowledge and use of different types of compasses aboard ships.

The respondents' general use of compasses was determined by the following questions: compass error determination, intervals of deviation check, use of a deviation table (curve), and use of a table to correct for speed/latitude errors. The respondents were asked about regular deviation check (error determination) of a magnetic compass, to which 152 (78.8%) of the respondents answered positively, while 41 (21,2%) answered negatively. When asked the same question regarding the gyro compass, 166 (86%) of respondents answered positively, while 27 (14%) answered negatively. To establish a correlation between the answers to these questions, the respondents were asked to determine the intervals of regular deviation check (error determination) of a magnetic and gyro compass. The distribution of responses to these questions is shown in Table 1.

The purpose of these questions is to see to what extent the officers use ship's compasses in navigation. The results show that only 91 (47.2%) of the respondents check the deviation of a magnetic compass, while 94 (48.7%) of the respondents check the deviation of a gyrocompass at regular intervals according to STCW regulations. A comparison of the responses to these questions revealed that of the original 78.8% (for magnetic compasses) and 86% (for gyrocompasses) of respondents who indicated that they perform a regular deviation check, approximately 40% are not aware of the relevant STCW regulations or do not use them appropriately.

Another segment of the appropriate use of compasses in navigation is the use of a deviation table (curve) and a speed/latitude error corrections table. Respondents were asked about the use of a magnetic compass deviation table (curve) in navigation, to which 112 (58%) of the respondents answered positively, while 81 (42%) answered negatively. When asked the same question about using a gyro compass speed/latitude

Table 1.
Intervals of deviation check of the magnetic and gyro compass (Brcko, 2023).

Intervals of regular deviation check	Magnetic compass	Gyro compass
	%	%
At least once of month	11.9	5.7
At least once a week	9.8	10.9
At least once a day	16.6	22.3
At least once a watch	16.6	18.1
At least once a watch and, when possible, after any mayor alteration of course	30.6	30.6
Other	14.5	12.4

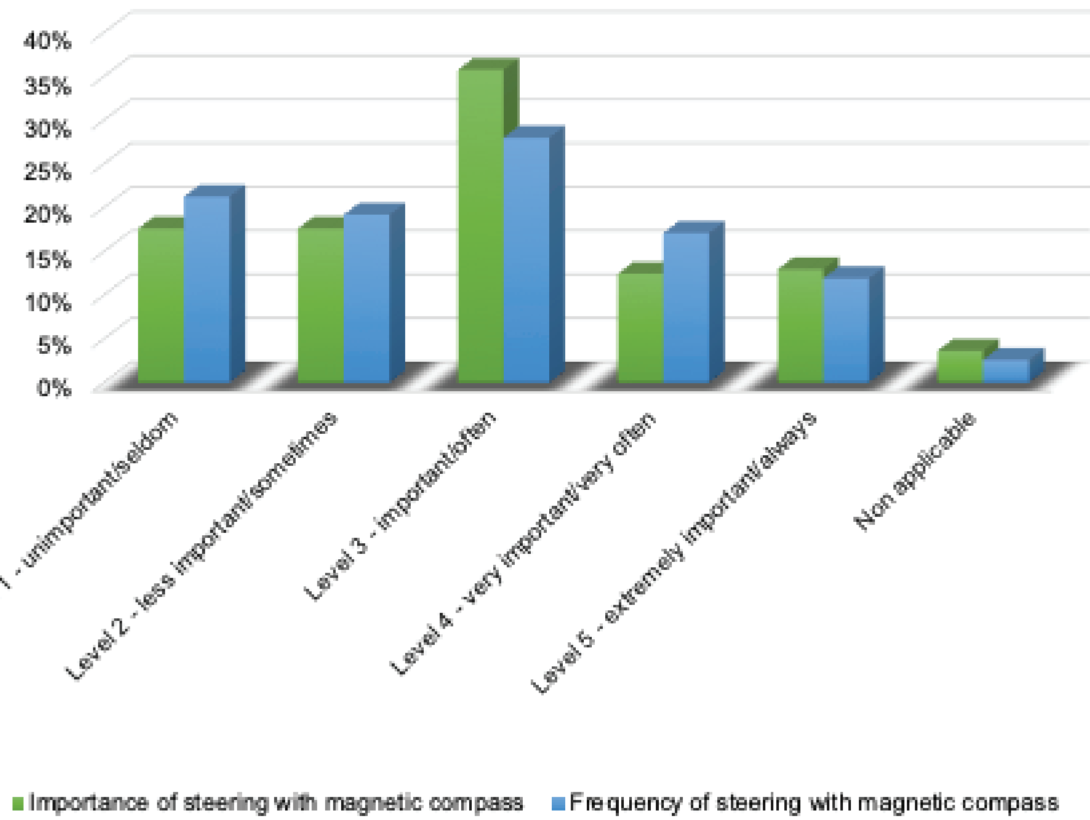

Figure 3.
The importance and frequency of steering with magnetic compass (Source: Authors).

error corrections table in navigation, 82 (42.5%) respondents answered positively, while 111 (57.5%) answered negatively. These questions are also directly related to the IMO requirements for the appropriate use of the compass. A relatively high percentage of negative responses about the use of the deviation table (curve) of the magnetic compass therefore indicates that the STCW requirements are not applied by more than 40% of the respondents. A very high percentage (57.5%) of negative responses to the use of the speed/latitude error corrections table for gyro compasses can be interpreted as meaning that gyrocompasses nowadays offer the possibility of automatic correction of speed/latitude errors.

To understand which compasses are most commonly used on ships, respondents were asked about the type of compass they use for steering. Respondents could give multiple answers to this question, with 19 (9.8%) using a magnetic compass, 179 (92.7%) using a gyro compass, 9 (4.7%) using an optical compass, and 7 (3.6%) using a satellite compass. The distribution of responses indicates that the largest percentage of respondents use the gyro compass for steering, while the magnetic compass is used primarily by respondents on non-SOLAS ships (where it is the only compass) or in emergencies. The responses also indicate that a relatively small number of respondents use modern optical and satellite compasses. Therefore, this number of respondents cannot be considered a relevant sample for determining the use of these compass types in navigation.

To provide context to the previous question, the respondents were asked to rate the importance and frequency of using magnetic and gyro compasses for steering. The responses for magnetic compasses are shown in Figure 3.

The data distribution in Figure 3 shows that the respondents rate the importance and frequency of steering with magnetic compasses about the same. In addition, the data shows that a small percentage of respondents indicate the highest importance (12.95%) and frequency (11.92%) in steering with magnetic compasses, which is almost completely consistent with

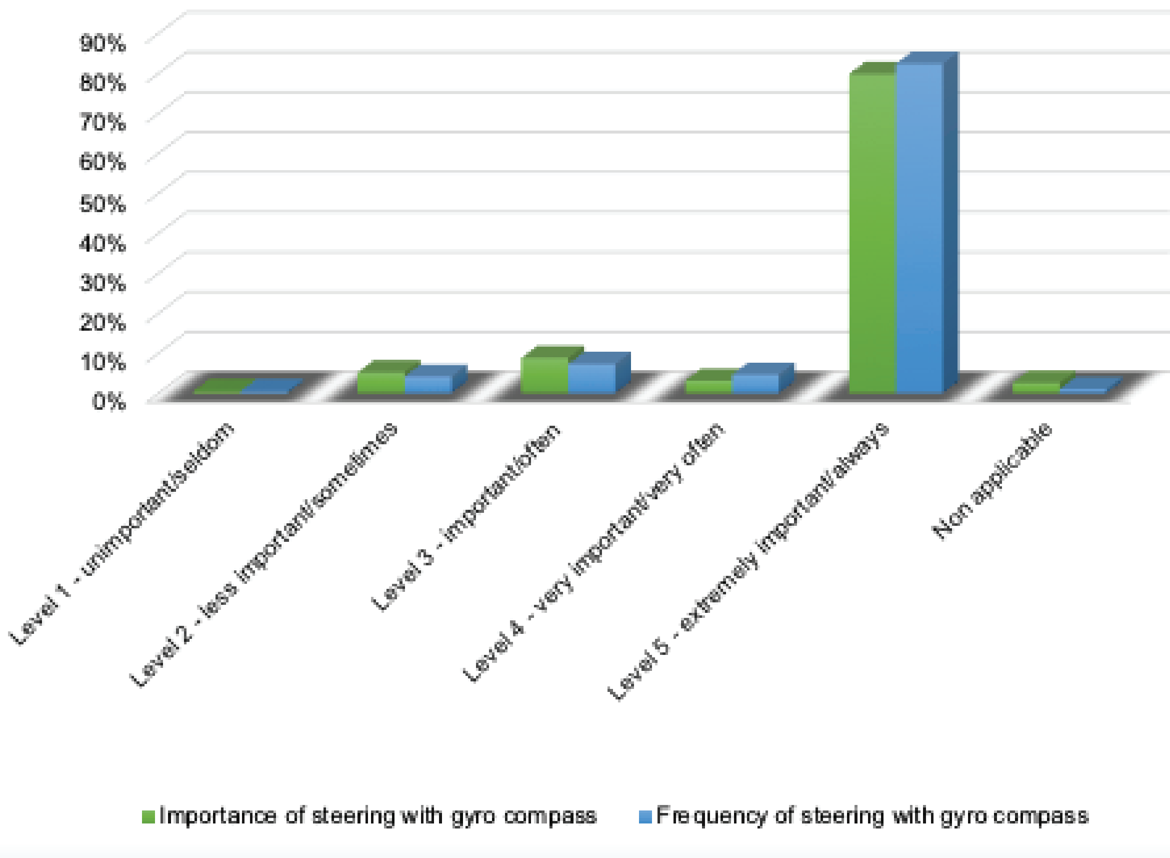

Figure 4.
The importance and frequency of steering with gyro compass (Source: Authors).

the answer to the previous question. These answers confirm the well-known fact that magnetic compasses are relatively rarely used for steering.

The respondents were also asked to estimate the importance and frequency of using gyrocompasses for steering. The responses are shown in Figure 4.

For this question too, the respondents rate the importance and frequency of steering with the gyrocompass about the same, but with a significantly different distribution of answers than for the previous question. The data shows that a large percentage of respondents give the highest importance (79.79%) and frequency (82.38%) to steering with a gyrocompass. It is therefore quite clear that the respondents recognise the current importance and frequency of using gyrocompasses. Furthermore, these answers confirm the well-known fact that gyrocompasses are most commonly used today for steering on ships.

5. ANALYSIS OF MARITIME ACCIDENTS

The use of compasses to determine the visual bearing is an important tool for the nautical guidance of a ship. Rule 7 of COLREG (Convention on the International Regulations for Preventing Collisions at Sea) states that there is a risk of collision if there is no appreciable change in the compass bearing of an approaching vessel (IMO, 1972). As already mentioned in the introduction, EMSA noted in its report the problem of the lack of use of the compass for risk assessment (EMSA, 2022). Another potential failure that can occur is a compass error, which can lead to a serious accident. To better understand the impact of this problem, an analysis of marine accidents, published by various organisations, such as the Marine Accident Investigation Branch United Kingdom, the Transport Accident Investigation Commission New Zealand, the Marine Accident Investigation and Shipping Security Policy Branch Hong Kong, the Accident Investigation Board Finland, the Australian Transport Safety Bureau, and the Transportation Safety Board of Canada has been conducted by the authors. The results of this analysis provide a valuable insight into the types of compass errors or human errors that have led to collisions and groundings, and highlight the importance of proper compass operation for safe navigation.

The authors have examined the published accident reports from commercial, fishing, and private vessels between 2000 and 2022, weighing 100 GT or above, as well as those weighing under 100 GT, with the exclusion of warships. Out of 544 accidents investigated, 23 collisions and 7 groundings were either directly or indirectly related to the use or operation of the ship's compass. The main cause of collisions was noncompliance with COLREG Rule 7, specifically noncompliance with observing compass azimuth at close-quarter situations (17 of the accidents).

A common factor in most of the grounding accidents was mechanical failure of the compass. One of the groundings occurred on 11th April 2018, when the landing craft Lauren Hansen ran aground near Cape Keith in Australia. The probable cause of the grounding was found to be a fault in the upper compass sensor unit, which relays heading information to the autopilot. In addition, no compass deviation log was maintained (ATSB, 2018). A similar accident that resulted in an environmental disaster was the grounding of the ship Rena at Astrolabe Reef in New Zealand on 5th October 2011. The accident occurred because the bridge crew gradually set the autopilot to an incorrect course without taking the gyrocompass error into account. The logbook and compass error log showed that the compass error on board the Rena was usually determined less than four times per day, often only once or twice (TAIC, 2014). Another accident resulting in grounding occurred with the passenger ferry m/v Finnfellow on 2 April 2000 on the north coast of Fögloe in the Aland Archipelago. The events leading to the grounding occurred as the vessel approached the end of a turn to starboard. During the turn, when only 2.5 degrees remained of a 50-degree course change, the gyrocompass jammed at the same reading for 66 seconds, resulting in the grounding (AIBF, 2001). Other accidents occurred mostly due to the following:

- Power failures that caused the gyrocompass to be misaligned (TSB, 2014),
- Failure to connect the compass to other equipment (converting the analogue signal to digital and vice versa) (TSB, 2009),
- The radar image was not gyro-stabilized or disabled the ARPA function of the ship's radar (MAIB, 2002a; TAIC 2000; TAIC 2001),
- Failure to check the deviation of the gyro and magnetic compasses (ATSB, 2018; TAIC, 2014),
- Insufficient practice in steering with the digital compass alone (MAIB, 2020; MAIB, 2021),
- Improper compass linked to an auto-pilot (MAIB, 2011),
- Non-functioning compass (MAIB, 2015),
- Use of unsuitable compasses e.g., electronic magnetic compasses may be unsuitable for use within a steel wheelhouse, etc. (MAIB, 2002b; MAIB, 2011).

The proportion of the most common errors is shown in Fig. 5. The outcome of the analysis served as a reinforcement to the importance of using accurate navigation tools and techniques in order to avoid collisions and other maritime accidents.

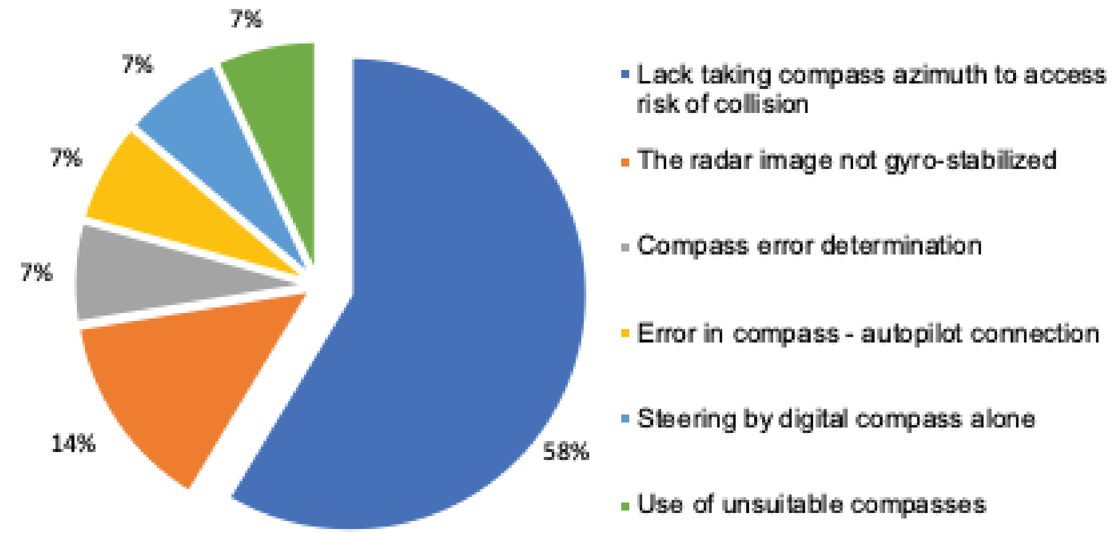

Figure 5.
The proportion of the most common errors involving operation or use of the ship's compass (Source: Authors).

6. DISCUSSION AND CONCLUSION

The paper is divided into two parts. One deals with the types and use of ship compasses and the analysis of their use in practice based on a survey, while the other part examines the problems related to ship compasses and the related errors resulting from the analysis of marine accidents.

The questionnaire is an essential part of the scientific research on the use of compasses aboard ships. Deck officers and masters have anonymously provided responses to be used for statistical analysis. The survey has collected data on the use of compasses in navigation, and the results seem to suggest that many respondents do not adequately apply the relevant STCW provisions. Only 47.2% of respondents check the deviation of a magnetic compass, and 48.7% check the deviation of a gyrocompass at regular intervals in accordance with STCW regulations. In addition, a relatively high percentage of negative responses about the use of the deviation table (curve) of a magnetic compass indicates that the STCW regulations are not applied by more than 40% of the respondents. A very high percentage (57.5%) of negative responses to the use of the speed/latitude error corrections table for gyrocompasses can be interpreted as meaning that gyrocompasses nowadays offer a possibility of automatic correction of speed/latitude errors. The largest percentage of respondents use the gyrocompass for steering, while the magnetic compass is used primarily by the respondents on non-SOLAS ships or in emergencies. A relatively small number of respondents use modern optical and satellite compasses. Overall, the survey results underscore the importance of seafarers to be aware of the appropriate use of compasses in navigation and to comply with the relevant regulations. Further education and training may be needed to improve the understanding and use of compasses among seafarers, especially given the technological advances in compass systems.

An analysis of marine accidents involving ships between 2000 and 2022 found that 23 collisions and 7 groundings were related to the use or operation of the ship's compass. The failure to comply with COLREG Rule 7, which states that the risk of collision exists if the compass bearing of an approaching ship does not appreciably change, was the main cause of collisions. Mechanical failure of the compass was a common factor in most grounding accidents. Other factors included power failures, failure to connect the compass to other equipment, and insufficient practice in steering with the digital compass alone. These findings emphasise the importance of proper compass operation, regular maintenance, and accurate navigation techniques to prevent collisions and other maritime accidents. It is crucial for ship operators and crew to comply with COLREG Rule 7, maintain accurate logs, conduct regular checks, and ensure the proper functioning of compasses and other navigation equipment to ensure safe navigation at sea. Training and proficiency in using compasses and other navigation tools should also be prioritised in order to enhance maritime safety.

This paper raises issues for further research on the use of compasses aboard ships, such as investigating the effectiveness of training programmes on the proper use and maintenance of ship compasses among ship officers; investigating the accuracy and reliability of modern optical and satellite compasses compared to traditional magnetic and gyro compasses; analysing the influence of weather conditions and sea state on the accuracy of ship compasses and their impact on navigational safety; the study of the role of ship design and compass installation in reducing compass-related accidents; or examining the impact of advances in navigation technology on the use and relevance of marine compasses in today's maritime environment.

CONFLICT OF INTEREST:

The authors declare no conflict of interest.

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