Spatial and Statistical Analysis of Operational Conditions Influencing Accident Formation in Narrow Waterways: A Case Study of Istanbul Strait and Dover Strait

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Abstract

Identifying accident-prone areas in narrow waterways, which are the nodal points of global maritime trade, assessing accident risks, and reviewing existing safety measures are essential for countries adjacent to narrow waterways as well as all other stakeholders of maritime trade. Furthermore, this is a requirement to ensure safety-sustainable maritime trade. In this study, marine accident density maps were generated utilizing Geographical Information Systems (GIS) software based on reports of collision, contact, grounding, and sinking accidents that occurred in Istanbul Strait (IS) and Dover Strait (DS) between 2004-2020. The Chi-Square independence test, one of the main statistical methods, was then used to determine if there were statistically significant relationships between the operational conditions and the accident type, the accident severity, and the Kernel density. Finally, the operational conditions and statistical results were presented to experts, who are familiar with the area, discussed, and then validated. As a result, marine accident density maps for IS and DS were presented and the hazards arising from operational conditions in these narrow waterways were determined. The results of the study will help to raise awareness about the current hazards arising from operational conditions in IS and DS, which are important hubs of maritime trade.

Keywords: Istanbul Strait, Dover Strait, Narrow waterways, Marine accidents, Geographical Information Systems (GIS), Spatial analysis

1. INTRODUCTION

Coastal areas, especially narrow waterways, are regions where marine accidents frequently occur (Bateman et al., 2007; Huang et al., 2013; Squire, 2003; Ulusçu et al., 2009). Despite the developments in maritime technology and the international safety rules that have come into force, marine accidents continue to occur in narrow waterways and are a serious threat to the maritime industry (Akhtar and Utne, 2014; Macrae, 2009). According to the European Maritime Safety Agency (EMSA) data, approximately 3000 marine accidents occurred annually between the years 2015-2020. In this period, the decrease in the number of accidents between two consecutive years does not reach more than 7% (EMSA, 2021). The fact that accidents could not be prevented at the targeted level on a global scale makes the effectiveness of the measures taken against accidents somewhat questionable (Chauvin et al., 2013; Schröder-Hinrichs et al., 2012; Uğurlu et al., 2020). In narrow waterways, traffic separation lines, pilotage services, and vessel traffic services are essential applications that ensure navigational safety (Praetorius and Hollnagel, 2014; Tian et al., 2020; van Westrenen and Praetorius, 2014). On the other hand, local traffic, strong currents, sharp turns, intense environmental lights, marine topography, the inadequacy of anchorage areas, and transit ship traffic are the main factors that threaten the safety of navigation on narrow waterways (Köse et al., 2003; Başar, 2010; Ugurlu et al., 2013).

The Istanbul Strait (IS) and the Dover Strait (DS) are important and busy narrow waterways for maritime trade. Accidents and the factors that cause accidents in these narrow waterways are variable in nature (Yildiz et al., 2021a). Intensifying ship traffic day by day brings potential accident risks (Aydogdu et al., 2012; Emecen Kara, 2016). Therefore, it is necessary to identify reoccurring and variable risks in narrow waterways and determine relevant risk control options, to ensure sustainable maritime trade. Every year, approximately 150,000 ships pass through DS (Commission, 2000) and 50,000 ships through IS (UAB, 2021). Between 2011 and 2018, 2,370 marine accidents occurred in the whole English Channel area and 106 marine accidents in Turkish Straits, including IS (EMSA, 2018; Qu et al., 2012). Numerical data and academic studies have proven that IS and DS are hazardous navigational areas.

The most common accident types among marine accidents are collision, contact, sinking, and grounding (Chauvin et al., 2013; Graziano et al., 2016; Martins and Maturana, 2010; Zaccone et al., 2020). These marine accidents also occur frequently in narrow waterways. All four accident types are closely related to the structure of narrow channels, traffic density, and environmental conditions (Aydogdu et al., 2012; Squire, 2003). Therefore, this study focuses on these specific accident types (collision, contact, sinking, and grounding).

IS has been studied frequently due to its strategic importance and geographical location. Akten (2004) determined the risky sea areas and revealed the associated risks by conducting a spatial analysis of 461 marine accidents that occurred in IS between the years 1953-2002. Arslan and Turan (2009) revealed the factors affecting the occurrence of marine accidents in IS utilising the Analytic Hierarchy Process (AHP) and Strength, Weakness, Opportunity, Threat (SWOT) analysis methods. Aydogdu et al. (2012) observed the effect of local traffic on the Istanbul Strait by performing Marine Traffic Fast Time Simulation modelling. Uğurlu et al. (2016) evaluated marine accidents in the Istanbul Strait regarding economic loss and death/injury. Similarly, Aydogdu (2014) determined the dangerous areas and threats at the southern entrance of the Istanbul Strait in terms of ship traffic with the Generic Fuzzy AHP model.

By comparison to IS, the number of studies related to marine accidents in DS is very limited. Roberts (2008), in his study, examined the fatal accidents that occurred on British merchant ships between 1919 and 2005 and revealed the main causes of death in the area. These are listed as sinking in storms or heavy weather, fires and explosions in holds, and collisions in restricted visibility. As a result, he emphasized that the innovations made in the field of occupational health and safety reduce the deaths caused by accidents. Squire (2003) examined the relationship between ship accidents and ship traffic in DS. As a result of the study, the causes of accidents in DS were revealed and recommendations were made to prevent them. It was emphasized that violations of the International Regulations for Preventing Collisions at Sea (COLREG) have a great impact on accidents and the Traffic Separation Schemes (TSS) structure also plays an active role in the occurrence of accidents.

On 20 March 2018, a collision occurred between a Maltese flagged general cargo vessel and a Belgian flagged fishing vessel in DS. As a result of the accident, the fishing vessel completely sank, and all crew members were rescued by search and rescue operation. The general cargo vessel was damaged at the bow (Malta, 2019). On 7 April 2018, at Beylerbeyi (in the sector Kandilli) in IS, a Maltese flagged 225m bulk carrier contacted the shore due to rudder failure. The total cost of the accident to the shipping company, including the damage to coastal structures, was over $50 million (ECON, 2019). These and similar marine accidents, which have recently occurred in both narrow waterways, prove that the safety measures taken in narrow waterways should potentially be reconsidered. Determining risky sea areas in narrow waterways with high traffic density, identifying current risks, and reviewing existing safety measures are important for countries adjacent to narrow waterways and other parties of the maritime industry.

This study created a marine accident density map with ArcMap 10.5 software by using the reported marine accidents in IS and DS between 2004-2020 (ESRI, 2017; IBM, 2013). The existence of the relationship between important factors such as accident type (collision, contact, grounding, sinking), accident severity (less serious, serious, very serious), time of day (day, night), the season in which the accident occurred in the sea areas where the accidents are concentrated was tested with Chi-Square, which is a well-known and used statistical method. Furthermore, the factors that showed a significant relationship in the areas with intense accidents were interpreted in line with the opinions of experts who have extensive knowledge of the area. The study presents marine accident density maps for IS and DS, as well as the hazards arising from operational conditions in these narrow waterways. The results of this study will contribute to raising awareness about the current dangers arising from operational conditions in IS and DS.

2. GEOGRAPHIC INFORMATION SYSTEMS (GIS) BACKGROUND

GIS provides the ability to visualise, export, and analyse geographic information (Toreyen et al., 2011). Today, GIS software can perform almost any imaginable operation on geographic data and recognise hundreds of different file formats (Goodchild, 2009). Due to these features are being used for scientific purposes in many fields, including accident analysis (Ayalew and Yamagishi, 2005; Kavzoglu et al., 2014; Leidwanger, 2013). GIS is a vital and comprehensive management tool for traffic safety that makes it possible to visualise (Erdogan et al., 2008) and interpret accident data on a map (Liang et al., 2005). In maritime transport, GIS enables the distribution, classification, and interpretation of multiple accident data points on a digital map (Uğurlu et al., 2015).

GIS is a helpful tool for analysing marine accidents as it allows the processing of both spatial data and attributes data. In this study, ArcMap 10.5 is used for spatial density analysis. The Kernel Density Analysis method was preferred to transform accident data points into density maps. The Kernel Density Analysis method provides an estimation of the probability density function (f(x)) of any continuous random variable (x) by using non-parametric regression analysis. By using the sample data of an event or situation, it reveals the value range function of the probability of this event occurring in a certain neighbourhood. For example, let $x_1, x_2, x_3, \ldots, x_i$ be independently and identically distributed samples (accidents in a given area). The density distribution function $\hat{f}_h(x)$ of these samples is calculated as follows (Anderson, 2009; Okabe et al., 2009):

$$\hat{f}_h(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x-x_i}{h}\right) \quad (1)$$

where;

$\hat{f}_h(x)$: Kernel density distribution function

K : Kernel Function with symmetric probability density function and not a negative value

h : Correction parameter called search radius (bandwidth); should always be h>0, but the dataset should be kept as small as it allows

n : Sample size

x : Kernel Centre (origin of the specified location for analysis)

x_i : i^{th} sample

x-x_i : Distance between Kernel Centre and sample value (distance)

3. METHOD

In this study, spatial and statistical analyses were constructed with ship accidents within the traffic separation schemes in 2 narrow waterways (IS and DS). The Kernel Density estimation method was used in the spatial analysis of accident data, and Chi-Square independence test was used in the statistical analysis of the data. The results of the analyses were shared and interpreted with experts from the sector who have the necessary knowledge and experience in IS and DS. The study was completed in five consecutive steps (Figure 1).

Figure 1. Flow chart of the study

3.1. Obtaining accident reports and preparation of the dataset

In the first step of the study, a database containing spatial and attribute data of ship accidents, in IS and DS, was created. Data was collected from 17 different international marine accident databases (Table 1). Accident investigation organisations are members of the International Transport Safety Association (ITSA) and are recognised by many international institutions and organisations, such as IMO and EMSA.

Table 1. Scrutinised marine accident databases

In accordance with the scope of the study, a total of 6,548 accidents that occurred in the 16 years between 01.01.2004 and 01.01.2020 were scrutinised. Of these accidents, 5,175 accidents were obtained from the GISIS database (GISIS, 2020), 944 accidents from the MAIB database (MAIB, 2020), and 429 accidents from the UEIM database (UEIM, 2021). Each accident's spatial information (Global Positioning System (GPS) data) was then positioned on the electronic chart and was reviewed as to whether the accident would be included in the data set of the study. Following the spatial analysis, the various accident types were examined. Since collision, contact, grounding, and sinking accidents will be examined within the scope of the study, the accidents that occurred in other categories were excluded from the data set of the study. As a result, 274 (IS: 240, DS: 34) out of 6,548 marine accidents were taken as the data set to be used in the study. In all of these accidents, at least one of the ships involved is subject to IMO regulations (vessels of 500 gross tonnages or above).

3.2. Spatial analysis of accidents and identification of hot areas

At this step, the hot spot areas where accidents are concentrated were determined by using the Kernel Density Analysis method, and a marine accident density map was created for each narrow waterway. Raster nautical charts were preferred to interpret anchor points, traffic separation schemes, lighthouses, buoys, and geographical shapes in the density map created for narrow waterways (ESRI, 2019; OpenCPN, 2020). The primary purpose of Kernel Density

Analysis is to generate density distribution maps in the desired search radius from the core points where the accidents occur (Bonnier et al., 2019). The search radius is required to calculate Kernel densities in the geographic area where accidents (point data) are located. Conceptually, it is assumed that there is a uniform area around each accident within the distance of the search radius (Figure 2a) (Anderson, 2009). The Kernel density value is the highest in the centre of the accident and decreases with distance, thus the Kernel density value reaches zero at the far end of the search radius distance (Figure 2b). When calculating the Kernel density value in each output raster cell (in the grid) (Eq. 1), the sum of the Kernel density values formed around all the point data affecting that cell is taken (Figure 2c). The optimum selection of the Kernel search radius is very important for accurately detecting dense areas (Prasannakumar et al., 2011). If the search radius is defined as too high, non-dense areas will also come out as "high density". If the search radius is specified as too low, then hot spots will be detected instead of dense areas (Figure 2d). Both selections will create erroneous results, and that leads to incorrect implications.

Figure 2. The illustration of the principle of Kernel Density Analysis (Gatrell et. al., 1996; ESRI, 2017; Exchange, 2021)

For applying Kernel Density Analysis in the study, kernel radii were optimised by considering other approaches applied in the studies in the literature (Xie and Yan, 2008; Anderson, 2009; Tehrany et. al., 2015; Sandhu et. al., 2016). Trials in the range of (0.7°×0.7°), (0.5°×0.5°), (0.3°×0.3°), (0.1°×0.1°), (0.09°×0.09°), (0.07°×0.07°), (0.05°×0.05°), (0.03°×0.03°), (0.01°×0.01°) were conducted for each narrow waterway. As a result of the application, "Marine Accidents Density Maps" were obtained for both narrow waterways.

3.3. Statistical analysis of operational conditions affecting accident occurrence in high density areas

This stage of the research aims to determine the relationship between operational conditions and accident type, accident severity, and Kernel density. Operational conditions refer to the internal-external environmental factors that the ship is in, both of which play a role in accident formation. The operational conditions, which are the focus of this study, emerged as the 5th step of the HFACS-PV structure developed by Uğurlu et al. 2018. Although operational conditions do not cause accidents by themselves, they play a complementary role in the occurrence of accidents by combining with unsafe actions (Figure 3). For example, let's take a ship that runs aground in shallow waters as a result of faulty manoeuvring. Faulty manoeuvring is an unsafe action, and shallow water is an operational condition. The ship runs aground as a result of faulty manoeuvring, but if there were no shallow waters, the grounding would not have occurred. Shallow water alone is not a sufficient reason for the ship to run aground, and incorrect manoeuvring alone is not a sufficient reason to run aground. But when two factors come together (complement each other), an accident happens. Every maritime accident, such as collision, contact, grounding, or sinking, contains at least one operational condition by nature (Yildiz et al., 2021b).

Figure 3. a) Human Factor Analysis and Classification System for Passenger Vessel (HFACS-PV) structure; b) An overview of the formation of marine accidents: operational conditions and operators' errors and violations

The Chi-Square independence test was used to determine the relationship between operational conditions, accident type, and accident severity in the "very high density" and "high density" areas. The Chi-Square independence test is used to determine whether there is a statistically significant relationship between two variables (Güngör and Bulut, 2008; McHugh, 2013). One of the most significant advantages of the Chi-Square independence test is that it can be applied to nominal data as well as numerical data (Franke et al., 2012; McHugh, 2013). Since the research aim is to examine the relationship between the variables, the Chi-Square independence test has been preferred. The Chi-Square independence test was applied individually for each narrow waterway (IS, DS). First, the significance of the relationship between marine accident types and operational conditions in the "very high density" and "high density" areas were analysed for each narrow waterway. Subsequently, the significance of the relationship between accident severity and operational conditions was examined. Finally, a significant relationship between the Kernel Density of the areas and the operational conditions was tested. Eighteen null hypotheses were established to test the Chi-Square independence (Table 2). IBM Statistical Package for the Social Sciences (SPSS) 25.0 software was used to accurately implement the Chi-Square independence test (IBM, 2013). As a result of this step, the existence of the statistical relationship between accidents in narrow waterways and operational conditions was determined.

Table 2. Chi-Square hypotheses established in the study

3.4. Evaluation of spatial and statistical analysis results with experts

In the final stage of the research, the Kernel Density Analysis (Density Maps) and Chi-Square test results are evaluated, along with expert opinions. Each expert was asked to interpret the results of the spatial and statistical analysis by examining the results for each narrow waterway where they have operational experience as shown in Table 3. The results of IS were presented to vessel traffic operators and maritime pilots who have worked or currently work in this field. In this way, the results were shared with the industry and the industry's feedback on the research findings was reviewed. For DS, the results were shared with the oceangoing masters who have passed through this area many times. In the collection of expert opinions, an online interview was conducted with each expert. At the beginning of the interview, the experts were given detailed information about the aims, data set, and scope of the study. The Kernel Density Analysis results and Chi-Square test results were then presented to the experts, and they were asked to interpret these results. In this phase of the study, the objective is to reveal the effect of operational conditions on accident formation in the "very high density" and "high density" areas where accidents are concentrated. In addition, at this stage, the opinions, and suggestions of the experts regarding existing hazards and the safety measures applied in IS and DS were received. As a result, recommendations were made to reduce or control the operational hazards in narrow waterways. A total of 23 experts with appropriate but different qualifications and skills participated in this study. Seven of the experts are VTS Operators, four are Coastal Safety tugboat masters and chief officers, three are oceangoing masters, four are maritime pilots, two are officials of Istanbul Technical University Turkish Straits Maritime Application and Research Center, and three are marine accident investigators and maritime faculty members. All details regarding the experts (their skills, sea experience, position, rank, etc.) are presented below.

Oceangoing Master (OM) (3 persons): All oceangoing masters who participated in this study have adequate experience and transit through IS (10-100 times) and DS (10-30 times). Total sea service durations of participating masters vary between 10 and 20 years. One of the participants has been working in the rescue unit of the Main Search and Rescue Coordination Centre of Turkey for more than 3 years.

VTS Operator (VTSO) (7 persons): All participant VTS operators hold oceangoing master competency. The sea service durations of the participants vary between 5 and 13 years. In addition, each participant has more than 3 years of experience as a VTS operator. All of them have passed through IS (20-100 times) and DS (10-90 times). One of the participants is also the former head of the Turkish Vessel Traffic Operators Association.

Maritime Pilot (MP) (4 persons): All participants in this category have experience as a maritime pilot in the Turkish Straits System. All are oceangoing masters, and their sea experience is varying between 10 and 28 years. One of the participants is the former head of the Turkish Maritime Pilots' Association. Each of the pilots has passed through IS (100-1000 times) and DS (10-100 times).

Officials of Istanbul Technical University Turkish Straits Maritime Application and Research Centre (ITUBOA) (2 persons): One of the participants is the director of the canter. At the same time, he is a seafarer holding a Chief Oceangoing Officer (COO) rank and is also a lecturer at Istanbul Technical University. The other participant holds oceangoing master competency and has served as a maritime pilot in the Turkish Straits for more than 30 years. They have held positions as the head of the Turkish Maritime Pilots' Association, EMSA representative, Head of Pilots in Istanbul Strait, Director of Bahçeşehir University Turkish Straits Application and Research Centre, Honorary Member of the Turkish Straits Maritime Application and Research Centre (ITUBOA), as well as a member of the team that developed the Turkish Straits Traffic Separation Scheme. They were also involved in the planning of anchorage areas of IS and the preparation of navigation charts TR292, TR2921, and TR2923.

Marine Accident Investigator (MAI) and Faculty Member in maritime universities (FM) (3 persons): All participants hold a PhD and are actively teaching in the field of maritime safety. The sea service duration of the participants varies between 5 and 15 years. All the participants have research experience in marine accident analysis and maritime safety concerning the Turkish Straits.

Chief Officer of Coastal Safety Tug (COCST) (1 person): The participant holds the competency of the oceangoing master and has 4 years of experience in ship salvage and tug assistance duties in IS.

Master of Coastal Safety Tug (MOCST) (3 persons): All participants hold the competency of oceangoing master and have more than 2 years of experience in ship salvage and tug assistance duties in IS as tug masters.

Table 3. Experts and demographics

4. RESULTS & DISCUSSION

Spatial analysis, Kernel Density Analysis, and Chi-Square independence test results obtained in the study are presented below for IS and DS. The relationship between the accidents in narrow waterways and the operational conditions has been demonstrated based on expert opinions, throughout this section. The operational conditions that should be considered in the risk analysis and safety assessment, which must also be reviewed before each ship passage through narrow waterways, are discussed.

4.1. Istanbul Strait Spatial and Statistical Analysis Results

The Istanbul Strait, connecting the Sea of Marmara and the Black Sea, is one of the narrowest and densest waterways in the world. Its approximate length is 16.6 nautical miles, and its average depth is 35 meters. The IS is divided into 3 VTS sectors: Sector Turkeli, Sector Kandilli, and Sector Kadıköy, from north to south. The narrowest part of the IS is the Kandilli turn with a width of 700 meters in Sector Kandilli. The traffic flow order in the IS is regulated by the Ministry of Transport and Infrastructure according to the Turkish Straits Maritime Traffic Order Regulation. Accordingly, while passing through the IS, the transit speed should be 10 knots and the distance between the ships should be at least 8 cables (Official Gazette, 2019). There are two-way currents in the IS. The first of these is the surface current from north to south with a strength of 1.0-8.0 knots, and the second is the deep current between 0.5-2.0 knots. The biggest turn in the IS, where there are many turns due to its curved structure, is the Yeniköy turn with 83 degrees. When the spatial distribution of the accidents in IS is examined, it can be seen that there is a concentration of accidents in anchorage areas (Figure 4). The most common type of accident is collision with 144 accidents. The optimum kernel search radius was determined and applied as $0.03^{\circ} \times 0.03^{\circ}$. This was determined by considering the geographical structure of IS, the location of the sectors, and areas where the prevailing current and wind directions change. The areas were divided into five classes (Very High (VH), High (H), Medium (M), Low (L), and Very Low (VL)) according to the numerical value of their kernel densities. At the end of the application, a Marine Accidents Density Map was obtained for IS, based on the kernel density value of each grid. There are 4 "very high density" sea areas (90 accidents) and 5 "high density" sea areas (47 accidents) in IS (Figure 5).

Figure 4. Point distribution map of accidents in IS

Figure 5. Kernel density map of IS

A total of 137 marine accidents occurred in the "very high density" and "high density" sea areas. According to the spatial distribution of accidents, Sector Kadıköy is the VTS area where ship accidents are most common in IS (Figure 4). All of the "very high density" (K1, K2, K3 and K4) areas are around the Ahırkapı anchorage area in Sector Kadıköy (Figure 5). This is where the anchored ships, ships waiting to pass the strait, and the vessels that leave from anchorage to pass the strait are dense. T3, T4 and T5 are among the "high density" sea areas in

Sector Kadıköy. In addition, 2 areas within the strait itself were identified as the "high density" sea areas. The first one is the area (T2) between Umur Banks and Yeniköy, where the current speed (1-3 kts) and direction (S-SW-SE) vary. The other is the Kandilli turning point (T1), the narrowest and most curved part of IS. The common features of these two "high density" areas within the strait are sharp turns and strong currents. The results of this study confirm the conclusions of previous studies which have determined that greater risks are posed at the southern entrance of IS (Sector Kadıköy) (Aydogdu et al., 2012).

Within the "very high density" areas, ships between 101-150 m in length (48.9%), 31 years or older (45.6%), and dry cargo ships (85.6%) were found to have the highest percentages of involvement in these accidents. It has been determined that most of the accidents in these “very high density” areas occurred in winter (45.6%) and at night (66.7%). In the "high density" areas, the most common ship-related operational conditions were found in vessels of 100 m or less in length (53.2%), 11-30 years of age (74.5%), and dry cargo type (66.0%). The season and day status of the accidents in these areas are similar to the "very high density" areas (Table 4). These results confirm what many literature studies have concluded, which is that night shifts are much riskier than daytime shifts, especially in the areas of anchorage, drift, and traffic participation at the southern entrance of IS (Akten, 2004; Arslan and Turan, 2009).

Table 4. Distribution of the number of accidents by operational conditions in IS

As a result of the Chi-Square tests for accidents that occurred in the "very high density" and "high density" areas in IS, a significant relationship was found between accident type and ship type, accident severity, season, and density categories (Table 5). In addition, a significant relationship was determined between kernel density and ship size, ship type, and seasons.

However, significant relationships were not identified between accident severity and other operational conditions (Table 5).

Table 5. Chi-Square test results of IS

When accident type and ship type are cross-examined (Table 6), it can be seen that the most common accident types in dry cargo ships are collision (63.0%) and grounding (20.4%). One of the study's remarkable findings is that although container ships are the 4th ranked ship type that makes the most transits according to IS ship passing statistics, it is the 2nd ranked ship type most frequently involved in the accident statistics. Container ships were mostly involved in the collision (72.2%) and contact (22.2%) accidents in IS (Table 6). Based on the research results, it can be postulated that the high speed of container ships may affect this result. In previous studies on narrow waterways, it was revealed that high speed plays a key role in accident formation, especially in collision and contact accidents (Qu et al., 2011).

When the relationship between accident types and accident severity in IS was examined, 66.7% of "very serious accidents" occurred as a result of sinking and 22.2% as a result of collision accidents. In "serious accidents", collisions had the largest share with 65.4%, in terms of ship type-accident severity, while contacts took second place with 17.3%. These results show that, compared to the results of Wang et al. (2021), a collision accident may have more serious consequences if it occurs in IS.

Table 6. Cross-table between accident type and ship type, accident severity for IS

According to Table 7, when accident type and seasons are cross-examined spring results are similar to winter ones, whereas autumn results are similar to summer ones. Accordingly, the most frequent accident types in the spring and winter seasons are collision (52.2% and 66.7%) and grounding (30.4% and 17.5%), respectively. The most frequent collisions (67.6% and 50.0%) and contacts (16.2% and 35.0%) occurred in the autumn and summer seasons. These results clearly show that changing seasonal conditions also affect accident types. In addition, it has been observed that at least half of the accidents that occurred in every season in IS are collision accidents. This result shows that traffic density in IS is always one of the highest risks in the area and is in concurrence with previous studies (İnce and Topuz, 2004; Arslan and Turan, 2009; Aydoğdu et al., 2012; Aydoğdu, 2014).

When accident type and Kernel categories ("high" and "very high") are analysed (Table 7), it can be seen that collision accidents (75.6%) have a very high share in the "very high density" areas. It is also shown in Figure 5 that the "very high density" areas (K1 – K4) are in and around the Ahırkapı anchorage area. The main reason for such a high collision rate is the ships' anchoring without sufficient distance due to congested anchorage areas. In the "high density" areas, contact (40.4%) and collision (36.2%) accidents are the most frequent accident types. Similarly, it is postulated that the strong currents, in these areas, are a key factor in vessels being involved in contact situations. When Figures 4 and 5 are considered together, it is seen that contact accidents are mostly concentrated in the areas where the current speed is highest. Ships that cannot maintain sufficient steering control in these areas, which also have sharp turns, face the danger of running adrift and aground. In previous studies, it has been reported that the risk of accidents increases in areas where there are strong and variable currents, at sharp turning points (Akten, 2004; Istikbal, 2006). These results are very useful for understanding which types of accidents and hazards are most likely in specific areas of IS.

Table 7. Cross-table between accident type and season, the density of Kernel area for IS

According to the Chi-Square test results (Table 5), no significant relationship was found between the accident severity and the operational conditions. Therefore, in this study, it cannot be concluded that "increasing ship length also increases the severity of accidents in IS", as stated in the study conducted by Erol et al. (2018).

When the Kernel density categories and ship size are cross-examined (Table 8), there was no significant difference identified in the distribution of accidents involving ships of 100 m or less in length by density category. However, it was determined that 3 out of every 4 accidents in ships over 100 m were in the "very high density" areas. Considering that the "very high density" areas are around the anchorage area, these results are evidence of congestion at anchorage and that ships are anchored without a sufficient safe distance between them (Yildiz et al., 2021a).

While dry cargo, container, and other types of ships were mostly involved in accidents in the "very high density" areas, tanker vessels were mostly involved in the "high density" areas. The low accident rate in the "very high density" areas involving tankers, which are the 2nd ranked ship type that makes the most transits from IS, may be related to the fact that personnel working on such ships may pay more attention to safety warnings. The risk perception and understanding of the safety culture of employees in different industries were compared by Nævestad et al. (2019). the study showed that crew members on tanker vessels are less likely to compromise safety when compared to crew on other types of ships.

When the relationship between the seasons and the density category is examined, it has been observed that accidents occurring in spring, autumn, and winter were mostly in the "very high density" areas. On the other hand, the rate of accidents in summer was higher in the "high density" areas. It is known that the weather and sea conditions in IS in summer are calmer and more stable than in other seasons. These results reveal the effect of changing seasonal conditions on accidents and support the results of previous studies (Arslan and Turan, 2009; Erol et al., 2018).

Table 8. Cross-table between the density of Kernel area and ship size, ship type, the season for IS

The results of the study for IS (Chi-Square and spatial analysis) were presented to the experts and they were asked to evaluate the impact of each operational condition on the accidents that occurred in IS. The evaluations of the 22 experts who are competent in IS (see Table 3) regarding the study are presented in Figure 6.

Figure 6. Expert judgements for operational conditions in IS.

4.2. Dover Strait Spatial and Statistical Analysis Results

DS is the narrowest part of the English Channel connecting the Atlantic Ocean and the North Sea. One of the world's busiest narrow waterways, DS is approximately 18 nautical miles wide at its narrowest point. Although the distance between the coasts is large, there are banks such as South Falls Bank, Colbart Bank (Ridge Bank), and Varne Bank, which create shallows on the English side of the Channel and narrows the safe waterway. The Varne Bank is a sandbank approximately 0.5 miles wide and 6 miles long. More than 400 commercial vessels (more than 150,000 annually) pass through the strait every day. Vessel traffic services in DS are carried out with the cooperation of two different countries, France and the United Kingdom. Ships passing in the north-east direction have to report to the French Coast guard, while ships passing in the south-west direction have to report to the Channel Navigation Information Service (CNIS) (Lefevre, 1994; Neill, 1990). In DS, accidents are slightly more concentrated at the northern (UK-side, Dover-side) passageway of the traffic separation scheme. In addition to this, it is understood that accidents are intense on the ferry line between Dover and Calais (Figure 7). Collision and grounding are the most common accident types in DS (Table 9). The optimum kernel search radius was determined as 0.09˚×0.09˚, considering the geographical structure of the Dover Strait, the traffic separation scheme, the size of the radar monitoring area, and the spatial distribution of the accidents. A Marine Accidents Density Map is obtained based on kernel density values for DS and is presented in Figure 8. Five "very high density" sea areas and 8 "high density" sea areas were identified in DS. 71% of the accidents examined in DS occurred in these two categories of sea area.

Figure 7. Point distribution map of accidents in DS

Figure 8. Kernel density map of DS

Off the coast of Dover, are the areas where the domestic sea traffic is intense and the safe waterway is narrowed (K2, K3, K4), and the area containing the Varne Bank (K5) are the "very high density" sea areas. In addition to these, the vicinity of the Foxtrot 3 buoy (K1) was also identified as one of the "very high density" areas in DS (Figure 8). This area is an area where traffic is multidirectional and the buoy acts as a junction. The "high density" sea areas in DS are highly scattered and spread across the entire strait. "High density" areas are mostly located in the middle of the southern approach (T6, T7, T8) and northern approach (T1, T2, T3, T5) separation lines. The only exception is the area at the exit of the Port of Calais (T4) (Figure 8). In this area, ferry traffic is heavy, and the safe waterway is very limited. The findings of this study are consistent with Squire's (2003) study. Squire (2003) concluded that half of the accidents in DS occurred at the bottleneck between South Falls - Varne and most of the accidents occurred in the northern part of the separation line.

In DS, the ship type most frequently involved in accidents in the "very high density" areas is the "other" category, which also includes ferries, while dry cargo ships are in second place. In the "high density" areas, container ships are the most frequently involved in accidents, while the "other" category is in second. More than 100 reciprocal ferry services operate in DS every day (MCA, 2014). The heavy ferry traffic in the region has had an impact on the accident numbers to bring the "other" category to the fore in accidents in both "very high density" and "high density" regions.

The factors of ship size and ship age encountered in accidents in DS are similar in the "very high density" and "high density" areas. In both areas, ships over 150 m (81.8% and 61.5%, respectively), 10 years and under (81.8% and 53.8%, respectively) are the most common ship-related operational conditions in accidents. Ships transiting DS are larger than ships transiting IS. This is the main reason for the difference in ship size between the accidents on the two narrow waterways.

Accidents in the "very high density" areas occurred mostly in winter (36.4%) and during daytime (54.5%). In the "high density" areas, the most accidents occurred in spring (38.5%) and winter (38.5%), and at night (61.5%) (Table 9). In the northern high latitudes, harsher weather and sea conditions prevail in winter than in summer. The results are consistent, as bad weather and sea conditions adversely affect safe navigation, especially in areas where the strait is narrow, and shallows are dense.

Table 9. Distribution of accidents in Dover Strait by operational conditions

Unlike in IS, the most common accident types in DS in the "very high density" areas were grounding (45.5%) and contact (36.4%) accidents, respectively. In the "high density" areas, collision (61.5%) and grounding (23.1%) accidents were observed most frequently (Table 9). T1 and T2 high-density areas in the IS Kernel density map are the points where the safe waterway becomes narrows and sharp turns occur in the strait. In DS, the K1 and T1 areas are the areas where traffic participation/leaving is intense, and the K5 area is where the Varne Bank is located. In these areas, the ship breadth/waterway breadth ratio increases. For this reason, it is extremely important and necessary to consider the ratio of ship dimensions (length, width, and draft) and area characteristics (water depth, width, turning angle) when planning a ship passing through both narrow waterways and when developing a numerical risk model that will analyse the risk of each transit.

As a result of Chi-Square tests for accidents occurring in the "very high density" and "high density" areas in DS, significant relationships ($p<0.05$) were found between accident type-ship size and accident severity-ship size. No significant relationship was found between the density category of the geographical areas where the accidents occurred and the operational conditions (Table 10).

Table 10. Chi-Square test results of DS

When accident type and ship size are cross-examined (Table 11), ships under 101m were involved in contact (50.0%) and sinking (50.0%) accidents, although they were few. Ships with a length of 101-150m are riskier in terms of grounding (60.0%) and collision (40.0%). 70-80% of the ships passing through DS are ships larger than 150m. Ships over 150 m were mostly involved in the collision (47.1%) and grounding (29.4%) accidents. These results show that there is a correspondence between the size of the ships passing through the area and the ships involved in the accidents.

When the relationship between accident severity and ship size is examined, it is seen that 66.7% of accidents resulted as "very serious" in ships under 101m. On the other hand, 66.7% of the accidents resulted as "less serious" in ships with a length of 101-150m. In ships of 151mand above, where accidents occurred most frequently, 61.1% of the accidents resulted as "serious". These results show that there are varying risks depending on the size of the ships that pass through DS.

Table 11. Cross-table between accident type-ship size and accident severity-ship size for DS

The results of the study for DS (Chi-Square and spatial analysis) were presented to the experts and they were asked to evaluate the impact of each operational condition on the accidents that occurred in DS. The evaluations made by the 15 experts who are competent in DS (See Table 3) are given in Figure 9.

Figure 9. Expert judgements for operational conditions in DS

There is no compulsory pilotage in DS today. On the other hand, in IS, if the vessel that will pass is not a risky ship (longer than 200m, carrying dangerous cargo, etc.), the right of passage without a pilot is left to the preference of the ship's captain. Due to economic concerns and keeping the speed of operation high, only half of the ships that passed through IS in 2020 received a pilot (UAB, 2021). It should be noted that when a pilot is not taken, the master of the ship assumes the duties of both a pilot and the ship's captain. In this case, the captain must have a great understanding of the regional characteristics (landforms, atmospheric conditions, sea conditions, maritime traffic, etc.). Experts who participated in the study emphasized the issue of granting the right of passage without a pilot to the ship's captains, who will make the passage, according to their navigation experience in the Turkish Straits. In this way, they stated that the skills and experience required to pass without a pilot can be validated to an acceptable extent.

5. CONCLUSION

In this study, operational conditions (not human factors directly, but those which affect operational conditions indirectly) that play a complementary role in the occurrence of accidents were determined and analysed by using GIS, statistical methods, and expert opinions. Factors other than operational conditions were excluded from the scope of the study. The outputs of the study reveal how regional characteristics (landforms, atmospheric conditions, sea conditions, etc.) and ship-related characteristics affect the occurrence of accidents in the narrow waterways examined.

When the expert opinions and the results of the study are evaluated together, it is understood that there is a relationship between the accidents that occurred in narrow waterways and the operational conditions examined. Thus, ship-specific risks should be evaluated as well as risks specific to the narrow waterway (area), while evaluating the risks that threaten safety in narrow waterways. In the light of the results of the study, it is important to determine the risk factors arising from the operational conditions (ship size, ship type, ship age, transit time, VTS Sector, traffic density) specific to each of the vessels making passages through narrow waterways, to increase and maintain the safety of navigation. In addition, given the statistical data, it is necessary to determine the risk factors arising from the operational conditions (narrowest part of the channel, density categories, and numbers, seasonal risk, day status) specific to each narrow waterway (IS, DS, *etc*.). The channel passing operation should be dynamically planned for each ship and each narrow waterway. Risk analysis of each passage should be carried out meticulously for each ship that will enter the channel. The numerical results to be obtained from these analyses may also be considered when deciding on compulsory pilotage and compulsory tugboat escort.

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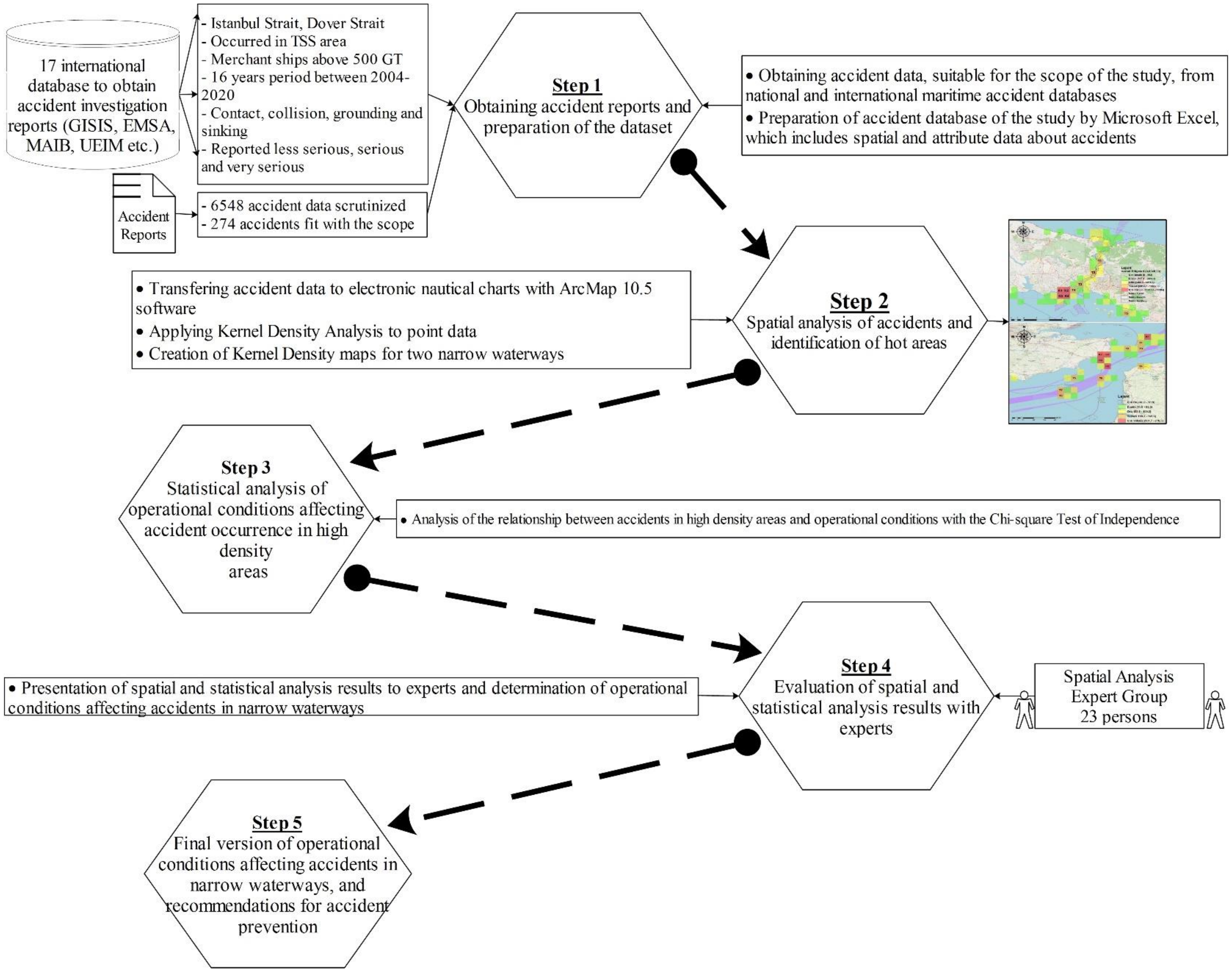


Figure 1. Flow chart of the study

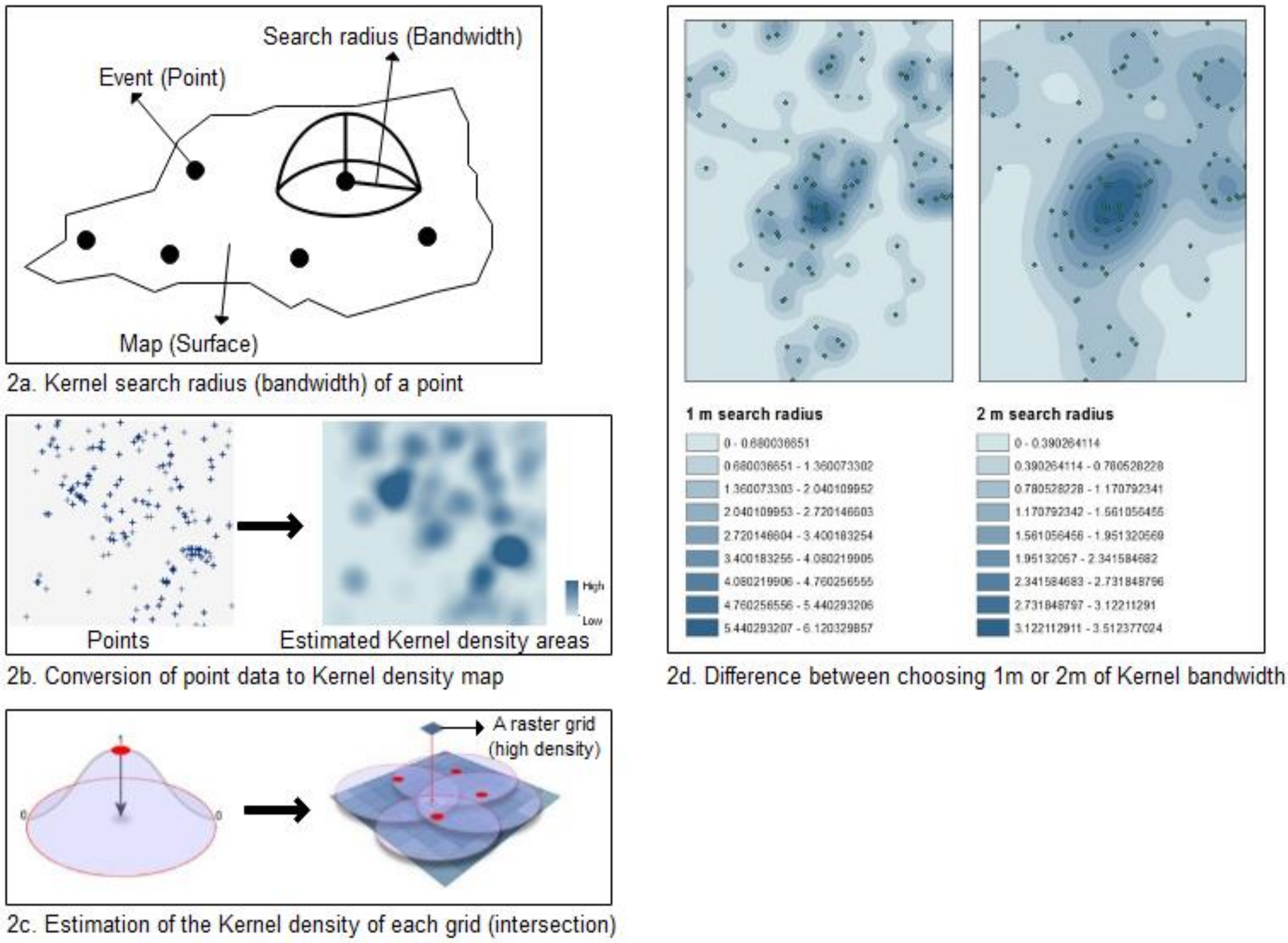
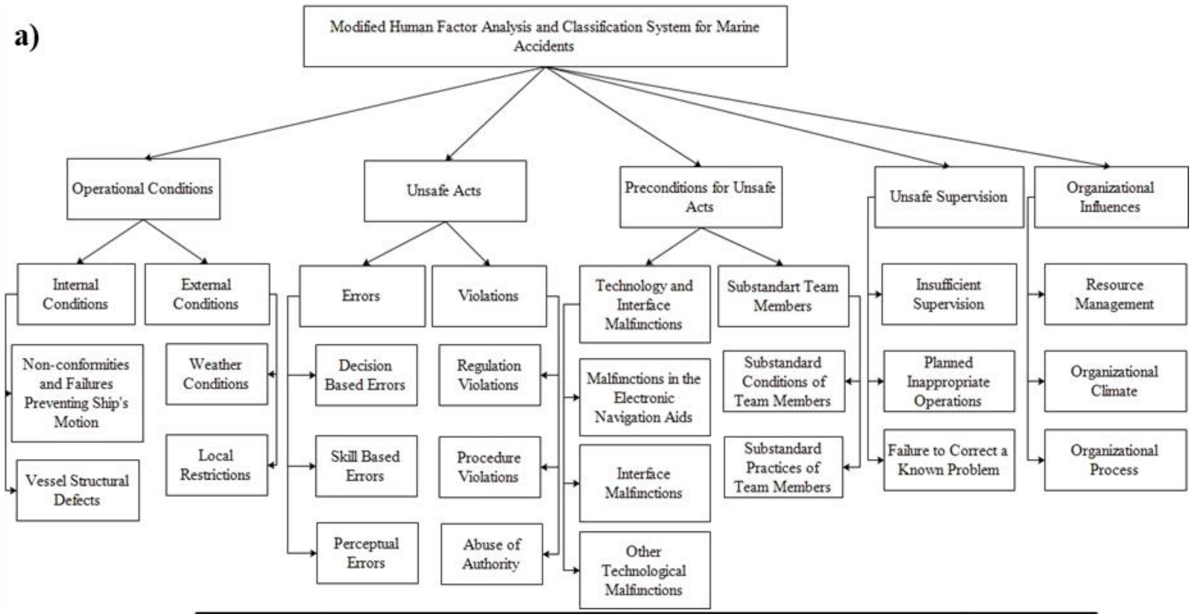


Figure 2. The illustration of the principle of Kernel Density Analysis (Gatrell vd., 1996; ESRI, 2017; Exchange, 2021)

a)



b)

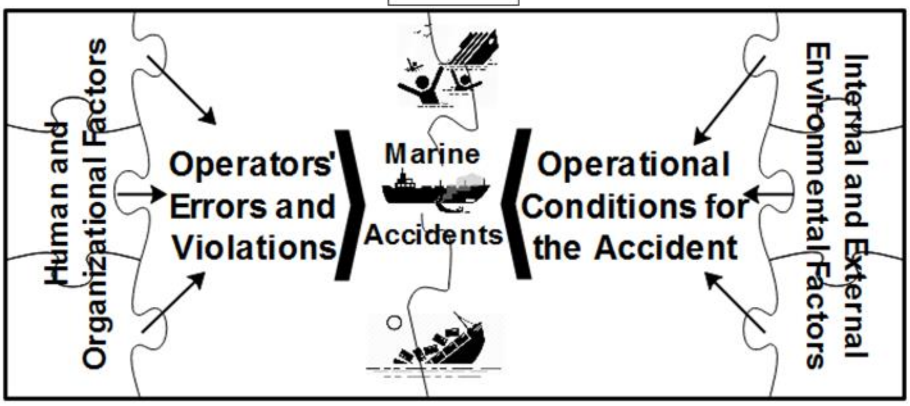


Figure 3. a) Human Factor Analysis and Classification System for Passenger Vessel (HFACS-PV) structure; b) An overview of the formation of marine accidents: operational conditions and operators' errors and violations

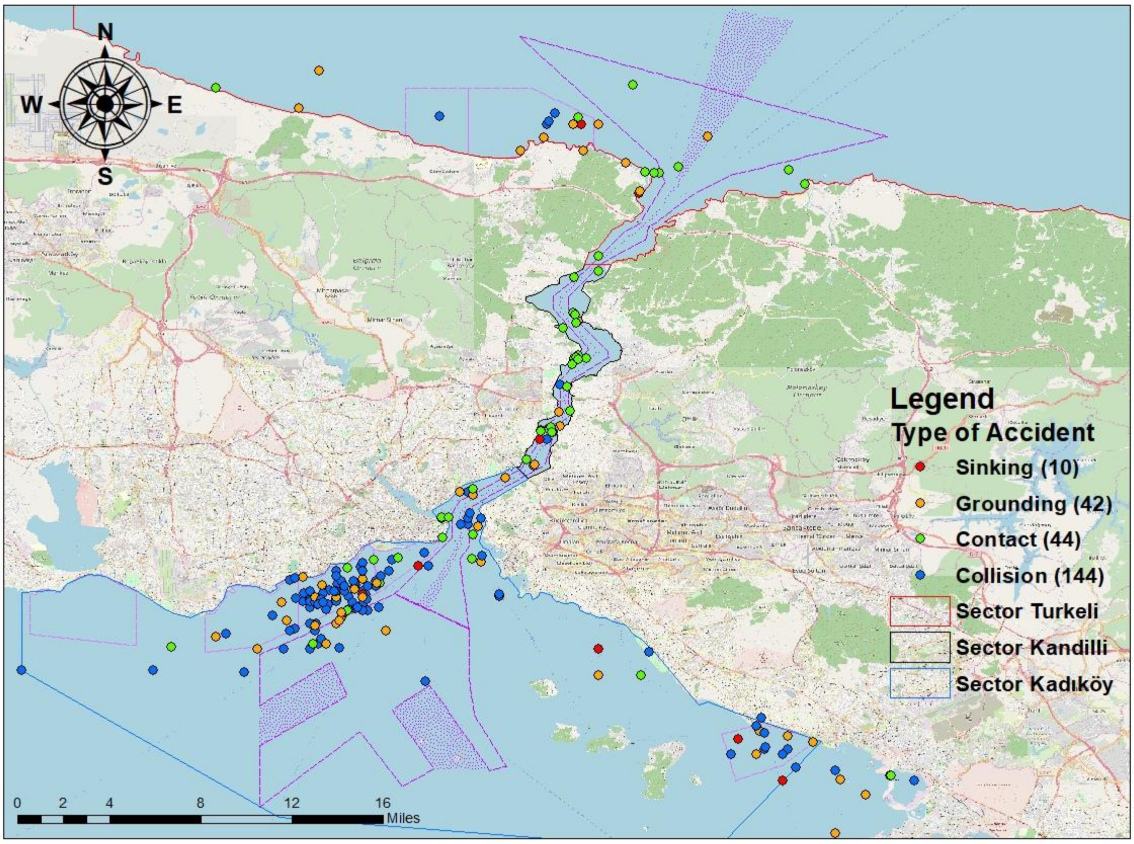


Figure 4. Point distribution map of accidents in IS

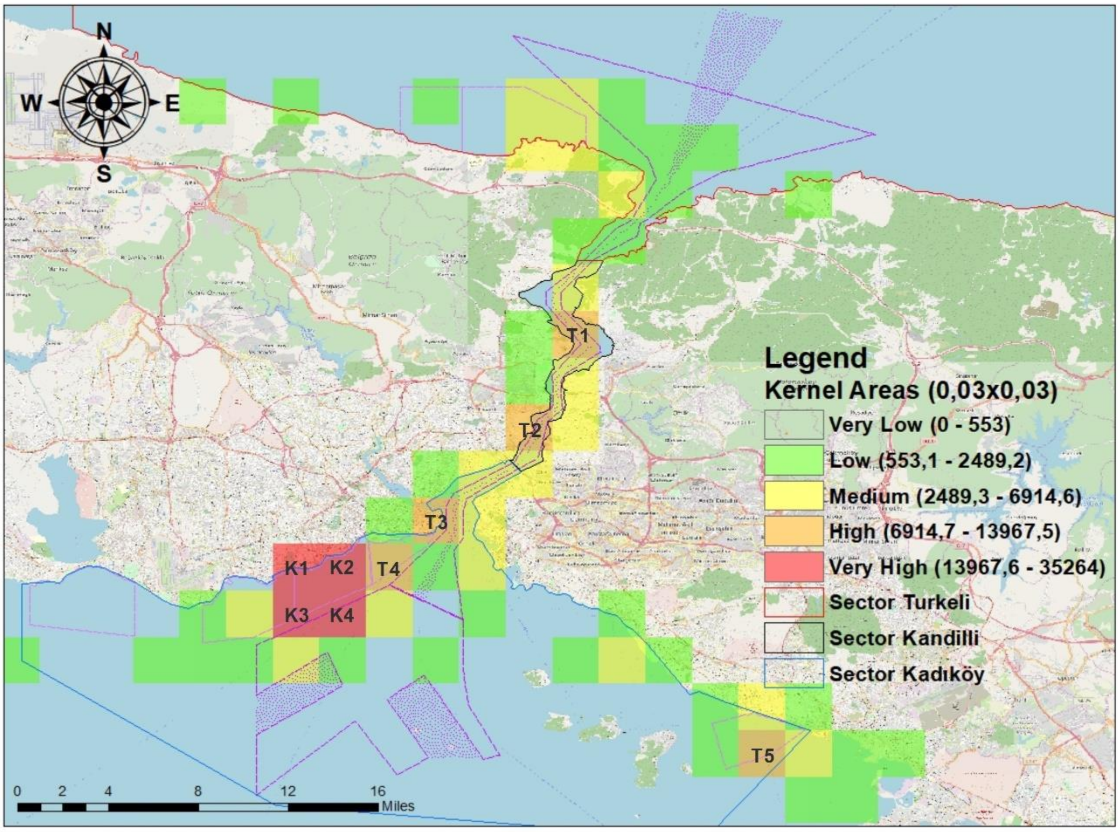


Figure 5. Kernel density map of IS

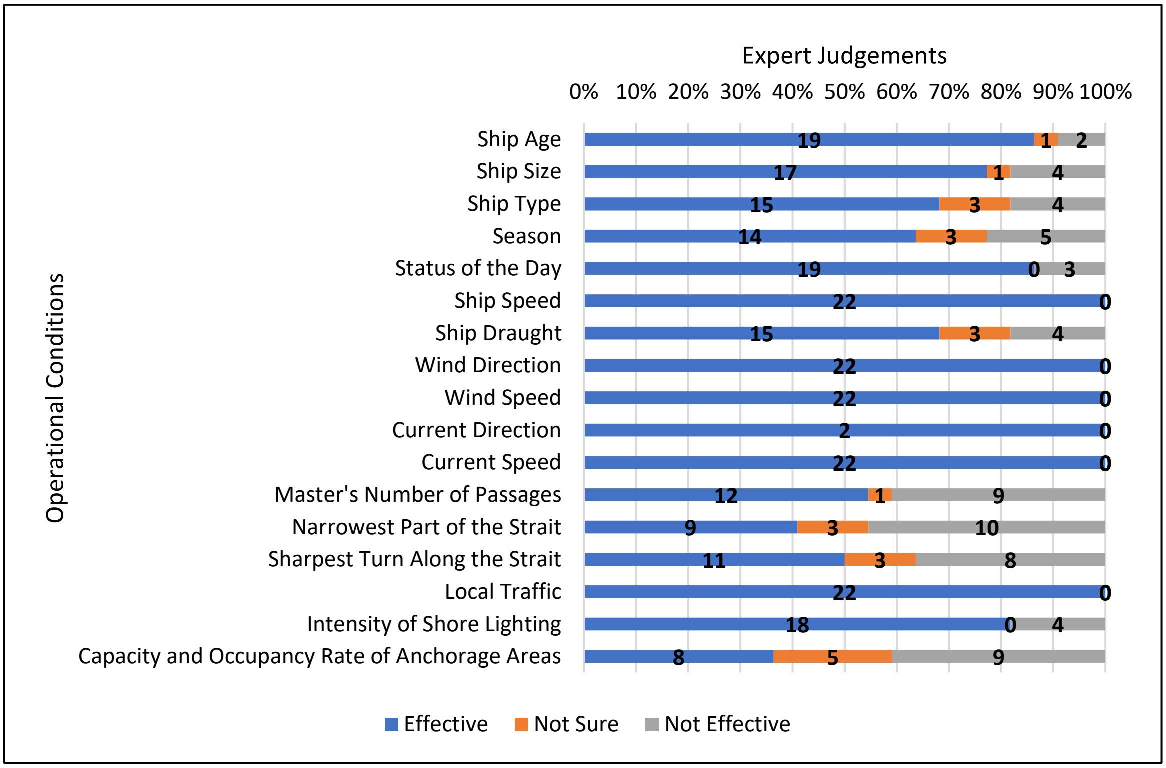


Figure 6. Expert judgments for operational conditions in IS

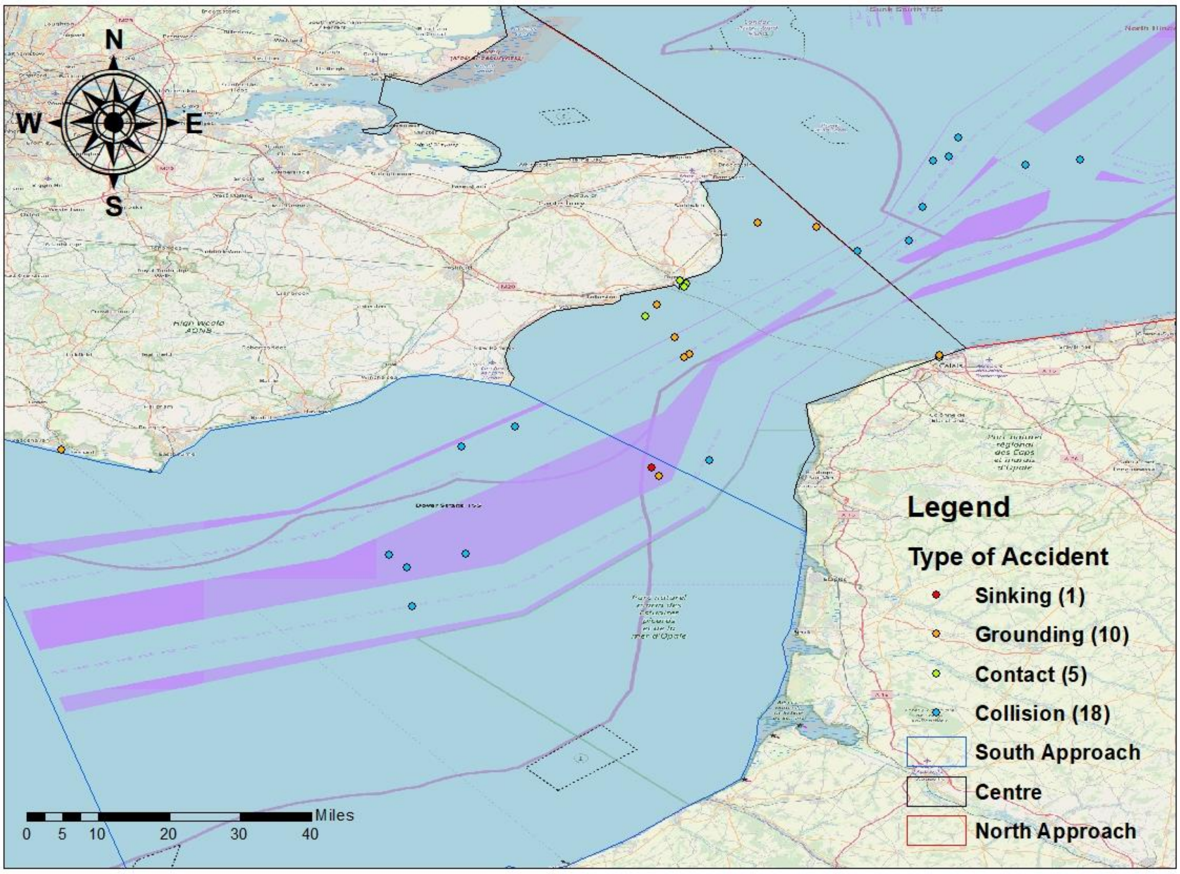


Figure 7. Point distribution map of accidents in DS

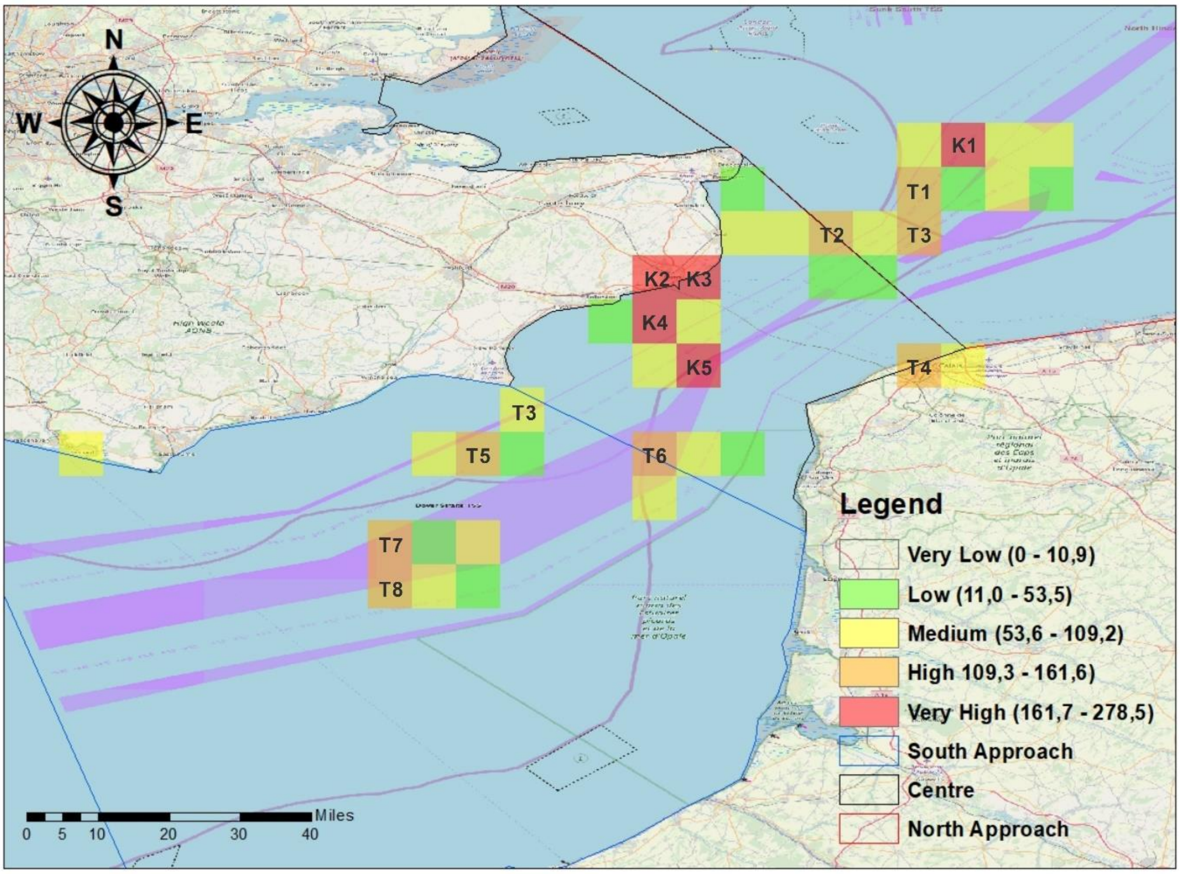


Figure 8. Kernel density map of DS

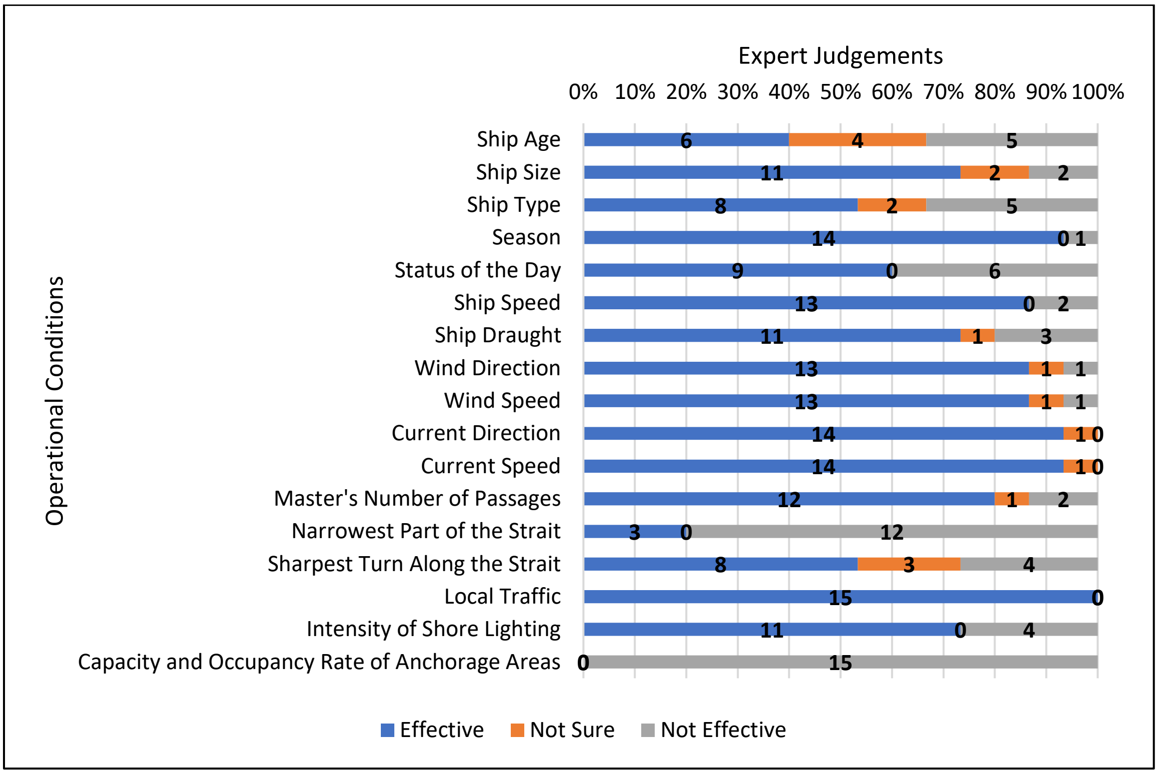


Figure 9. Expert judgments for operational conditions in DS

Table 1. Marine accident databases

Country/organisation	Name	Abbreviation
Australia	Australian Transport Safety Bureau	ATSB
Canada	Transportation Safety Board of Canada	TSB
IMO	Global Integrated Shipping Information System	GISIS
Finland	Safety Investigation Authority	SIA
France	Civil Aviation Safety Investigation and Analysis Bureau	BEA
Europe	European Maritime Safety Agency	EMSA
Japan	Japan Transport Safety Board	JTSB
Netherlands	Dutch Safety Board	DSB
New Zealand	Transport Accident Investigation Commission	TAIC
Norway	Accident Investigation Board Norway	AIBN
Russia	Interstate Aviation Committee	IAC
Singapore	Air Accident Investigation Bureau of Singapore	AAIB
Sweden	Swedish Accident Investigation Authority	SAIA
China	Aviation Safety Council	ASC
Turkey	Transport Safety Investigation Center	UEIM
United Kingdom	Marine Accident Investigation Board	MAIB
United States	National Transportation Safety Board	NTSB

Table 2. Chi-Square hypotheses established in the study

Hypothesis
$H0_0$: There is no significant relationship between **accident type and age of the ship**.
$H0_1$: There is no significant relationship between **accident type and ship size (length).**
$H0_2$: There is no significant relationship between **accident type and type of ship.**
$H0_3$: There is no significant relationship between **accident type and accident severity.**
$H0_4$: There is no significant relationship between **accident type and season.**
$H0_5$: There is no significant relationship between **accident type and day status (day/night).**
$H0_6$: There is no significant relationship between **accident type and Kernel Density.**
$H0_7$: There is no significant relationship between **accident severity and the age of the ship.**
$H0_8$: There is no significant relationship between **accident severity and ship size (length).**
$H0_9$: There is no significant relationship between **accident severity and type of ship.**
$H0_{10}$: There is no significant relationship between **accident severity and season.**
$H0_{11}$: There is no significant relationship between **accident severity and day status (day/night).**
$H0_{12}$: There is no significant relationship between **accident severity and Kernel Density.**
$H0_{13}$: There is no significant relationship between **Kernel Density and the age of the ship.**
$H0_{14}$: There is no significant relationship between **Kernel Density and ship size (length).**
$H0_{15}$: There is no significant relationship between **Kernel Density and type of ship.**
$H0_{16}$: There is no significant relationship between **Kernel Density and season.**
$H0_{17}$: There is no significant relationship between **Kernel Density and day status (day/night).**

Table 3. Experts and demographics

No.	Current rank	Experience in current rank (Years)	Previous sea service			Total number of passages		Participation	
			Total (Years)	Last competency	Experience master (Months)	IS	DS	IS (22)	DS (15)
1	FM	8	15	OM	4	>50	>50	+	+
2	FM	9	7	OM	11	>30	>20	+	+
3	OM	5	12	OM	70	>50	>30	+	+
4	VTSO	3	13	OM	24	>50	>90	+	+
5	OM	8	14	OM	96	>30	>20	+	+
6	VTSO	3	13	OM	24	>100	-	+	-
7	OM	6	10	OM	72	>100	>30	+	+
8	COCST	4	8	OM	6	>60	2	+	-
9	VTSO	3	5	COO	-	>50	>20	+	+
10	MP	3	12	OM	48	>100	>20	+	+
11	VTSO	3	7	OM	-	>20	>10	-	+
12	MP	15	28	OM	120	>1000	2	+	-
13	VTSO	6	12	OM	72	>100	>15	+	-
14	MP	9	8	OM	36	>1000	>10	+	+
15	VTSO	3	14	OM	72	>100	>100	+	+
16	MP	16	20	OM	108	>1000	>20	+	+
17	ITUBOA	16	4	COO	-	>30	>5	+	-
18	VTSO	13	20	OM	15	>100	>20	+	+
19	MAI	18	8	OM	12	>30	>5	+	-
20	ITUBOA	30	30	OM	120	>1000	>20	+	+
21	MOCST	8	8	OM	30	>100	>5	+	-
22	MOCST	5	8	OM	8	>80	>20	+	+
23	MOCST	7	8	OM	4	>80	>5	+	-

Table 4. Distribution of the number of accidents by operational conditions in IS

Operational Conditions		IS (N=240)		IS (VH+H=137)			
				f		%	
		f	%	VH	H	VH	H
Ship Type	Dry Cargo	173	**72.1**	77	31	**85.6**	**66**
	Tanker	22	9.2	1	7	1.1	14.9
	Container Ship	32	13.3	10	8	11.1	17
	Other (RoRo, Passenger, etc.)	13	5.4	2	1	2.2	2.1
Ship Size	Length Overall (LOA)≤100	93	38.8	27	26	30	**55.3**
	101≤LOA≤150	96	**40.0**	44	15	**48.9**	31.9
	151≤LOA	51	21.3	19	6	21.1	12.8
Ship Age	Age≤10	45	18.8	11	5	12.2	10.6
	11≤Age≤30	115	**47.9**	38	25	42.2	**53.2**
	31≤Age	80	33.3	41	17	**45.6**	36.2
Season	Spring	46	19.2	18	5	20	10.6
	Summer	43	17.9	7	13	7.8	27.7
	Autumn	61	25.4	23	14	25.6	29.8
	Winter	90	**37.5**	42	15	**46.7**	**31.9**
Status of the Day	Day (06:01-18:00)	86	35.8	30	21	33.3	44.7
	Night (18:01-06:00)	154	**64.2**	60	26	**66.7**	**55.3**
Accident Type	Grounding	42	17.5	15	8	16.7	17
	Contact	44	18.3	3	19	3.3	**40.4**
	Collision	144	**60.0**	68	17	**75.6**	36.2
	Sinking	10	4.2	4	3	4.4	6.4
Accident Severity	Less Serious	2	0.8	1	0	1.1	0
	Serious	219	**91.3**	82	45	**91.1**	**95.7**
	Very Serious	19	7.9	7	2	7.8	4.3

Table 5. Chi-Square test results of IS

Pairwise Comparisons (Test Hypotheses)		IS	
		Significant Relationship	Significance (*p*)
Accident Type	Ship Age	No	0.103
	Ship Size	No	0.052
	Ship Type	**Yes**	0.015
	Accident Severity	**Yes**	0.001
	Season	**Yes**	0.039
	Status of the Day	No	0.192
	The density of the Kernel Area	**Yes**	0.001
Accident Severity	Ship Age	No	0.051
	Ship Size	No	0.052
	Ship Type	No	0.627
	Season	No	0.642
	Status of the Day	No	0.128
	The density of the Kernel Area	No	0.555
The density of the Kernel Area	Ship Age	No	0.468
	Ship Size	**Yes**	0.015
	Ship Type	**Yes**	0.006
	Season	**Yes**	0.008
	Status of the Day	No	0.192

Table 6. Cross-table between accident type and ship type, accident severity for IS

			Ship Type				Accident Severity		
			Dry Cargo	Tanker	Container Ship	Other	Less Serious	Serious	Very Serious
Accident Type	Grounding	Number	22	1	0	0	1	21	1
		Ship Type-Accident Severity (%)	**20.4**	12.5	0.0	0.0	100.0	16.5	11.1
	Contact	Number	12	5	4	1	0	22	0
		Ship Type-Accident Severity (%)	11.1	62.5	**22.2**	33.3	0.0	**17.3**	0.0
	Collision	Number	68	2	13	2	0	83	2
		Ship Type-Accident Severity (%)	**63.0**	25.0	**72.2**	66.7	0.0	**65.4**	**22.2**
	Sinking	Number	6	0	1	0	0	1	6
		Ship Type-Accident Severity (%)	5.6	0.0	5.6	0.0	0.0	0.8	**66.7**
Total		Number	108	8	18	3	1	127	9
		Accident Type (%)	78.8	5.8	13.1	2.2	0.7	92.7	6.6

Table 7. Cross-table between accident type and season, the density of the Kernel area for IS

			Season				The density of the Kernel Area	
			Spring	Summer	Autumn	Winter	High	Very High
Accident Type	Grounding	Number	7	1	5	10	8	15
		Season- Density of Kernel Area (%)	**30.4**	5.0	13.5	**17.5**	17.0	16.7
	Contact	Number	1	7	6	8	19	3
		Season- Density of Kernel Area (%)	4.3	**35.0**	**16.2**	14.0	**40.4**	3.3
	Collision	Number	12	10	25	38	17	68
		Season- Density of Kernel Area (%)	**52.2**	**50.0**	**67.6**	**66.7**	**36.2**	**75.6**
	Sinking	Number	3	2	1	1	3	4
		Season- Density of Kernel Area (%)	13.0	10.0	2.7	1.8	6.4	4.4
Total		Number	23	20	37	57	47	90
		Accident Type (%)	16.8	14.6	27.0	41.6	34.3	65.7

Table 8. Cross-table between the density of Kernel area and ship size, ship type, and season for IS

			Ship Size (m)			Ship Type				Season			
			30-100	**101-150**	**151≤**	**Dry Cargo**	**Tanker**	**Container Ship**	**Other**	**Spring**	**Summer**	**Autumn**	**Winter**
The density of the Kernel Area	High	Number	26	15	6	31	7	8	1	5	13	14	15
		Ship Size- Ship Type-Season (%)	**49.1**	25.4	24.0	28.7	**87.5**	44.4	33.3	21.7	**65.0**	37.8	26.3
	Very High	Number	27	44	19	77	1	10	2	18	7	23	42
		Ship Size- Ship Type-Season (%)	**50.9**	**74.6**	**76.0**	**71.3**	12.5	55.6	66.7	**78.3**	35.0	**62.2**	**73.7**
Total		Number	53	59	25	108	8	18	3	23	20	37	57
		Ship Size- Ship Type-Season (%)	38.7	43.1	18.2	78.8	5.8	13.1	2.2	16.8	14.6	27.0	41.6

Table 9. Distribution of accidents in Dover Strait by operational conditions

Operational Conditions		**DS (N=34)**		**DS (VH+H=24)**			
				f		**%**	
		f	**%**	**VH**	**H**	**VH**	**H**
Ship Type	Dry Cargo	6	17.6	3	1	**27.3**	7.7
	Tanker	5	14.7	2	2	18.2	15.4
	Container Ship	10	**29.4**	2	6	18.2	**46.2**
	Other (RoRo, Passenger, etc.)	13	38.2	4	4	**36.4**	**30.8**
Ship Size	Length Overall (LOA)≤100	4	11.8	1	1	9.1	7.7
	101≤LOA≤150	7	20.6	1	4	9.1	30.8
	151≤LOA	23	**67.6**	9	8	**81.8**	**61.5**
Ship Age	Age≤10	18	**52.9**	9	7	**81.8**	**53.8**
	11≤Age≤30	16	47.1	2	6	18.2	46.2
	31≤Age	0	0.0	0	0	0	0
Season	Spring	8	23.5	2	5	18.2	**38.5**
	Summer	7	20.6	2	2	18.2	15.4
	Autumn	6	17.6	3	1	27.3	7.7
	Winter	13	**38.2**	4	5	**36.4**	**38.5**
Status of the Day	Day (06:01-1800)	15	44.1	6	5	**54.5**	38.5
	Night (18:01-06:00)	19	**55.9**	5	8	45.5	**61.5**
Accident Type	Grounding	10	29.4	5	3	**45.5**	**23.1**
	Contact	5	14.7	4	1	**36.4**	7.7
	Collision	18	**52.9**	2	8	18.2	**61.5**
	Sinking	1	2.9	0	1	0	7.7
Accident Severity	Less Serious	10	29.4	5	5	45.5	38.5
	Serious	19	**55.9**	6	6	**54.5**	**46.2**
	Very Serious	5	14.7	0	2	0	15.4

Table 10. Chi-Square test results of DS

Pairwise Comparisons (Test Hypotheses)		**DS**	
		Significant Relationship	**Significance (*p*)**
Accident Type	Ship Age	No	0.397
	Ship Size	**Yes**	0.016
	Ship Type	No	0.077
	Accident Severity	No	0.054
	Season	No	0.516
	Status of the Day	No	0.368
	The density of Kernel Area	No	0.393
Accident Severity	Ship Age	No	0.122
	Ship Size	**Yes**	0.002
	Ship Type	No	0.330
	Season	No	0.067
	Status of the Day	No	0.411
	The density of Kernel Area	No	0.397
The density of Kernel Area	Ship Age	No	0.148
	Ship Size	No	0.203
	Ship Type	No	0.415
	Season	No	0.523
	Status of the Day	No	0.431

Tablo 11. Cross-table between accident type-ship size and accident severity-ship size for DS

			Ship Length (m)		
			30-100	101-150	151≤
Accident Type	Grounding	Number	0	3	5
		Ship Size (%)	0.0	**60.0**	**29.4**
	Contact	Number	1	0	4
		Ship Size (%)	**50.0**	0.0	23.5
	Collision	Number	0	2	8
		Ship Size (%)	0.0	**40.0**	**47.1**
	Sinking	Number	1	0	0
		Ship Size (%)	**50.0**	0.0	0.0
Accident Severity	Less Serious	Number	1	2	7
		Ship Size (%)	33.3	**66.7**	38.9
	Serious	Number	0	1	11
		Ship Size (%)	0.0	33.3	**61.1**
	Very Serious	Number	2	0	0
		Ship Size (%)	**66.7**	0.0	0.0