NATIONAL TECHNICAL UNIVERSITY OF ATHENS
SCHOOL OF NAVAL ARCHITECTURE AND MARINE ENGINEERING

DATABASE DEVELOPMENT OF NAVIGATIONAL ACCIDENTS OF CONTAINERSHIPS

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ATHENS JULY 2021

Acknowledgments

I would like to warmly thank Mrs. Eleftheria Eliopoulou and Mr. Georgios Zaraphonitis who are my supervisors of my work for giving me the opportunity to be involved in this project as well as for their guidance and assistance throughout.

Secondly, I would like to express my honest appreciation and gratefulness to Dr. Rainer Hamann who advised and guided me by providing his generous and continuous help.

Finally, I would like to thank my parents and my sister as well as my close friends for the support and understanding during this period.

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Περίληψη

Στην παρούσα διπλωματική εργασία πραγματοποιείται η μελέτη των ατυχημάτων σύγκρουσης, επαφής και προσάραξης πλοίων μεταφοράς εμπορευματοκιβωτίων (containerships) κατά την περίοδο 1990-2020. Αρχικά διερευνήθηκαν τα αίτια που προκάλεσαν τα ατυχήματα, καθώς και οι συνέπειές τους. Για το σκοπό αυτό χρησιμοποιήθηκε η βάση δεδομένων DCCS-Database (Database with Cellular Container Ships Accidents) του Εργαστηρίου Μελέτης Πλοίου, στην οποία καταχωρήθηκαν 658 νέες εγγραφές (περίοδος 2008-2020) και εμπλουτίστηκαν σύμφωνα με τις επίσημες αναφορές των ατυχημάτων (investigation reports). Επίσης, αναπτύχθηκαν δέντρα σφαλμάτων των ατυχημάτων σύγκρουσης, επαφής και προσάραξης τα οποία βασίστηκαν, κατά κύριο λόγο, στις επίσημες αναφορές των ατυχημάτων. Τέλος, πραγματοποιήθηκε στατιστική ανάλυση των δεδομένων της τα αποτελέσματα της οποίας παρουσιάζονται στην συνέχεια της παρούσας εργασίας.
Μέσω των αποτελεσμάτων της στατιστικής ανάλυσης εξήχθησαν σημαντικά συμπεράσματα τα οποία θα βοηθήσουν σε μελλοντική έρευνα και ανάλυση.

Η διπλωματική εργασία μου ανατέθηκε από τον Τομέα Μελέτης Πλοίου και Θαλασσίων Μεταφορών και εκπονήθηκε υπό την επίβλεψη της δρ. Ελευθερίας Ηλιοπούλου, ΕΔΙΠ/ΕΜΠ και του κ. Γεώργιου Ζαραφωνίτη καθηγητή της σχολής Ναυπηγών Μηχανολόγων Μηχανικών σε συνεργασία με τον Dr. Rainer Hamann.

Abstract

In the present diploma thesis, the accidents of collision, contact and grounding of container vessels occurred in the period 1990-2020 are studied in terms of the causes and related consequences. Specifically, 658 new casualty records were added in the DCCS casualty database (period 2008-2020), the registered information was populated accordingly and was further enhanced by using official investigation reports when available. Fault Trees of collision, contact and grounding accidents were developed based mainly on the study of official investigation reports. Afterwards, the statistical data processed and the relevant analysis is presented. Furthermore, the results of the statistical analysis were evaluated and lead to significant conclusions that could facilitate in further future assessments.

My diploma thesis was carried out in the Ship Design Laboratory of the School of Naval Architecture and Marine Engineering of NTUA under the supervision of Dr. Eleftheria Eliopoulou and prof. George Zaraphonitis in collaboration with Dr. Rainer Hamann.

1 Introduction

1.1 Literature review of Formal Safety Assessment Methodology

The protection and safety of human life and property as well as the protection of the environment are of outmost importance in maritime transport. In many cases, serious marine accidents mainly happen because of lack of safety procedures and may cause loss of human lives, serious environmental pollution and serious damage or loss of property. The gravity of the consequences of maritime accidents is the main reason for the development of methodologies, codes and regulations by the International Maritime Organization (IMO) as well as rules by classification societies, with the main goal of improving safety and protecting the marine environment. These regulations are usually based on studies that assess the risk of the corresponding accident types.

A well-known process that assesses the risk related to each hazard, considering alternative strategies and finding resolutions to reduce the risks and their consequences to acceptable levels is the Formal Safety Assessment. An FSA study is composed of the following steps (MSC-MEPC.2-Circ.12, 2018):

Step 1 Identification of Hazards

Step 2 Risk Analysis

Step 3 Risk Control Options

Step 4 Cost Benefit Assessments

Step 5 Recommendations for Decision-Making

The main subject of the present diploma thesis focuses on a subset of Step 2 of the FSA. More specifically, the probabilities of the causes leading to navigational accidents of containerships are calculated and the consequences related to collision, contact and grounding accidents are investigated.

In the following, a literature review is briefly presented in order to make more sufficient the purpose of this study.

Formal safety assessment of containerships (Wang et al.,2001)

This paper attempts a critical evaluation of the FSA framework as it applies to containerships. A test case was used to demonstrate the feasibility of the described approach. It becomes apparent that there is still plenty of space for improvement on containership safety. Areas on which such improvement can be achieved include, but are not limited to, the vessels’ strength and stability, fire-fighting and life-saving equipment, human reliability and information availability, reliability and interchange.

FSA – container vessels/Details of the Formal Safety Assessment (MARITIME SAFETY COMMITTEE, 2007)

This study presents a completed Formal Safety Assessment study conducted by a scientific group in context of the EU funded research project SAFEDOR (2005-2009) and was submitted to IMO (MSC 83/INF.8).

Casualty analysis of Cellular Container Ships (Eliopoulou et al., 2013)

This study presents an investigation of recorded casualties pertaining to cellular type containerships for the period 1990-2012 and addresses the need for careful evaluation of employed databases and use of primordial data as important parameters for the risk modeling and quantification.

According to the results, during the second decade covered by the study (2002-2012), the frequency of serious accidents is increased, especially in collision events, where the calculated frequency is about 2.5 times higher than the corresponding one for the time period 1990-2001.

Assessment of Safety Performance of Container Ships (Hamann et al., 2013)

This study, which is the continuation of the previous one, focuses on the development of the new risk models for container ships. New risk models were developed taking into consideration the fleet at risk and casualty reports for a period from 1990 to October 2012, and the recent developments with respect to assumptions and models used in the risk models, e.g. consideration of uncertainty.

According to the results, risk evaluation using the criteria proposed in FSA Guidelines showed that the risk (societal as well as individual) for containerships is in the area of tolerable region, which means that the ALARP process should be applied in order to make risk as low as reasonably practicable.

1.2 Scope of work

The objective of this diploma thesis is to study navigational accidents involving containerships that occurred within the time period 2008-2020 and draw conclusions about the causes of the accidents and related consequences, which may be pollution of the marine environment, loss of human life and ship/cargo loss or damage.

For this reason, a database was used in MS Access 2010 which was provided by the Ship Design Laboratory of NTUA. This database includes primordial casualty data derived from IHS database, such as the type and severity of the accident, the geographical area, weather information but also the characteristics of the ship, the vessel's damage extent due to the incident, and the consequences to human life and environment.

The first step of the procedure is to study the existing description of accident and gather more information and general data defining each accident from reliable sources. This process was carried-out in order to clarify the situation of each case, so as to be accurately evaluated and categorized. At the same time, fault trees for the three categories of accidents, collision, contact and grounding are also being constructed.

In the second step of the procedure the database was enhanced with all the available information gathered. This process was carried-out in order to provide a better description of the incident and more specifically the conditions of the environment where the accident occurs, as well as the causes that led to the incident.

Finally, the most interesting part of the research is the statistical analysis of the three navigational accidents, collision, contact and grounding. At this step calculations were performed with respect to the probabilities of:

- The main causes,
- The conditions and the area of the incidents
- The consequences due to the accidents.

In addition, the overall frequency of occurrence of a navigational event was estimated and compared with previous studies (Eliopoulou et al., 2013). The annual frequencies of each event for the time period 1990-2020 are also presented and discussed.

1.3 Thesis Structure

This diploma thesis consists of 6 chapters describing in detail the whole methodology of the work and the derived results.

Initially, in Chapter 1 a reference is made to the FSA process, and to previous studies already carried out with reference to the statistical analysis of container ship accidents. At the same time, the purpose of the thesis and its structure are analyzed.

In Chapter 2, the basic characteristics of containerships are described along with their advantages and disadvantages. Afterwards a historical overview of containerships evolution is presented and finally three typical cases of navigational accidents namely collision, contact and grounding are discussed.

In Chapter 3, an introduction is made to the fault trees, their structure, and generally to the methodology of the fault tree analysis. The constructed fault trees of collision, contact and grounding events are developed according to the official reports of accidents (investigation reports provided by IMO GISIS).

In Chapter 4, the methodology that was used to enhance the information of SDL-DCCS database is presented. Specifically, the formal investigation reports are listed as well as the reliable sources that were examined in order to select additional information for the accidents. Afterwards the enhancement of the database is described and the new added fields are listed. The main purpose behind the introduction of these new fields, is to have a better estimation of the accident and finally make a better evaluation of the results.

In Chapter 5, the results of the statistical analysis of the collision, contact and grounding accidents are presented. At first, general statistical results from all the accident records of the SDL-DCCS database are displayed. Afterwards, probabilities related to the fault trees analysis are presented and finally probabilities of the predefined event trees (Hamann et al, 2013) are listed.

In Chapter 6, the conclusions that were derived from the statistical analysis of Chapter 5 are listed, and suggestions for further research and analysis are discussed.

Finally, the references and the sources from which data have been obtained for the thesis are presented.

1.4 Basic definitions

Marine Casualty: A marine casualty means an event, or a sequence of events, that has resulted in any of the following which has occurred directly in connection with the operations of a ship (IMO 1997, A 20/Res.849):

- Death or serious injury
- Loss of a person from a ship
- Loss, presumed loss or abandonment of a ship
- Material damage to a ship
- Stranding or disabling of a ship
- Collision
- Material damage to marine infrastructure external to a ship that could seriously endanger the safety of the ship, another ship or an individual
- Severe damage to the environment, or the potential for severe damage to the environment brought about by the damage of a ship or ships.

Collision: striking or being struck by another ship (regardless of whether under way, anchored or moored). (IMO 2000, MSC Circ.953)

Grounding: being aground or hitting/touching shore or sea bottom or underwater objects (wrecks, etc.) (IMO 2000, MSC Circ.953)

Contact: : striking any fixed or floating object. (IMO 2000, MSC Circ.953)

Containership: A container ship is defined as a sea-going vessel specifically designed, constructed and equipped with the appropriate facilities to carry cargo containers. Containers are stowed in cargo spaces, i.e. in cargo holds below or above deck. (IMO 2007, MSC 83/21/2)

Annual Operational Fleet at Risk is defined as the number of ships that operate in the corresponding period and it is calculated according to the monthly operation of each vessel based on data from the IHS database.

Annual Frequency of accidents is calculated by dividing the total annual number of registered accidents by the number of ships operating in that year (annual operational fleet at risk).

2.Containerships

The idea of shipping products in containers is a very old one. The ancient mariners used sealed vases – or amphorae – to transport oil or wine. Later cultures used large trunks to ship valuables aboard their sailing vessels. But containerization is a modern phenomenon just over 50 years old.

Therefore, this phenomenon, led to the design and construction of container ships. The cargo carried on containerships must be placed in specially designed boxes in order to make a safer, quicker and more cost-effective transport compared to conventional transport methods. These special boxes are called "containers" and they are placed in an appropriately configured area.

Specifically, the container is a metal structure with a rectangular form; the dimensions are standard and have sufficient strength to carry the load with safety. The construction is based on formulated standards and is created in specific sizes, the most common of which are presented in the following table:

Table 2.1: Standard container dimensions

TYPE	DIMENSIONS (m)
20 FEET (TEU[1]) TYPE	6,1 x 2,44 x 2,44
40 FEET (FEU[2]) TYPE	12,2 x 2,44 x 2,44

The main advantages of the containerships are listed below:

- Ship is loading/unloading faster
- The available volume of containers is used at 100% because of the standard dimensions of containers
- All the container vessels are capable of loading containers on the main deck of the ship with suitable docking systems
- The cargo is carefully packed in containers and is protected more effectively during its transport
- The standard dimension of containers leads to the construction of trucks and railway carriages which are specially designed to carry containers. Therefore, long-distance combined transport networks are developed.

[1] Twenty foot equivalent unit
[2] Forty foot equivalent unit

In addition, the containerships have disadvantages, which are presented below:

- The additional cost of the container itself
- The weight of container is included in the vessel's deadweight which has a negative impact on the cargo carrying capacity of the ship
- The unbalance of the worldwide trade; specific countries or geographical regions are net importers i.e. imports are more than exports, and other countries are net exporters. For this reason in countries that are net importers, a large number of empty containers is collected and since these containers should be returned, additional expenses arise. (Ζαραφωνίτης Γ.,2005)

2.1 History of containerships

Since the beginning of containerization appeared in the mid-1950s, containerships undertook six general waves of changes, each representing new generations.

1st Generation

The first generation is related to ships that had been converted from bulk carrier or tanker with capacity up to 1000 TEU. The first containership named Ideal-X, was a tanker that was converted to a container vessel during World War II. In the 1960s, containership was not an ordinary mean of maritime transport and the conversion of existing bulk carrier or tanker was the least expensive solution since the ports didn't have the equipment to manage the containers. The main problem was that the cargo was moving exclusively on the main deck and not in the cargo holds.

2nd Generation

In 1970, due to the increase in the number of containers up to 2000 TEUs in transport, fully cellular containership was designed and built. These ships, where now able to carry cargo on deck and in holds, and were equipped with cells where containers are placed in piles of different heights. In addition, the particular design had no cranes and this allowed more containers to be placed on the main deck. These ships were much faster, reaching speeds up to 24 kn. At the same time, new terminals were constructed worldwide in order to accommodate the necessary equipment for loading/unloading of containerships.

3rd Generation

In the 1980s, based on the fact that more and more containers were transported, the cost per TEU became lower, resulting to the construction of larger ships reaching a capacity of up to 3000 TEUs.

4th Generation

In 1985, the limitation of the Panama Canal (locks), led to the construction of container ships, which had a narrow and long design and a capacity of up to 4,000 TEU. Maximum dimensions of these ships called PANAMAX containerships are X m beam and Y m in length.

5th Generation

In 1988, container ships APL 10 were built and for the first time this category exceeded the limit of 32.2 m of the Panama Canal. The Post Panamax had, until 1996, a capacity of about 6600 TEUs.

6th Generation

This category is related to vessels with capacity of around 8000 TEUs and their requirements are associated with ports of greater depth and special loading and unloading equipment (they are exceeding the Panama Canal restrictions).

New Panamax

This category of vessels has been designed according to the limitations of the enlarged Panama Canal and the capacity is approximately 12500 TEU. Panamax and New Panamax containerships compose a specific category that effectively serves America and the Caribbean Sea.

Post New Panamax

In 2006, the shipping company Maersk presented the ships Emma Maersk E Class with capacity of between 11000 and 14500 TEUs. This ship size, does not satisfy the requirements of the extended Panama Canal because they are larger and carry cargo up to 18000 TEU (Triple E Class).

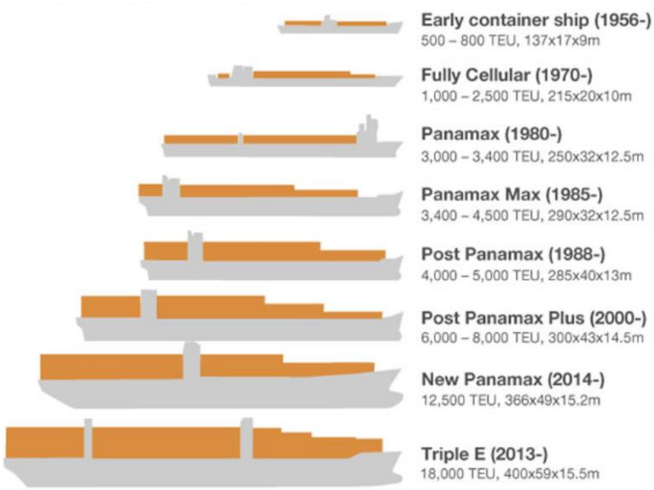


Figure 2.1.1: Historical Evolution of Containerships
(https://mrbarlow.wordpress.com/2013/04/06/evolution-of-container-ships/)

2.2. Basic characteristics of containerships

As mentioned in Chapter 2.1, containerships are special class vessels because they carry standard size cargo. This fact, affects their design and their construction.

Containerships have transverse bulkheads that are separating the cargo area into a specific number of holds while they don't have any longitudinal or horizontal subdivision except from two longitudinal bulkheads that specify the cargo and double hull area. The size of the holds is an integer multiple of the container dimensions (length, width, height), in order to use as much as possible the cargo hold area. In addition, the hatch covers have increased dimensions so that horizontal movements during loading or unloading of the containers are not required. It is noticed that some new and smaller size containerships are not equipped with hatches (open top ships) resulting to reduced time for loading/unloading, cost and total light weight of the ship. Finally, a basic characteristic of containerships is that, due to the higher speed requirement, they have a finer hull form with sharper stem and stern comparing to other types of cargo vessels i.e. tankers, bulk carriers etc. For this reason, the space is not adequate for the installation of the large main engines, required due to the higher service speed. Therefore, in order to have a better weight distribution along the vessel's length and also to reduce trim, usually the engine room is moved forward, which results to available cargo space for one or two holds aft of the engine room.

Due to the standardization of cargo, the following categorization (Table 2.2.1) of container boxes is established:

Table 2.2.1: Categorization of containers

Standards	suitable for normal cargo
High Cube	specifically for light, voluminous cargos or those with excessive height (up to 2.67 m)
Hard Top	with removable solid steed roof; suitable for heavy lifts, cargos of excessive height, for loading from above and from door end
Open Top	with removable tarpaulin; suitable for cargos of excessive height, for loading from above (e.g. by crane); loading from door
Flats	suitable for heavy lifts and over-width cargos; non-containerizable cargo can be placed on several flats, side by side
Platforms	suitable for heavy-lifts and out of gauge cargos; non-containerizable cargo can be accommodated on several platforms
Ventilated	for cargos requiring ventilation
Insulated	for cargo requiring transport at a constant temperature above or below freezing point
Reefer	for cargo requiring transport at a constant temperature below or above freezing point; with built-in reefer unit
Bulk	for loose/bulk cargos
Tank	for liquid chemicals; containers are also available for the transport of liquids and liquid foods

Figure (2.2.1) presents the general arrangement of the containership "COLOMBO EXPRESS" with capacity 8600 TEU.

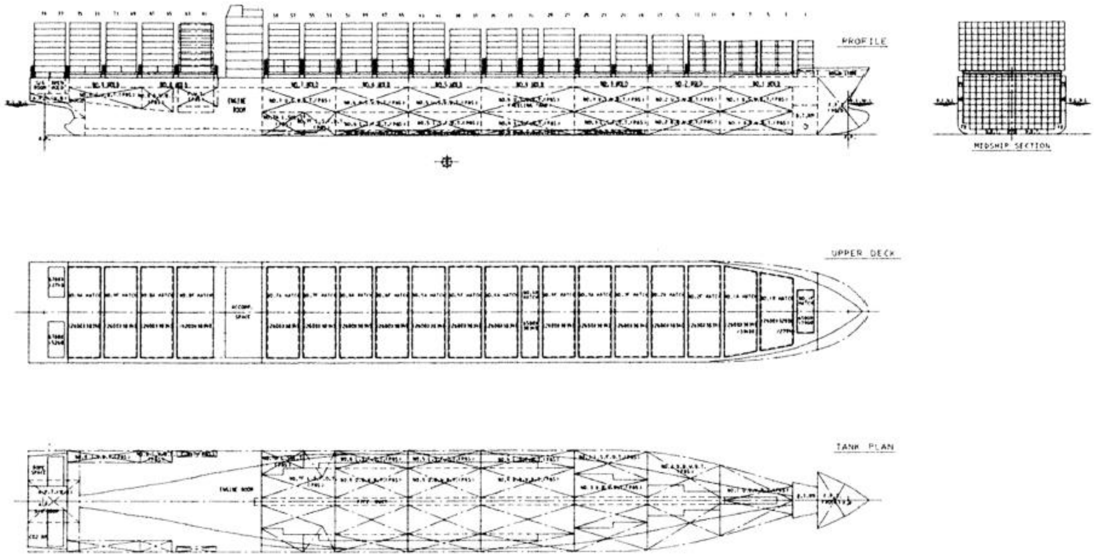


Figure 2.2.1: General arrangement of the containership "COLOMBO EXPRESS" ("Significant Ships of 2005" (Lingwood et al., 2005))

2.3 General review of navigational accidents-Incident cases

In this chapter, a review of the navigational accidents is presented along with some accident cases pertaining to each accident category namely collision, contact and grounding.

Collision

Collision events consist of scenarios where two vessels accidentally come into contact with each other. The investigated scenarios contain collisions when the containership is striking or being struck by another ship. A collision involves at least two ships and in statistics each collision event is registered as two casualties – one for each involved vessel. The basic causes are because of, navigational problems such as human errors or machinery failure such as rudder failure, steering or propulsion failure.

Accident case "Hammonia Thracium" (Maritime and Port Authority of Singapore Ship Investigation Dept (IVD),2014)

At about 15:33 on 10 February 2014, a collision took place inside the precautionary area of the Singapore Strait TSS (off Pulau Sebarok) between *"Hammonia Thracium"* (departed from Singapore and crossing the precautionary area from the north) and Zoey (transiting west-bound). The collision occurred in good visibility and fine weather.

Despite Singapore VTIS calling Zoey to take early avoiding action, the Second Mate waited until the last moment to reduce speed and alter to port (to the south). However this could not avert the collision and Zoey collided head-on into *"Hammonia Thracium*"port mid-ship section.

There were no reported injuries but both vessels sustained material damages. Zoey sustained bow damages while the No. 4(P) Fuel Oil Tank of *"Hammonia Thracium"* was breached, spilling an estimated 70 mt of intermediate fuel oil. MPA activated the oil spill contingency plan and coordinated the containment and clean-up efforts. As of 13 February 2014, no more oil patches were reported.

Investigations revealed that the collision was not caused by mechanical failures, environmental or organisational factors. It appeared that the main causal factor was due to the human error of lack of situational awareness - the Second Mate of Zoey unfounded assumption that "*Hammonia Thracium*" would pass astern of Zoey.

Contributory causal factors include "*Hammonia Thracium*" not proceeding at a safe speed and the Master of Zoey displaying the human error of being unaware of role/task responsibilities.

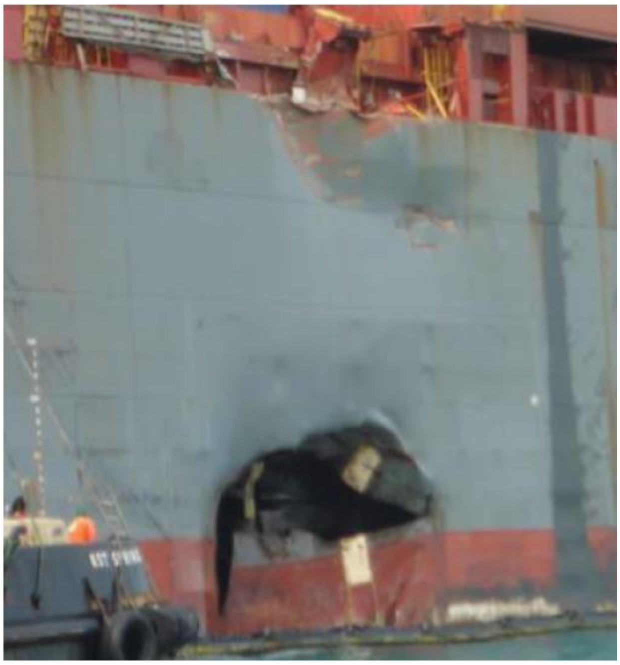


Figure 2.3.1: Damage of the port-mid section of Hammonia Thracium

Contact

Contact events consist of scenarios where the vessel accidentally comes into contact with a floating object or a fixed installation. Most contacts take place within congested waters with dense ship traffic, crossing routes and areas with large ship speed variations. The basic causes are because of bad visibility, navigational problems such as human errors or equipment failure such as radar failure, steering or propulsion failure.

Accident case "CMA CGM Centaurus" (The United Kingdom Merchant Shipping,2018)

At 11:37 on 4 May 2017, the UK registered container ship "*CMA CGM Centaurus*" made heavy contact with the quay and two shore cranes while executing a turn under pilotage during its arrival at Jebel Ali, United Arab Emirates. The accident resulted in the collapse of a shore crane and 10 injuries, including one serious injury, to shore personnel.

The MAIB investigation established that *"CMA CGM Centaurus"* was going too fast for the intended manoeuvre when the pilot started the turn. The pilot was aware that the ship might have been travelling a little faster than he would have liked when he initiated the turn, but was content that the ship would be able to complete it. The ship's bridge team were uncertain of the maximum speed required to complete the turn safely. There was no agreed plan for the intended manoeuvre, and therefore no shared mental model between the bridge team and the pilot. Consequently, the pilot was operating in isolation without the support of the bridge team, allowing the pilot's decision-making to become a single system point of failure.

The size of container ships has grown at a rapid pace, yet ports remain largely the same. Margins for error are therefore decreasing. It is imperative that pilots and ships' bridge teams work together and implement the best practices of Bridge Resource Management to ensure the safety of both ships and ports.

Figure 2.3.2: Containers falling from ship onto the quay

Grounding

Grounding events consist of scenarios where the vessel accidentally comes into contact with the sea bed or shore. Grounding is predominantly caused by navigation failure (powered grounding) or by propulsion, power or steering failure (drift grounding).

Powered grounding could happen when the vessel under power is having contact with the shore or touch bottom. The accident evolves in the same way as in case of drift grounding but the impact is stronger as the speed is greater.

Drift grounding could happen due to the loss of manoeuvrability, propulsion or steering system failure. In case of anchoring failure, absence of tugs and impossibility to recover the failure, the grounding cannot be avoided. As a result of the accident there may be, loss of structural integrity, while the ship may remain aground or afloat, or sink.

Accident case "Kea Trader" (Marine Safety Investigation Unit,2017)

At 00:55 on 12 July 2017, the Maltese registered container ship "*Kea Trader*" ran aground and stranded in position 22° 02.28' S 168° 38.25' E (Recif Durand) in the Pacific Ocean. At the time, the vessel was on a passage from Papeete, Tahiti, to Noumea, New Caledonia.

"Kea Trader" was using electronic chart display and information system (ECDIS) as the primary means of navigation and there were no paper charts on board. The officer of the watch (OOW) was monitoring a route displayed on the ECDIS. A salvage company was contracted by the managers to salve the vessel and to prevent marine pollution. The salvors reported water ingress in the double bottom tanks, duct keel and cargo holds. Containers in the lower tiers of the hold were flooded and fuel oil was detected in one of the cargo hold. Pounded repetitively by heavy swell, Kea Trader's engine-room bulkhead failed on 23 July. No oil pollution was reportedly observed in the sea. The vessel was declared a constructive total loss on 28 September.

Figure 2.3.3: Kea Tarader hard aground on Recif Durand

3. Fault trees

3.1 Fault tree analysis

Fault tree diagrams (or negative analytical trees) are rational block diagrams that show the state of a system (top event) with reference to the states of its elements (basic events). These diagrams are a graphical design methodology.

A Fault Tree Diagram is built top-down and its elements are events. It utilizes a graphic model of the paths through a system that leads to a predictable, undesirable loss event (or a failure). The paths associate contributory events and conditions, using standard rational symbols (AND, OR, etc.) (U.S. Nuclear Regulatory Commission,1981).

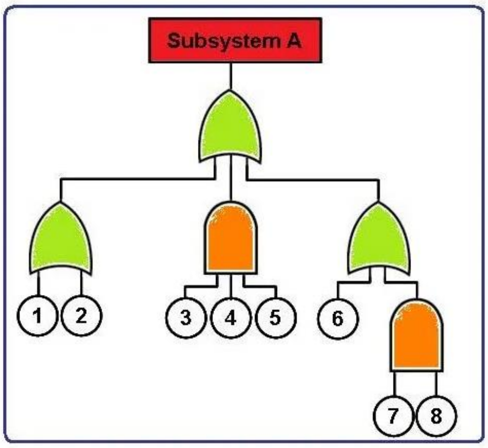


Figure 3.1.1: Fault tree diagram

Fault trees are elaborated utilizing gates and events (blocks). The two most regularly utilized gates in a fault tree are the **AND** and **OR** gates. For instance, there are two events (called input events) that can lead to another event (called the output event). If the occurrence of either one the input event causes the output event to occur, then these input events are joined using an **OR** gate. On the other hand, if both input events should happen in order for the output event to occur, then they are joined by an **AND** gate.

An example is given with a system composed by two input events, A and B, associated with an OR gate which is the output event ("top event"). If this event causes system failure and the two input events are parts of the failure of the system, the fault tree shows that the failure of A or B makes system break down.

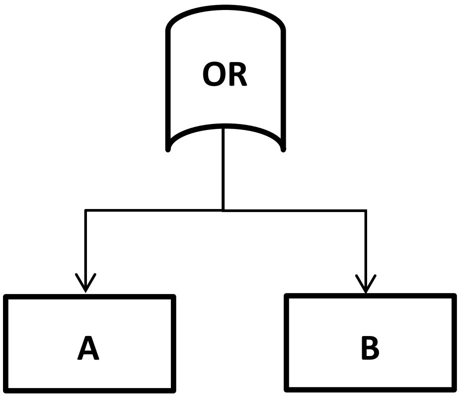


Figure 3.1.1: Schematic Representation of Fault Trees

Figure 3.1.2 presents an example of a fault tree pertaining to the causes of grounding events of containerships (Hamann et al., 2013).

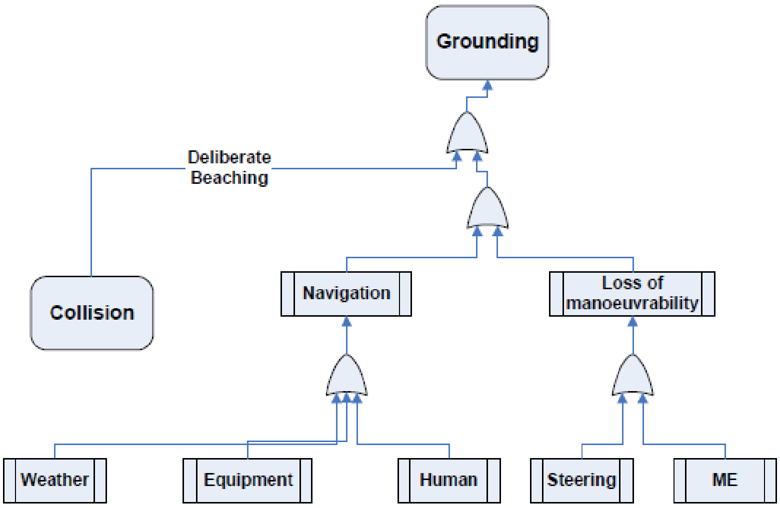


Figure 3.1.2: Causes for grounding accidents
(Hamann et al., 2013)

3.2 Development of fault trees for navigational accidents

In the present thesis, the fault tree analysis (FTA) was used to determine the causes of containership accidents namely collision, contact and grounding.

Initially, 39 investigation reports, related to collision accidents of containerships, were studied. Afterwards, the fault tree of collision accidents was constructed and presented in Figure 3.2.3. It is worth noting that relevant information was also gathered from internet reliable sources as well as from the complimentary texts of SDL-DCCS accident database.

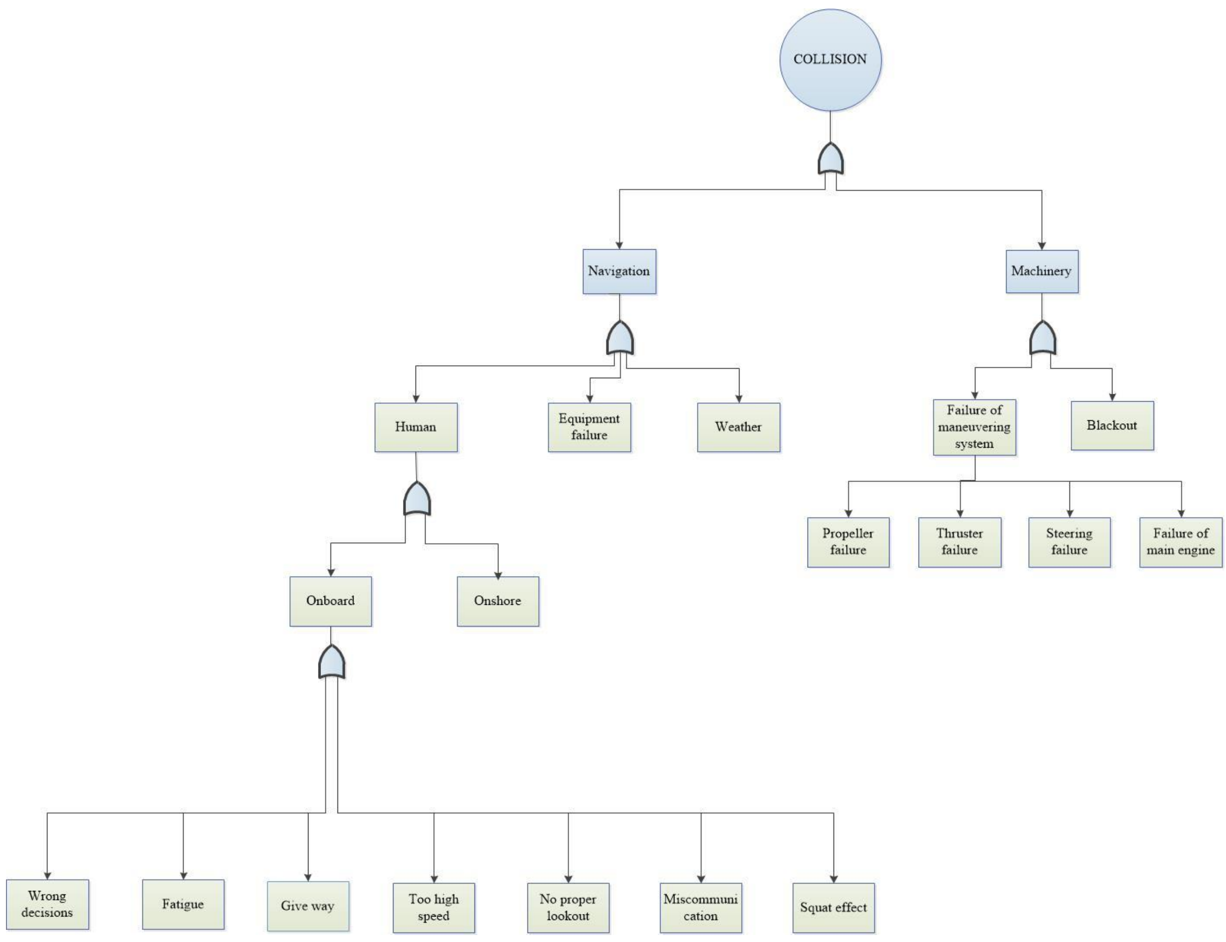


Figure 3.2.1: Fault tree related to collision accidents

The collision fault tree consists of the causes that lead to the accident.

The causes leading to navigational failure are divided into 3 main categories:

- Human error
    - Onboard
        - Wrong decisions: wrong actions or no actions to collision avoidance, wrong assessment of risk, manoeuvring error, improper route selection
        - Fatigue: heavy workload, bad health condition
        - Give way: non-compliance with the regulations/rules onboard or other
        - Too high speed
        - No proper lookout: no proper watch-keeping, less education
        - Miscommunication: no communication, bad communication between vessels or between pilot and crew
        - Squat effect: When a ship moves through the shallow water, some of the water displaced rushes under the vessel to rise again at the stern. This decreases the upward pressure on the hull, making the ship sink deeper in the water than normal and slowing the vessel.
    - Onshore: wrong instructions from shore, pilot related matters
- Equipment failure: failure of radar, VHF, mooring failure, dragging anchor
- Weather: ice, seaway, wind, Significant Wave Height, Wind Beaufort, Visibility

The causes leading to machinery failure are divided into 2 main categories:

- Failure of maneuvering system

- Propeller failure
- Thruster failure
- Steering failure
- Failure of main engine

- Blackout

Subsequently, 5 investigation reports, related to contact accidents of containerships, were studied. Afterwards, the fault tree of contact accidents was constructed and presented in Figure 3.2.2. It is worth noting that relevant information was also gathered from internet reliable sources as well as from the complimentary texts of SDL-DCCS accident database.

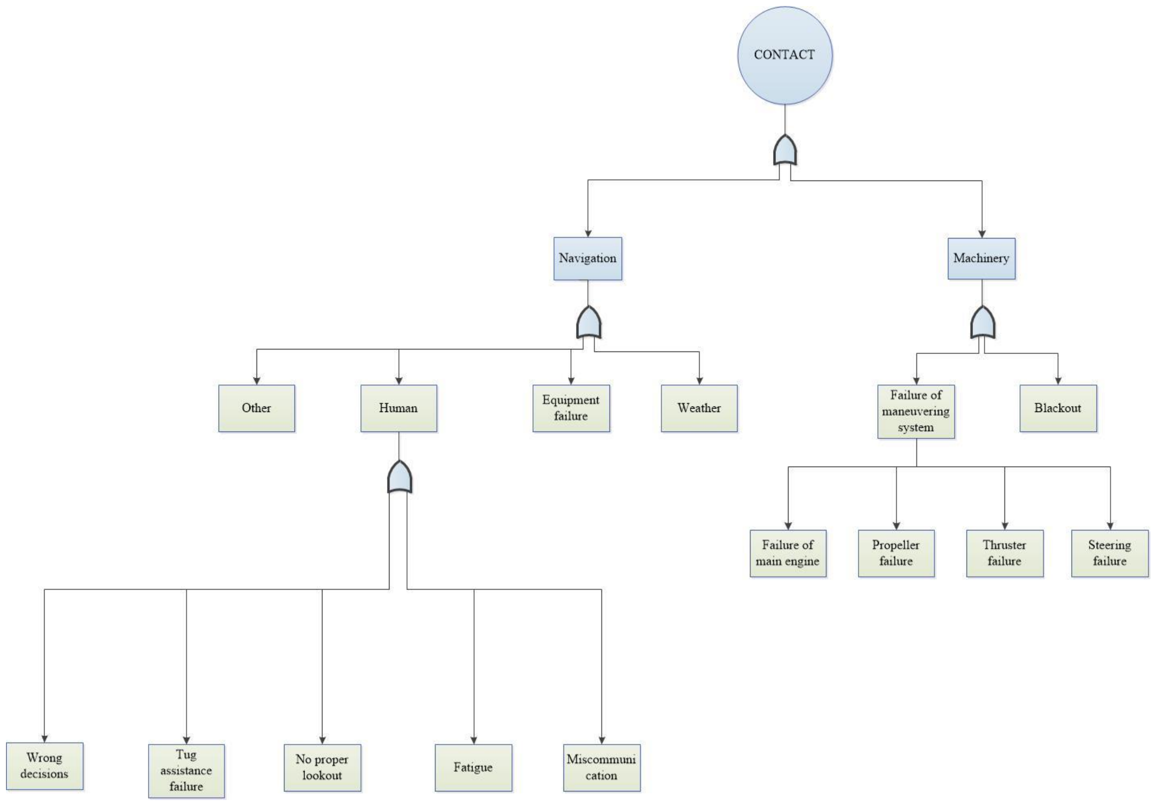


Figure 3.2.2: Fault tree related to contact accidents

The contact fault tree consists of the causes that lead to the accident.

The causes leading to navigational failure are divided into 4 main categories:

- Human error
    - Wrong decisions: lack of knowledge, slow response
    - Tug assistance failure
    - No proper look out: no proper watch-keeping, less education
    - Fatigue: heavy workload, bad health condition
    - Miscommunication: no communication, bad communication

- Equipment Failure: failure of radar, GPS, mooring failure, dragging anchor

- Weather: ice, seaway, wind, Significant Wave Height, Wind Beaufort, Visibility

- Other: contact with invisible floating object

The causes leading to machinery failure are divided into 2 main categories:

- Failure of maneuvering system
    - Propeller failure
    - Thruster failure
    - Steering failure
    - Failure of main engine

- Blackout

Finally, 4 investigation reports, related to grounding accidents of containerships, were studied. Afterwards, the fault tree of grounding accidents was constructed and presented in Figure 3.2.3. It is worth noting that relevant information was also gathered from internet reliable sources as well as from the complimentary texts of SDL-DCCS accident database.

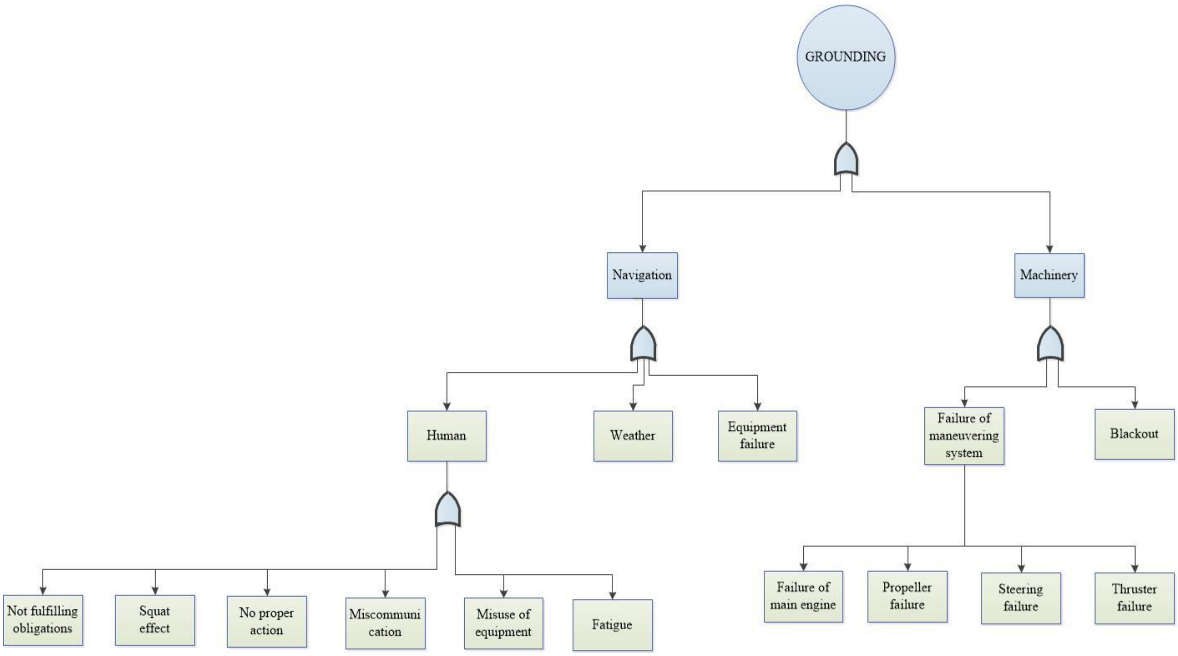


Figure 3.2.2: Fault tree related to grounding accidents

The grounding fault tree consists of the causes that lead to the accident.

The causes leading to navigational failure are divided into 3 main categories:

- Human error
    - Not fulfilling obligations
    - Squat effect: When a ship moves through the shallow water, some of the water displaced rushes under the vessel to rise again at the stern. This decreases the upward pressure on the hull, making the ship sink deeper in the water than normal and slowing the vessel.
    - No proper action: pilot error, wrong action, no action, no lookout of their duties
    - Miscommunication: no communication, bad communication
    - Misuse of equipment
    - Fatigue: heavy workload, bad health condition

- Equipment Failure: failure of radar, GPS, dragging anchor, uncharted area rock/reef

- Weather: ice, seaway, wind, Significant Wave Height, Wind Beaufort, Visibility

The causes leading to machinery failure are divided into 2 main categories:

- Failure of maneuvering system
    - Propeller failure
    - Thruster failure
    - Steering failure
    - Failure of main engine

- Blackout

4. DCCS accident database

4.1 Methodology of the study

For this diploma thesis, the Ship Design Laboratory of the National Technical University of Athens made available the SDL-DCCS accident database (Database with Cellular Container Ships Accidents) which has been developed in MS Access 2010. The thesis focuses on the navigational accidents related to containerships which are included in the database. (ref. Georgakopoulos et al., 2012)
Initial raw casualty data were retrieved from the IHS database. The new records that were inserted in SDL-DCCS accident database in the framework of the current thesis, were reviewed and enhanced by additional information to the extent available; the data at hand were re-analyzed and post-processed in the way to produce input to the global risk models.
The additional information was selected by searching for accident data from reliable sources. The data that are gathered after the search are derived from the database EMCIP (EMSA, EMCIP), the database GISIS (IMO, Global Integrated Shipping Information System), from formal investigation reports and articles obtained from the internet. Specifically, the investigation reports, which used to enhance the database information, are presented below:

Collision Accidents

- 27 publicly available investigation reports from reliable sources
- 10 investigation reports from the internet

Grounding Accidents

- 1 public investigation report and 1 not public investigation report from reliable source
- 3 investigation reports from the internet

Contact Accidents

- 3 public investigation reports from reliable source
- 2 investigation reports from the internet

For those records that investigation reports do not exist or they are not available, relevant information was gathered from articles available on the internet and from the complementary texts found in the raw data.

The database contains 3287 registered records in total. In the particular thesis, 658 new records were added and studied (ID number from 2263 to 3287), covering a period from 2008 to 2020 from which the 314 of them, were categorized as collision accidents, the 169 were contact accidents and the 175 were grounding accidents.
In general, the available data for each accident record is related to the main characteristics of the containership that is involved in the accident as well as to the causes, the consequences and the attributes of the accident.

The basic elements for each accident are listed below:

- The ship that is involved in the accident
- The type and severity of the accident
- The operational state of the ship at the time of the accident and the area that the accident occurred
- The weather conditions at the time of the accident
- The possibility of having water ingress because of the accident and the part of the ship that was damaged due to the incident
- The ship status and the damage extend on the ship after the accident

The database fields and the assumptions that are taken into consideration in order to populate properly are described in detail in (Georgakopoulos et al., 2012) and Appendix A.

Finally, after the process of searching, gathering and inserting information in the database, the data was exported in Microsoft Excel and a statistical analysis was performed afterwards. The relevant results are presented in the following chapters.

4.2 Expansion of SDL-DCCS accident database

In the present chapter the enhancement of the database is described and the new added fields are presented. The main purpose of considering the new fields is to provide a clearer description of the accident with respect to the conditions of the incident (location, visibility, sea state), the days that the vessel was out of service due to the accident and finally the main causes that led to the occurrence of this incident. The new fields that are added in the database are given below:

- Geographical location
- Out of service
- Visibility
- Significant Wave Height (Hs)
- Collision fault tree
- Contact fault tree
- Grounding fault tree

It is worth to mention that the fields “Visibility” and “Significant Wave Height (Hs)” were defined according to International standards. The new fields are described in detail below:

- In the Tab “Incident characteristics
    - Geographical Location: This field is completed from the section "precision text" of the database and is related to the exact location of the incident.

- In the tab “Outcome of Incident”
    - Days out of service: The days when the ship is not active because of the accident.

- New field "Visibility" with a drop down menu that contains the following:
    - Good
    - Moderate
    - Poor
    - Very poor

Note that "Visibility" is defined according to the international standards for describing reduced visibility in marine forecasts are as follows:

a. Very poor: Visibility less than 1,000 metres
b. Poor: Visibility between 1,000 metres and 2 nautical miles
c. Moderate: Visibility between 2 and 5 nautical miles
d. Good: Visibility more than 5 nautical miles

- Field "Significant Wave Height (H_s)": it is proposed to use the value of possible wave height. In cases where the Douglas scale does not give a value but a range (i.e. SCALE 4) it is proposed to use the maximum value of the range (i.e. SCALE 4, wave 2 m).

Table: 4.2.1: Douglas Scale

Douglas Scale	Sea State	Possible Wave Height (m)	Max Wave Height (m)
0	**Glassy**	0	0
1	**Rippled**	0.1	0 - 0.1
2	**Smooth**	0.2	0.1 - 0.5
3	**Slight**	0.6	0.5 - 1.25
4	**Moderate**	1.0 - 2.0	1.25 - 2.5
5	**Rough**	3.0	2.5 - 4
6	**Very Rough**	4.0	4 - 6
7	**High**	5.5 - 7.0	6 - 9
8	**Very High**	9 - 11.5	9 - 14
9	**Phenomenal**	14+	14+

- New fields related to designed Fault Trees (Chapter 3) of collision, contact & grounding:

Collision

- Collision Accident Causes
  - Collision due to
    - Machinery Failure (CN-Machinery Failure)
      - Manoeuvring systems (CN-Manoeuvring Systems Failure)
        - Propeller Failure
        - Steering Failure
        - Thruster Failure
        - Failure of Main Engine
      - Blackout
    - Navigation Failure (CN-Navigation)
      - Equipment failure
      - Human error (CN-Human Error)
        - Onboard (CN-Human Error-Onboard)
          - Fatigue
          - Give way
          - High speed
          - Miscommunication
          - No proper lookout
          - Squat effect
          - Wrong decision
        - Onshore
      - weather

Contact

- Contact due to
  - Machinery Failure (CT-Machinery Failure)
    - Manoeuvring systems (CT-Manoeuvring Systems Failure)
      - Propeller Failure
      - Steering Failure
      - Thruster Failure
      - Failure of Main Engine
    - Blackout
  - Navigation Failure (CT-Navigation)
    - Equipment failure
    - Human error (CT-Human Error)
      - Wrong decision
      - Tug assistance failure
      - No proper lookout
      - Fatigue
      - Miscommunication
    - Weather
    - Otner

Grounding

- Grounding Accident Causes
  - Grounding due to
    - Machinery Failure (GR-Machinery Failure)
      - Manoeuvring systems (GR-Manoeuvring Systems Failure)
        - Propeller Failure
        - Steering Failure
        - Thruster Failure
        - Failure of Main Engine
      - Blackout

- Navigation Failure (GR-Navigation)
    - Equipment failure
    - Human error (GR-Human Error)
        - Fatigue
        - Not fulfilling obligation
        - No proper action
        - Misuse of equipment
        - Miscommunication
        - Squat effect
        - Uncharted rock
    - weather

5.Accident Analysis

5.1 Statistical description of available accidents

This chapter presents a comprehensive statistical analysis of the accidents included in the SDL-DCCS database. The database includes 3287 recorded accidents in total occurred in the period of 1990-2020. The distribution of each accident category is presented in Table 5.1.1 and Diagram 5.1.1.

Table 5.1.1: Distribution of type of accidents

Type of accidents	No. of incidents
Collision	990
Contact	375
Fire/Explosion	261
Foundered	6
Grounding	564
Hull Fittings	87
Hull/Mchy. Damage	712
Occupational	30
Piracy	53
Structural Failure	90
War Loss/Hostilities	5
Summary	3173
Unknown/Not reported	114

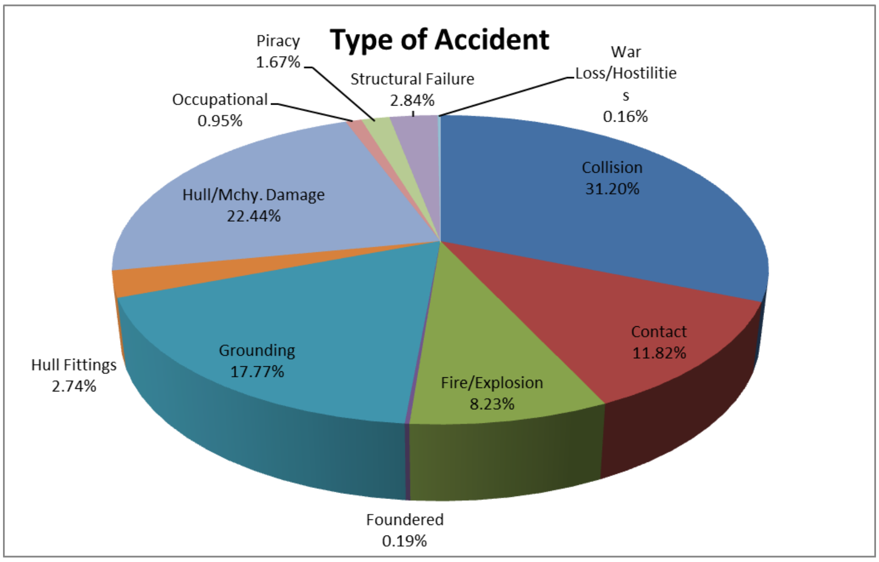


Diagram 5.1.1: Percentage of type of accidents

It is observed that the majority of the accidents are collision events (31.20%) and then hull/machinery damage (22.44%), grounding (17.77%), contact (11.82%) as well as fire/explosion (8.23%) and significantly less, the other categories. It must be noted that 114 accidents were not registered in any accident category due to lack of relevant information and consequently they were excluded from the analysis.

Table 5.1.2 presents the number and percentage of ships involved in an accident that were classified by IACS or Non-IACS Class Societies at the time of incident.

Table 5.1.2: Ship's Class at the time of the Incident

Class	Number of ships	Percentage %
IACS	2505	98
Non IACS	57	2
Summary	2562	100
Not reported	725	

Focusing on the casualties, only 57 events were recorded as Non-IACS ships within the study period, whereas 98% of ships involved in the accidents were under IACS Class Societies. It is worth mentioning that, in the present thesis it was decided to investigate the accidents of IACS Class ships and consequently only these records were extracted from IHS database. With respect to ship age, it was decided similarly to study only the ships that were built after 1981 and consequently only the relevant accidents were extracted from IHS database (Diagram 5.1.3).

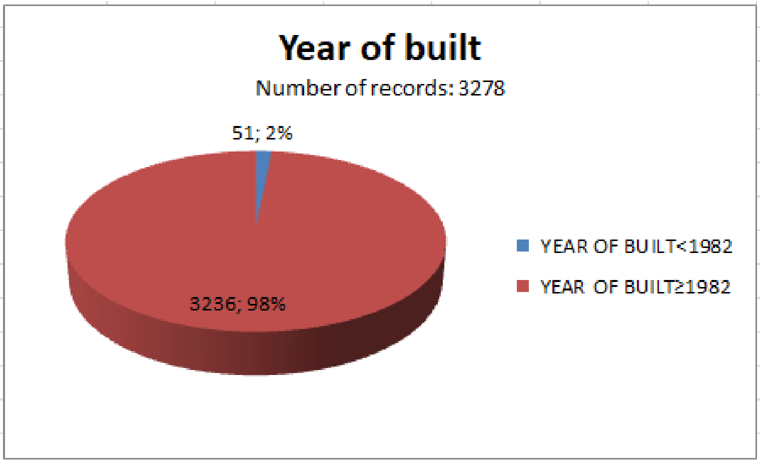


Diagram 5.1.3: Distribution of Year of Built

Diagram 5.1.4. presents the age of ships at the time of the incident. The number of accidents based on the age of the vessel at the time of the incident per age decade is:

- 2044 registered accidents for vessels' age between 0 to 10 years
- 1169 registered accidents for vessels 'age between 10 to 20 years
- 298 registered accidents for vessels' age between 20 to 30 years
- 6 accidents recorded for vessels' age over 30 years

Note that ships aged between 0 to 10 years presents a higher number of recorded accidents.

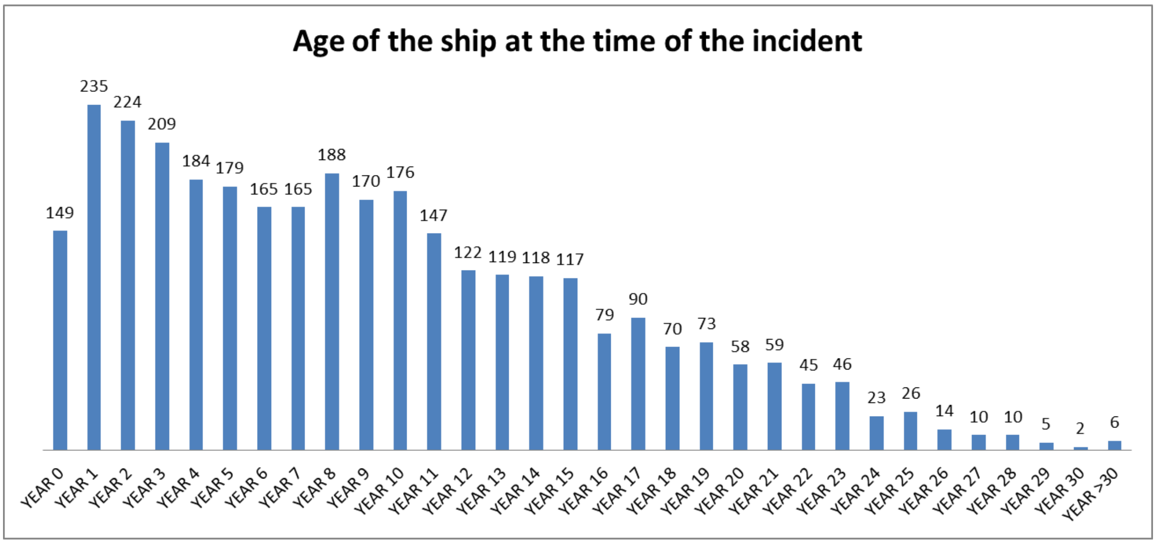


Diagram 5.1.4: Age of the ship at the time of the incident

Diagram 5.1.5 presents the number of accidents per year.

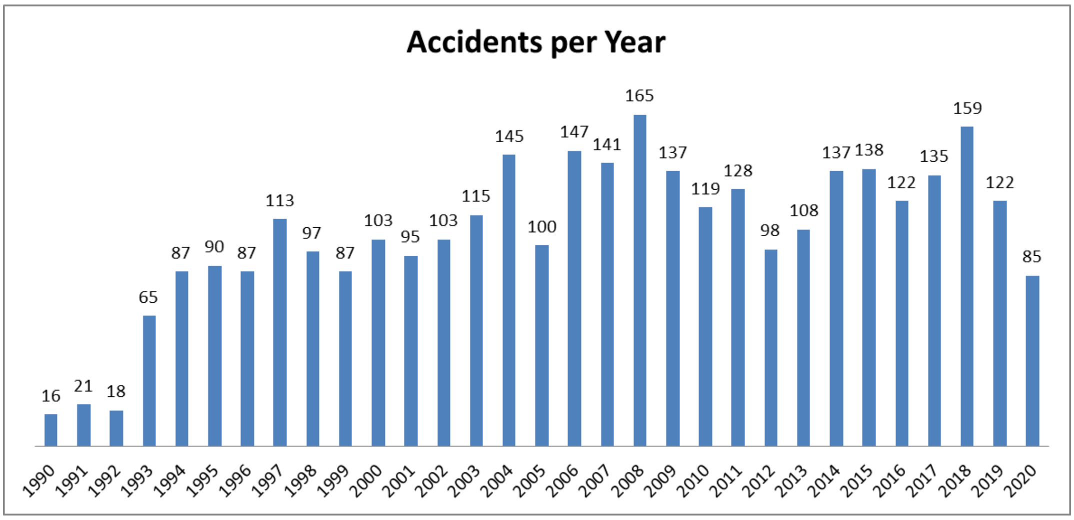


Diagram 5.1.5: Accidents per Year

It is observed that:

- During the first decade (1990-2000) the average number of accidents is 78 accidents per year
- During the second decade (2000-2010) the average number of accidents is 137 accidents per year
- During the third decade (2010-2020) the average number of accidents is 135 accidents per year

The highest number of accidents (165), occurred in 2008. After 2008, the year with the highest number of accidents is 2018 with a record of 159 incidents.

The degree of accidents' severity is presented below in the Diagram 5.1.6. The largest proportion of accidents in the database are serious (55%, 1819 records) whereas the non-serious accidents constitute a smaller percentage of 45% (1459 records).

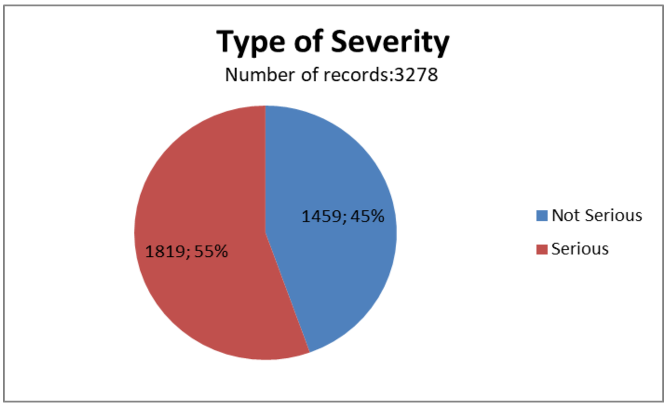


Diagram 5.1.6: Degree of accident's severity

Diagram 5.1.7. presents the distribution of accident's location. The accident's location can be grouped in three main categories, terminal areas, sea and restricted waters. This categorization of the locations is presented as follows:

- Terminal areas: port, anchorage, at berth, shipyard, drydock
- Sea: open sea, archipelagos, coastal waters (<12 nm)
- Restricted areas: restricted waters, river, port approach, inland waters, canal

The majority of the accidents according to the diagram 5.1.7 occur at sea (1280 incidents in total), secondly in terminal areas (878 total incidents) and finally in restricted areas (797 total incidents).

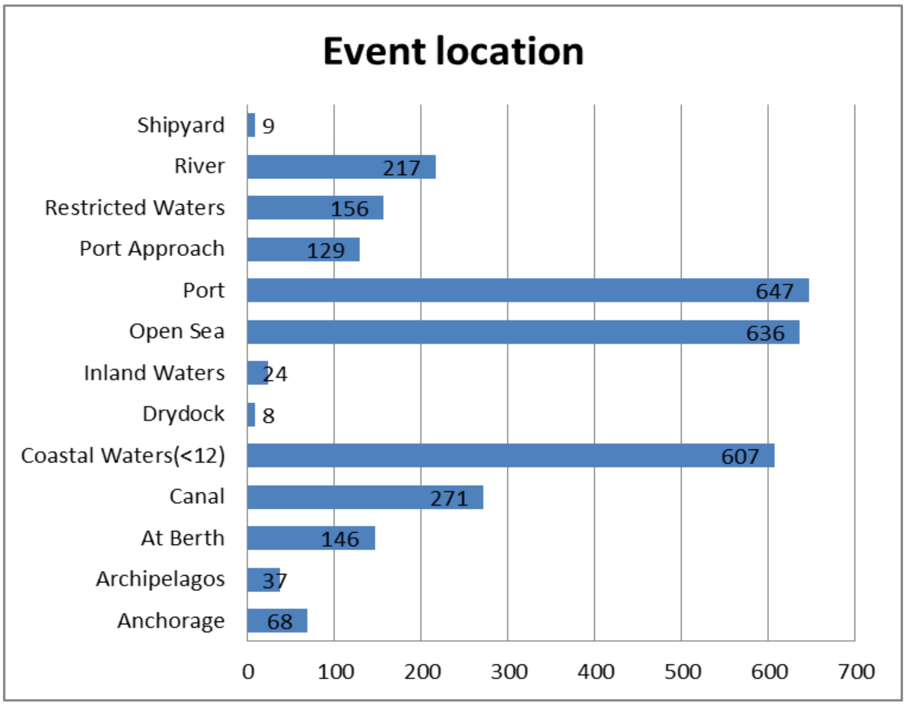


Diagram 5.1.7: Event location

Diagram 5.1.8 presents the damage extent of the ships involved in the accidents. The highest percentage of accidents (51%, 1230 records) the ship under investigation needed minor repairs due to the incident and in 39% (907 records) of cases the ship required major repairs. Furthermore, the percentage of accidents resulting to ship's total loss/break up is relatively low (only 1%, 29 records). Finally, a relatively small percentage of vessels had not sustained any damage (9%, 208 records).

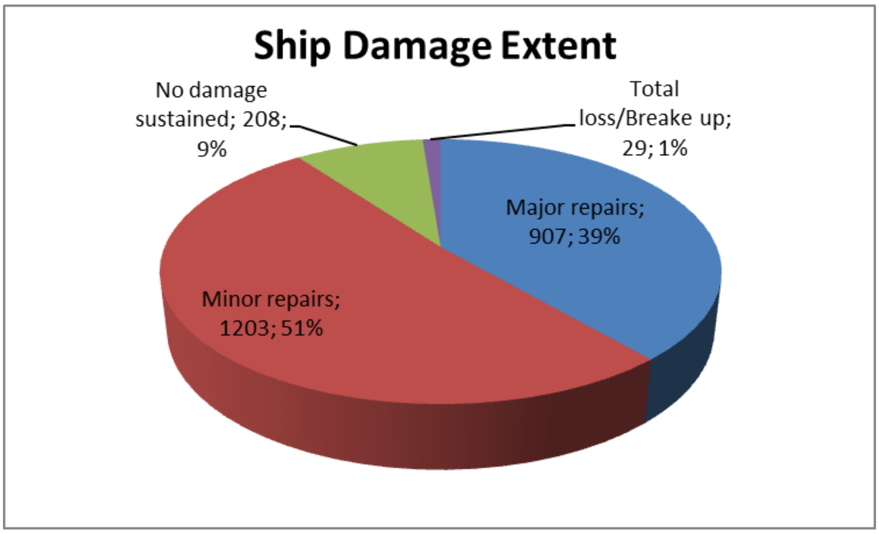


Diagram 5.1.8: Ship Damage Extent

5.2 Results from the Fault Trees

As per Chapter 3, the fault trees of the three (3) navigational accidents (collision, contact and grounding), which were developed using the investigation reports of the accidents are presented. Then, the relevant information was inserted into the database, a statistical analysis was carried out and the results are depicted as follows:

Collision accidents

The main causes for a collision incident can be grouped in two (2) main categories, navigational failure & machinery failure. Diagram 5.2.1 presents the percentage and the number of these causes that led to a collision accident.

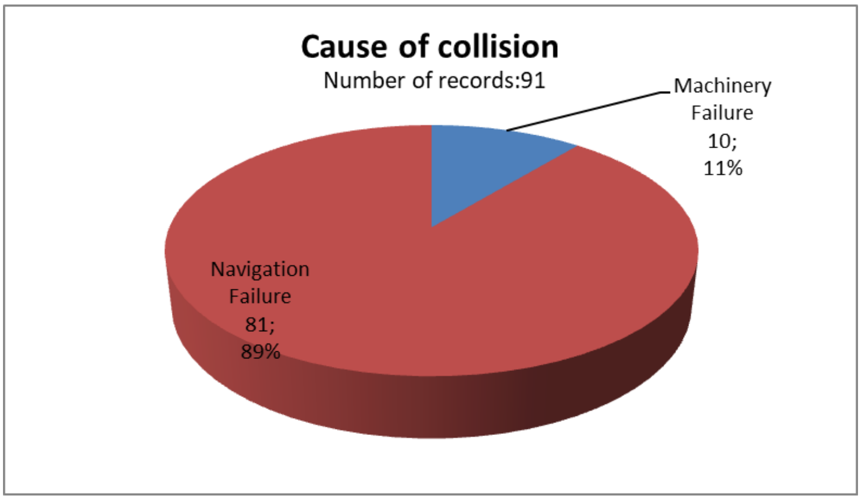


Diagram 5.2.1: Cause of Collision

It is observed that the highest percentage of accidents carried out due to navigational failure (89%, 81 cases), whereas machinery failure appeared in 10 cases (11%).

Diagram 5.2.2 presents the percentage and the relevant number of the causes leading to navigational failure and consequently to collision accidents. In the majority of cases, navigation failures are caused by human error with a percentage of 68% (55 cases), secondly by weather conditions at the time of incident with a percentage of 25% (20 cases) and finally by equipment failure (i.e. failure of radar, GPS, mooring failure, dragging anchor) with a percentage of 7% (6 cases).

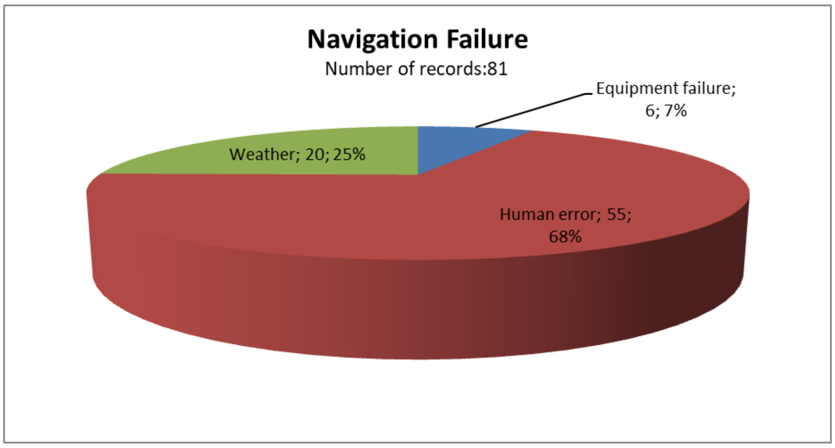


Diagram 5.2.2: Distribution of Navigation Failure

Focusing on human error, two (2) main categories have been considered, namely Onboard and Onshore. “Onboard” refers to cases that “human error” originates from a person onboard such as bad communication or wrong actions for collision avoidance while the “Onshore” describes the cases that are related to external guidance such as wrong instructions from the shore. All accidents included in the database, where human error was reported as an accident cause, it was always classified as Onboard error. No Onshore human error cases were reported. The relevant distribution is illustrated in Diagram 5.2.3. Wrong decision and no proper lookout correspond to 74% (37 cases) of the cases, miscommunication corresponds to 18% (9 cases) whereas vessel’s high speed corresponds to 8% of the cases.

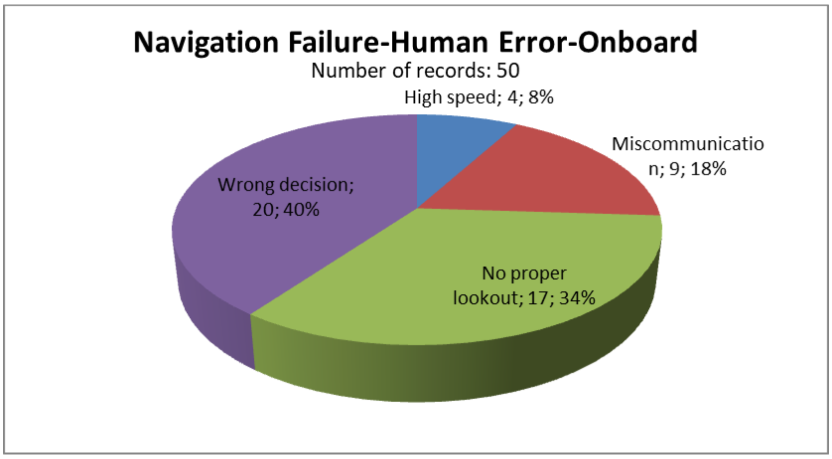


Diagram 5.2.3: Navigation Failure-Human Error-Onboard

Diagram 5.2.4 presents the distribution of machinery failure that led to a collision event. The basic causes for machinery failure can be grouped in two (2) main categories, maneuvering system failure (including main engine, shaft, propeller and rudder failures) and blackout. It is worth noting that the investigation of machinery failure of collision accidents shows that all incidents happened because of failure of maneuvering systems (i.e. no accidents found due to a blackout).

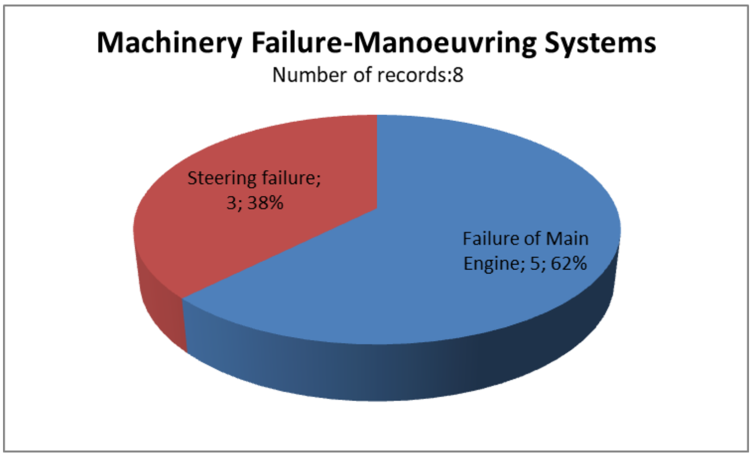


Diagram 5.2.4: Machinery Failure-Maneuvering Systems

Furthermore, the investigation indicates that failure of maneuvering systems came from Failure of the Main Engine with a percentage of 62% (5 cases) and to a lesser extent of 38% (3 cases) due to Steering Failure.

Contact accidents

Similarly to collision events, the causes for a contact incident can be divided in two main categories, navigational failure & machinery failure. Diagram 5.2.5 presents the percentage and the number of the causes that may lead to a contact accident.

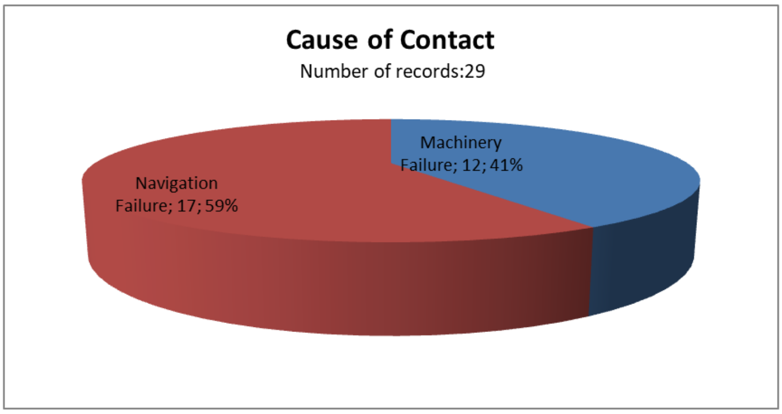


Diagram 5.2.5: Cause of Contact

The highest percentage of contact accidents was due to navigational failure (59%, 17 cases), whereas machinery failure appeared in 12 cases (41%).

Diagram 5.2.6 represents the percentage and the relevant number of the causes leading to navigational failure and consequently to contact accidents. The majority of navigation failures are caused by the weather conditions at the time of incident with an overall percentage of 65% (11 cases). Human error appears in 17% of the cases, the category "other" covers a percentage of 12% (2 cases) and the equipment failure (i.e. failure of radar, GPS, mooring failure, dragging anchor) has a significantly smaller percentage of 6% (1 case).

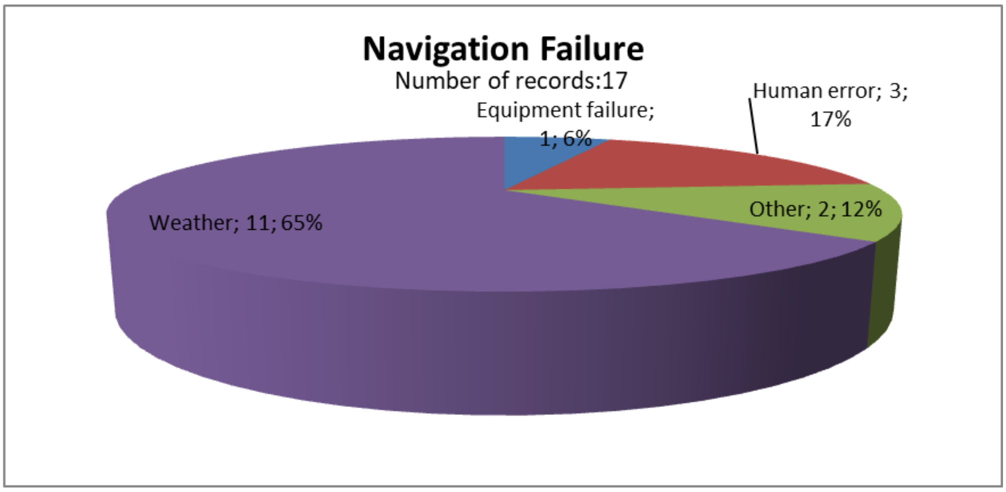


Diagram 5.2.6: Distribution of Navigation Failure

Table 5.2.7 presents the distribution of causes that may lead to Human error and consequently to Navigation Failure leading to contact accident.

Table 5.2.7: Navigation Failure-Human Error

	Values	Percentages
Miscommunication	1	50%
Wrong decision making	1	50%
Summary	2	100%
Unknown	1	

Focusing on the causes leading to Human error it is notable that "wrong decision making" and "no proper lookout" have a probability of 50% each. However, the results should be treated with caution because the sample is very small in order to draw conclusions and further investigation is required.

Diagram 5.2.8 presents the distribution of machinery failure that may lead to a contact event. The main causes of machinery failure are maneuvering system failure & blackout. It is worth noting that the accidents due to machinery failure came exclusively from failure of maneuvering systems (no blackouts).

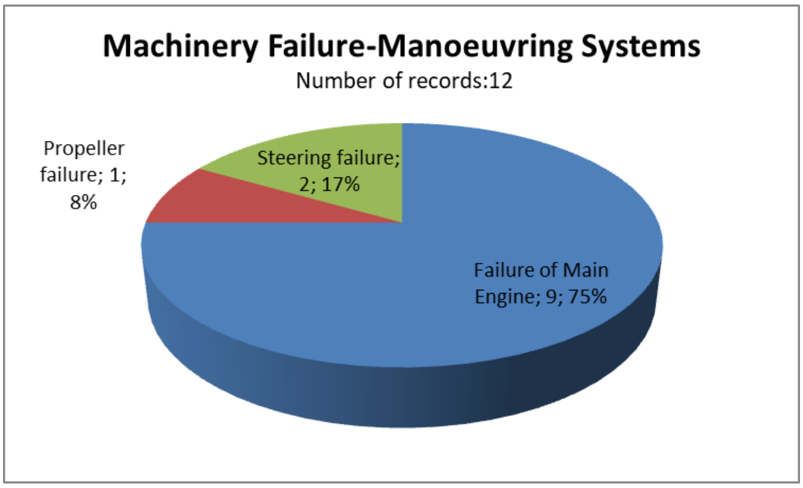


Diagram 5.2.8: Machinery Failure-Maneuvering Systems

The investigation indicates that failure of maneuvering systems is the result of Failure of the Main Engine in a percentage of 75% (9 cases) and due to Steering Failure in a percentage of 17% (2 cases). The propeller failure appears in a percentage of 8% (1 case).

Grounding accidents

Similarly collision and contact events, main causes for a grounding incident are the navigational failure & machinery failure. Diagram 5.2.9 presents the percentage and the number of these causes that led to a grounding accident. The highest percentage of groundings occurred from machinery failure (71%, 67 cases), whereas navigation failure appeared in 28 cases (29%).

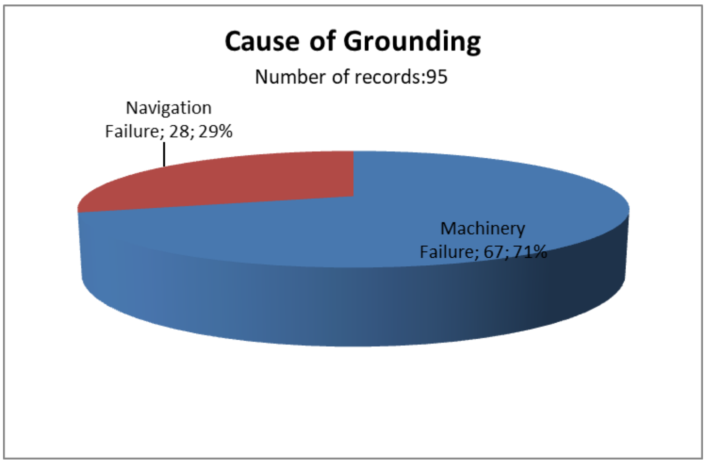


Diagram 5.2.9: Causes of Grounding

Diagram 5.2.10 represents the percentage and the corresponding number of the causes leading to navigational failure and consequently to grounding accidents. In the majority of cases, navigation failures are caused by human error with an overall percentage of 50% (13 cases), secondly by weather conditions with a percentage of

46% (12 cases) and finally by equipment failure (i.e. failure of radar, GPS, mooring failure, dragging anchor) with a percentage of 4% (1 case).

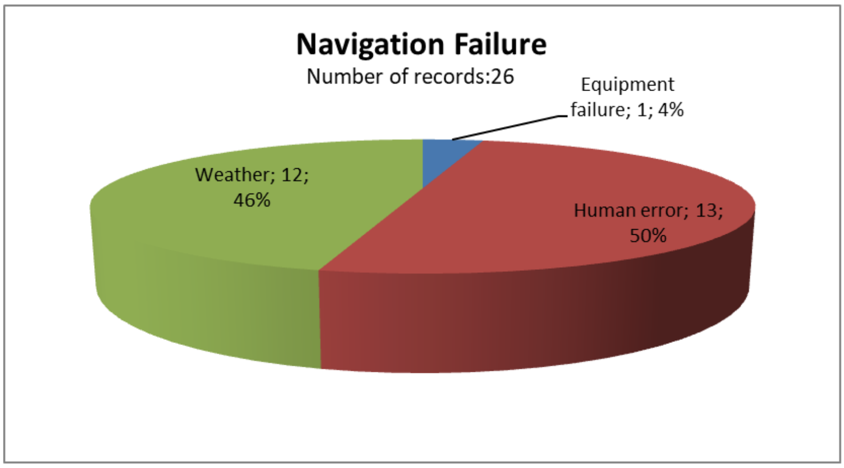


Diagram 5.2.10: Distribution of Navigation Failure

Focusing on the causes leading to human error (Diagram 5.2.11), this is mainly caused by no proper action with an overall percentage of 82% (9 cases), whereas “not fulfilling obligation” holds a percentage of 18% (2 cases).

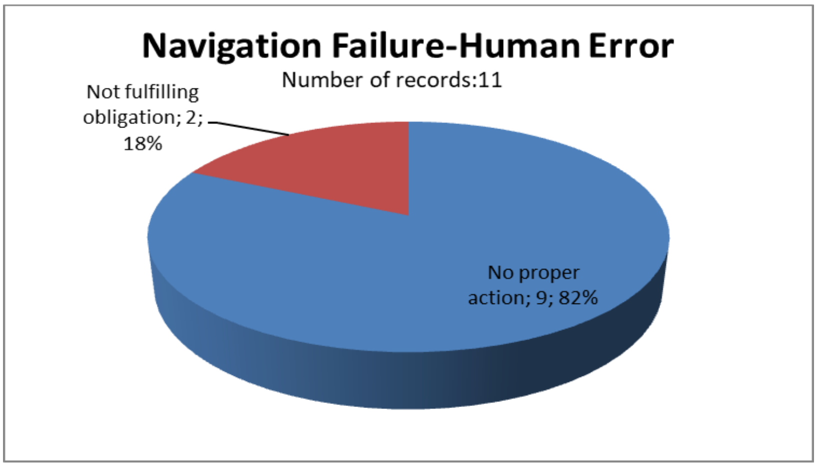


Diagram 5.2.11: Navigation Failure-Human Error-Onboard

Diagram 5.2.12 represents the percentage and the corresponding number of the causes leading to machinery failure and consequently to grounding accidents. The basic causes for machinery failure are the maneuvering system failure & the blackout, such as in collision and contact events. In the majority of cases, machinery failures are caused by maneuvering systems’ failure with an overall percentage of 89% (56 cases). In 7 cases, blackout was the cause of machinery failure (11%).

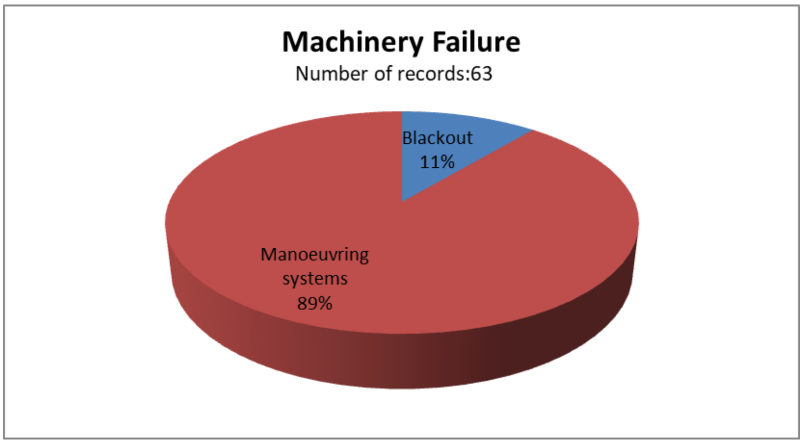


Diagram 5.2.12: Distribution of Machinery Failure

The analysis of failure of machinery systems shows that in 65% of the cases there was Failure of Main Engine whereas the remaining 35% came from Steering Failure, Diagram 5.2.13.

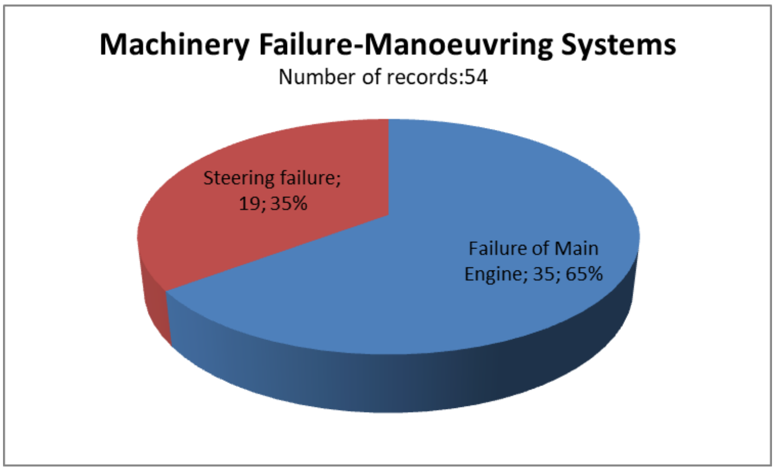


Diagram 5.2.13: Machinery Failure-Maneuvering Systems

Comparative Results

Diagram 5.2.16 presents the distribution of the main two (2) main causes that are responsible for the navigational accidents.

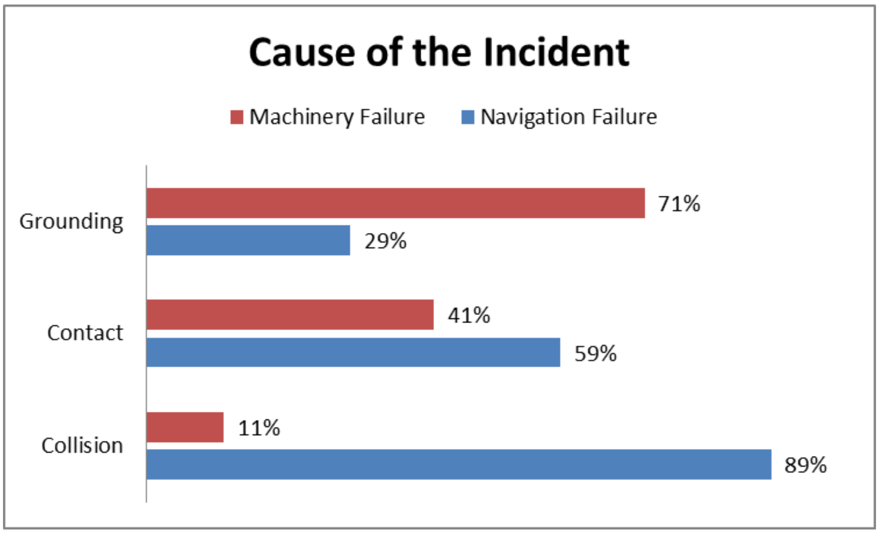


Diagram 5.2.16: Causes of the accident

In collision and contact accidents, the navigation failure presents the highest percentage of the causes (89% and 59% respectively) while in grounding events the highest percentage comes from machinery failure (71%). Collision and contact accidents mainly occurred in the ports & areas with high density traffic.

As per our analysis, grounding accidents mainly happened due to machinery failure because this type of failure in many cases may lead to drift grounding. Drift grounding is the most common failure leading to the accident according to the investigation reports and may happen due to the loss of propulsion.

Diagram 5.2.14 and 5.2.15 present the probabilities of the causes pertaining to navigational accidents.

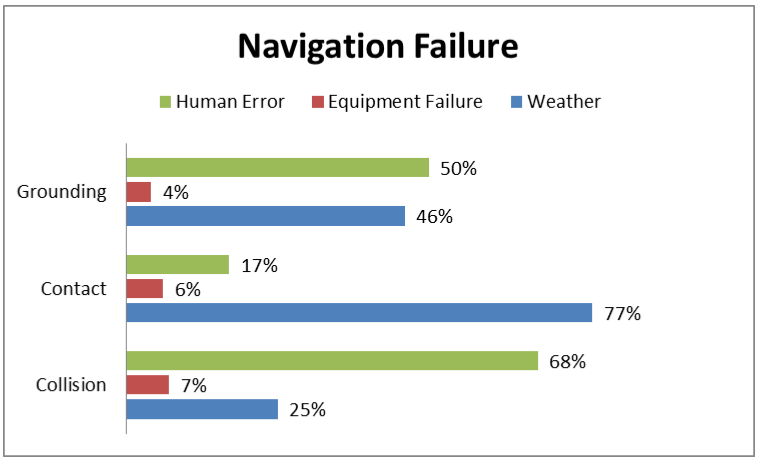


Diagram 5.2.14: Causes of navigation failure

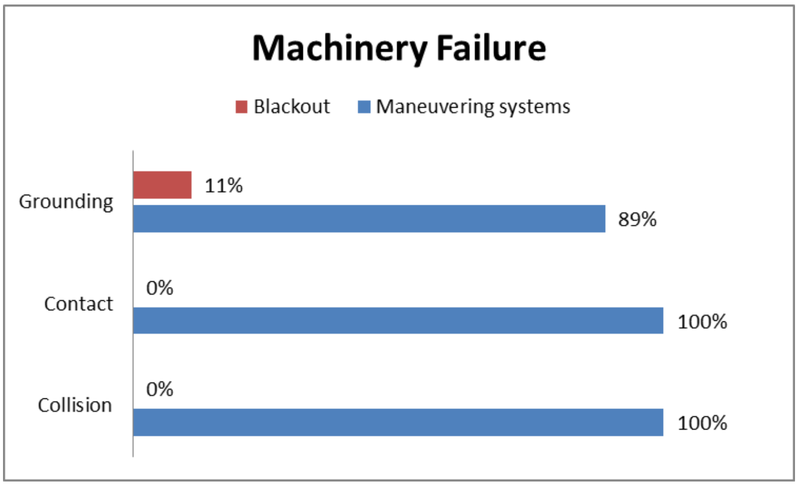


Diagram 5.2.15: Causes of machinery failure

With respect to navigational failure, the related causes of collision and grounding events present similarities. Human error comes up with the highest probability, namely 68% in cases of collisions and 50% in grounding cases. Regarding collision accidents, the highest percentage of the reasons that may lead to human error and consequently to the incident refers to wrong decisions (40%) and no proper lookout (34%) as well as for grounding accidents the highest percentage concerns no proper action (82%).

Weather condition at the time of incident seems to have an important role especially in cases of contact events (77%). The main reason that most incidents may occur due to weather are:

- Strong wind/wave may cut the moorings of the vessel and lead to contact with the quay/platform/pier
- Poor visibility because of the weather
- Wrong actions to avoid contact
- Loss of control of the vessel

Regarding machinery failure, the main reason that most incidents occur are:

- Wrong actions from the crew that may cause failure of the main engine or the steering system
- Unpredictable events that lead to failure of maneuvering systems and consequently to the accident, for example a possible breakdown of a part of the engine or a possible block of the rudder
- Wrong operation of the engine/steering system because of lack of knowledge/experience of the crew

5.3. Results from Event Tree Analysis

In this chapter, the casualty analysis was performed for a time period covering year 1990 and up to 2020, considering Cellular Containerships classified by IACS Societies that were built after year 1981, having Gross Tonnage ≥ 1,000 GT and excluded the vessels that had not sustained any damage because of the incident.
The presented results are focusing on cases of navigational accidents occurred during the operational phase of the ships in question i.e. excluding accidents to ships under repair works or during drydocking. The applied filters are listed below:

- Time Period:1990-2020
- IACS Class ships
- GT ≥ 1000
- Year of built ≥ 1982
- Collision, Contact and Grounding Accidents
- Ship damage extent: Major repairs, Minor repairs, Total loss

Note that the analysis of this chapter is based on the predefined event trees published in Hamann et al, 2013.

Collision Accidents

The types of collision incidents can be grouped in two (2) main categories, striking and struck. Diagram 5.3.1 presents the percentage and the number of the type of a collision accident.

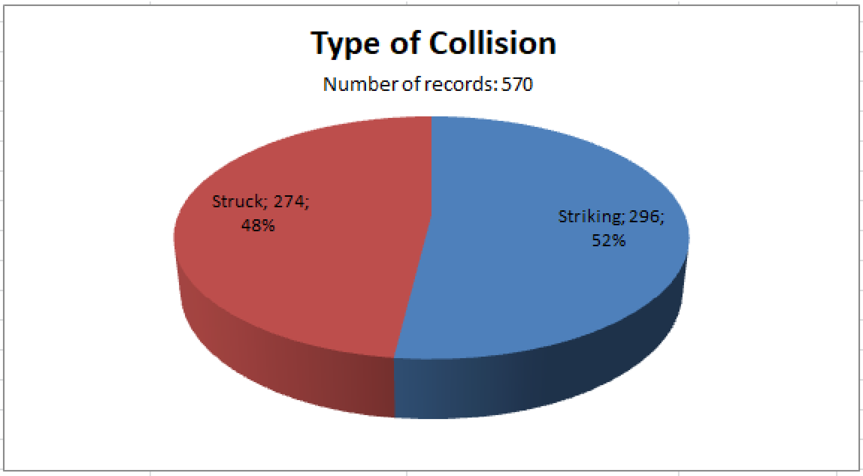


Diagram 5.3.1: Type of Collision

In total, 570 cases were classified as collision events where 48% of the total collision accidents, the containership was the struck vessel and in 52% was the striking one.

The areas where the collision occurred for both struck and striking ships are grouped in two (2) main categories and they are presented below, Diagram 5.3.2.

The Open Sea area consists of the following categories:

- Archipelagos
- Sea (open)
- Coastal (<12 nm)

The area Other includes the following categories:

- Anchorage
- At Berth
- Canal
- Inland Waters
- Port
- Port Approach
- Restricted Waters
- River

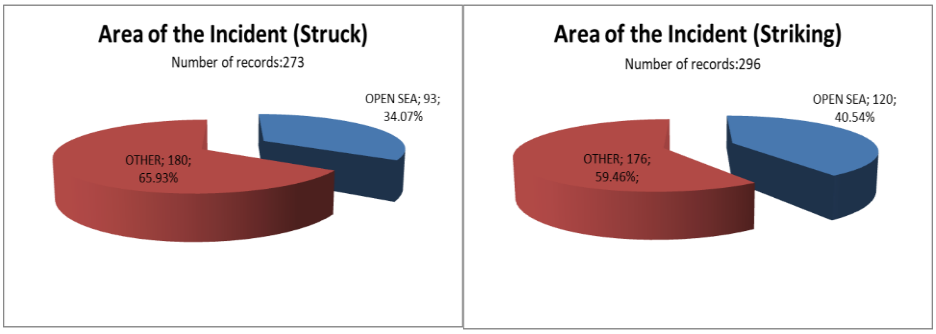


Diagram 5.3.2: Area of the Incident

The highest percentage of collision accidents for struck and striking ships takes place in the area "Other" (65.93%/180 cases and 59.46%/176 cases respectively) and a lower percentage occurs in the area "Open Sea" (34.07%/93 cases and 40.54%/120 cases respectively). It is noticed that Terminal areas and limited waters are the main sea location that collision accidents appeared. Especially, in terminal areas, many collisions happened during maneuvering operations.

Diagrams 5.3.3 and 5.3.4 present the percentages and the numbers of the type of the sub-areas where collision accidents takes place for both struck and striking ships. The “open sea” area is grouped in two (2) main categories “coastal waters” and “Open+Arch” which includes the areas “Open sea” and “Archipelagos”. The “Other” area is grouped in two (2) main categories “Limited Waters” which includes “Anchorage”, “Canal”, “Inland Waters”, “Restricted Waters” and “River” areas, and “Terminal Areas” which includes “Port”, “Port Approach” and “At Berth” areas.

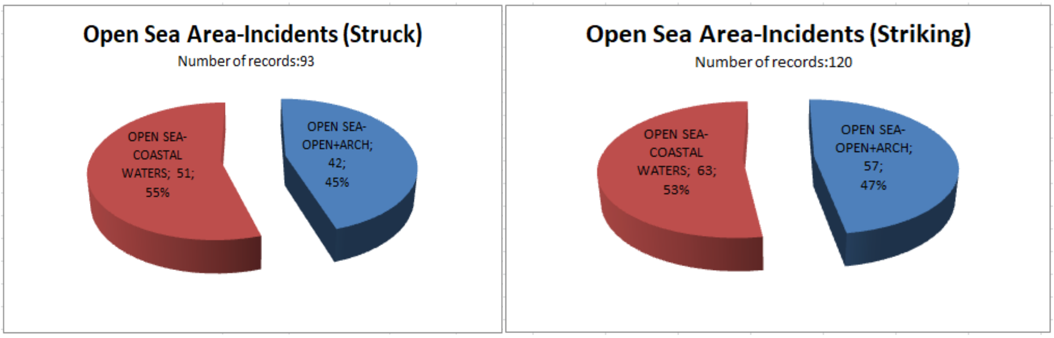


Diagram 5.3.3: Open Sea Area-Incidents

In case of accidents in Open Sea, the highest percentage of collision accidents, for struck and striking ships, takes place in the “Open Sea-Coastal Waters” sub-area (55%/51 cases and 53%/63 cases respectively) whereas the 47% happens in the “Open Sea-Open+Arch” sub-area (45%/42 cases and 47%/57 cases respectively).

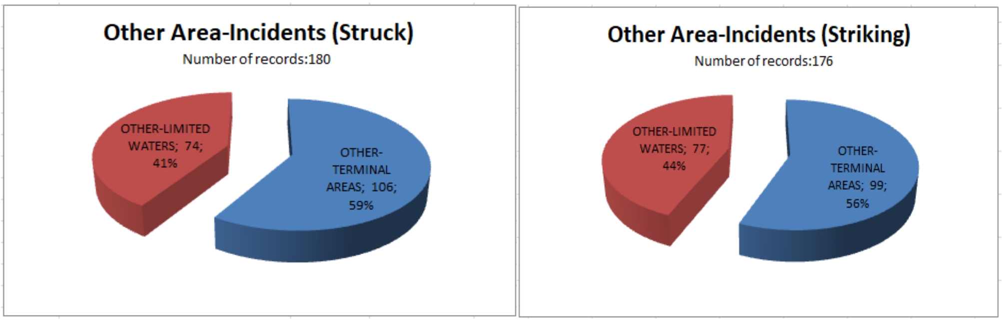


Diagram 5.3.4: Other Area-Incidents

In case of accidents in “Other” Areas, the highest percentage of collision accidents for struck and striking ships take place in the “Other - Terminal Areas” sub-area (59%/106 cases and 56%/99 cases respectively) whereas the 47 % happened in the “Other-Limited Waters” sub-area (41%/74 cases and 44%/77 cases respectively).

Tables 5.3.5 and 5.3.6 present the percentage and the numbers of the accidents where the containership had “Loss of Watertight Integrity” (LOWI) or not due to the incident for both struck and striking ships.

Table 5.3.5: LOWI Occurrence for struck ships

STRUCK				
LOWI Occurrence	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch - LOWI				
Yes	11	26.88%	100.00%	42
No	31	73.12%		
Open Sea-Coastal Waters - LOWI				
Yes	14	27.45%	100.00%	51
No	37	72.55%		
Other-Terminal Areas - LOWI				
Yes	10	9.43%	100.00%	106
No	96	90.57%		

Other-Limited Waters - LOWI				
Yes	16	21.62%	100.00%	74
No	58	78.38%		

Table 5.3.6: LOWI Occurrence for striking ships

STRIKING				
LOWI Occurrence	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch - LOWI				
Yes	13	22.81%	100.00%	57
No	44	77.19%		
Open Sea-Coastal Waters - LOWI				
Yes	11	17.46%	100.00%	63
No	52	82.54%		
Other-Terminal Areas - LOWI				
Yes	8	8.08%	100.00%	99
No	91	91.92%		
Other-Limited Waters - LOWI				
Yes	12	15.58%	100.00%	77
No	65	84.42%		

In the majority of collision scenarios, for both struck and striking ships, there is no existence of LOWI. Collision cases without LOWI for struck ships, vary from 72.55 to 78.38%, where the highest percentage appears in the area “Coastal Waters” and the lowest appears in the area “Limited Waters”. For striking ships, collision scenarios without LOWI vary from 77.19 to 91.92% where the highest percentage appears in the area “Terminal Areas” and the lowest appears in the area “Open+Arch”.

Tables 5.3.7 and 5.3.8 present the percentage and the numbers of the accidents with water ingress existence or not due to collision for both struck and striking ships given the LOWI occurrence.

Table 5.3.7: Water ingress for struck ships (LOWI Occurrence)

STRUCK				
Scenario	Value	Percentage of W.I.	Summary %	Summary
Open Sea-Open+Arch -LOWI-Water Ingress *Yes*	10	100.00%	100.00%	10
Open Sea-Open+Arch -LOWI-Water Ingress *No*	0	0.00%		
Open Sea-Coastal Waters-LOWI-Water Ingress *Yes*	13	92.86%	100.00%	14
Open Sea-Coastal Waters-LOWI-Water Ingress *No*	1	7.14%		
Other-Terminal Areas- LOWI-Water Ingress *Yes*	9	100.00%	100.00%	9
Other-Terminal Areas- LOWI-Water Ingress *No*	0	0.00%		

Other-Limited Waters-LOWI-Water Ingress *Yes*	13	92.86%	100.00%	14
Other-Limited Waters-LOWI-Water Ingress *No*	1	7.14%		

Table 5.3.8: Water ingress for striking ships (LOWI Occurrence)

STRIKING				
Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch - LOWI-Water Ingress *Yes*	13	100.00%	100.00%	13
Open Sea-Open+Arch - LOWI-Water Ingress *No*	0	0.00%		
Open Sea-Coastal Waters-LOWI-Water Ingress *Yes*	11	100.00%	100.00%	11
Open Sea-Coastal Waters-LOWI-Water Ingress *No*	0	0.00%		
Other-Terminal Areas-LOWI-Water Ingress *Yes*	8	100.00%	100.00%	8
Other-Terminal Areas-LOWI-Water Ingress *No*	0	0.00%		
Other-Limited Waters-LOWI-Water Ingress *Yes*	11	100.00%	100.00%	11
Other-Limited Waters-LOWI-Water Ingress *No*	0	0.00%		

It is observed that, for both struck and striking vessels, in the majority of the accidents in all regions and sub-regions when LOWI occurs there is also existence of water ingress. For struck ships, occurrence of water ingress varies from 92.86 to 100%. The highest percentage appears in the areas “Open+Arch” and “Terminal Areas” and the lowest appears in the areas “Limited Waters” and “Coastal Waters”. For striking vessels, there is always existence of water ingress.

Tables 5.3.9 and 5.3.10 present the percentage and the numbers of ship’s total loss for the different scenarios of a collision event.

Table 5.3.9: Total loss for struck ships (LOWI/Water Ingress Occurrence)

STRUCK				
Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch -LOWI-Water Ingress *Yes-Sinking*	1	10.00%	100.00%	10
Open Sea-Open+Arch -LOWI-Water Ingress *Yes-*No *Sinking*	9	90.00%		
Open Sea-Coastal Waters-LOWI- Water Ingress *Yes-Sinking*	0	0.00%	100.00%	13
Open Sea-Coastal Waters-LOWI- Water Ingress *Yes-No Sinking*	13	100.00%		
Other-Terminal Areas-LOWI-Water Ingress *Yes-Sinking*	1	11.11%	100.00%	9
Other-Terminal Areas-LOWI-Water Ingress *Yes-No Sinking*	8	88.89%		
Other-Limited Waters-LOWI- Water Ingress *Yes-Sinking*	3	23.08%	100.00%	13
Other-Limited Waters-LOWI- Water Ingress *Yes-No Sinking*	10	76.92%		

Table 5.3.10: Total loss for striking ships (LOWI/Water Ingress Occurrence)

STRIKING				
Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch -LOWI-Water Ingress *Yes-Sinking*	0	0.00%	100.00%	13
Open Sea-Open+Arch -LOWI-Water Ingress *Yes-*No *Sinking*	13	100.00%		
Open Sea-Coastal Waters-LOWI- Water Ingress *Yes-Sinking*	0	0.00%	100.00%	11
Open Sea-Coastal Waters-LOWI- Water Ingress *Yes-No Sinking*	11	100.00%		
Other-Terminal Areas- LOWI-Water Ingress *Yes-Sinking*	0	0.00%	100.00%	8
Other-Terminal Areas- LOWI-Water Ingress *Yes-No Sinking*	8	100.00%		

Other-Limited Waters-LOWI-Water Ingress *Yes-Sinking*	0	0.00%	100.00%	10
Other-Limited Waters-LOWI-Water Ingress *Yes-No Sinking*	10	100.00%		

It is observed that for both struck and striking vessels, in the majority of the regions and sub-regions when LOWI occurs and water ingress takes place due to collision, the ship does not sink. For struck ships, the cases where the ship remains afloat vary from 76.92 to 100%. The highest percentage appears in the area “Coastal Waters” and the lowest appears in the area “Limited Waters”. For striking vessels, there are no registered cases with ship sinking.

Tables 5.3.11 and 5.3.12 present the percentage and the numbers of cases where the ship under investigation needed Major repairs or Minor Repairs due to the incident, for both struck and striking ships, given LOWI existence and water ingress occurrence.

Table 5.3.11: Major and Minor Repairs for struck ships (LOWI/Water Ingress Occurrence)

STRUCK				
Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch -LOWI-Water Ingress *Yes*-No *Sinking-Major*	9	100.00%	100.00%	9
Open Sea-Open+Arch -LOWI-Water Ingress *Yes*-No *Sinking-Minor*	0	0.00%		
Open Sea-Coastal Waters-LOWI- Water Ingress *Yes- No Sinking-Major*	13	100.00%	100.00%	13
Open Sea-Coastal Waters-LOWI- Water Ingress *Yes- No Sinking-Minor*	0	0.00%		
Other-Terminal Areas-LOWI-Water Ingress *Yes- No Sinking-Major*	8	100.00%	100.00%	8
Other-Terminal Areas-LOWI-Water Ingress *Yes- No Sinking-Minor*	0	0.00%		
Other-Limited Waters-LOWI- Water Ingress *Yes-No Sinking-*	10	100.00%	100.00%	10

Major				
Other-Limited Waters-LOWI- Water Ingress *Yes-No Sinking-Minor*	0	0.00%		

Table 5.3.12: Major and Minor repairs for striking ships (LOWI/Water Ingress Occurrence)

STRIKING				
Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch -LOWI-Water Ingress *Yes*-No *Sinking-Major*	11	84.62%	100.00%	13
Open Sea-Open+Arch -LOWI-Water Ingress *Yes*-No *Sinking-Minor*	2	15.38%		
Open Sea-Coastal Waters-LOWI- Water Ingress *Yes- No Sinking-Major*	10	90.91%	100.00%	11
Open Sea-Coastal Waters-LOWI- Water Ingress *Yes- No Sinking-Minor*	1	9.09%		
Other-Terminal Areas-LOWI-Water Ingress *Yes- No Sinking-Major*	8	100.00%	100.00%	8
Other-Terminal Areas-LOWI-Water Ingress *Yes- No Sinking-Minor*	0	0.00%		
Other-Limited Waters-LOWI- Water Ingress *Yes-No Sinking-Major*	10	100.00%	100.00%	10
Other-Limited Waters-LOWI- Water Ingress *Yes-No Sinking-Minor*	0	0.00%		

It is observed that the majority of struck and striking vessels in all regions and sub-regions needed major repairs in cases of LOWI and water ingress existence. Struck ships, in all the studied cases, needed major repairs. For striking ships, the cases where the ship under investigation needed major repairs vary from 84.62 to 100%. The highest percentage appears in the areas “Terminal Areas” and “Limited Waters” and the lowest appears in the area “Open+Arch”.

Tables 5.3.13 and 5.3.14 present the cases where the ship under investigation, without existence of LOWI and water ingress, needed Major or Minor Repairs due to the accident.

Table 5.3.13: Major and Minor Repairs for struck ships (No LOWI/Water Ingress Occurrence)

STRUCK				
Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch –No LOWI- *Major*	3	27.27%	100.00%	11
Open Sea-Open+Arch –No LOWI- *Minor*	8	72.73%		
Open Sea-Coastal Waters-No LOWI- *Major*	6	37.50%	100.00%	16
Open Sea-Coastal Waters-No LOWI- *Minor*	10	62.50%		
Other-Terminal Areas- No LOWI- *Major*	10	26.32%	100.00%	38
Other-Terminal Areas- No LOWI- *Minor*	28	73.68%		
Other-Limited Waters-No LOWI – *Major*	7	18.42%	100.00%	38
Other-Limited Waters-No LOWI- *Minor*	31	81.58%		

Table 5.3.14: Major and Minor Damages for striking ships (No LOWI/Water Ingress Occurrence)

STRIKING				
Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch –No LOWI- *Major*	3	15.79%	100.00%	19
Open Sea-Open+Arch –No LOWI- *Minor*	16	84.21%		
Open Sea-Coastal Waters-No LOWI- *Major*	2	6.67%	100.00%	30
Open Sea-Coastal Waters-No LOWI- *Minor*	28	93.33%		
Other-Terminal Areas- No LOWI- *Major*	4	10.81%	100.00%	37
Other-Terminal Areas- No LOWI- *Minor*	33	89.19%		
Other-Limited Waters-No LOWI – *Major*	4	12.90%	100.00%	31
Other-Limited Waters-No LOWI- *Minor*	27	87.10%		

It is observed that the majority of struck and striking vessels, in all regions and sub-regions, needed minor repairs due to collision, in cases without LOWI and water ingress occurrence. For struck ships, the cases where the ship under investigation needed minor repairs vary from 62.5 to 81.58%. The highest percentage appears in the area "Limited Waters" and the lowest one in the area "Coastal Waters". For striking ships, the cases where the ship under investigation needed Minor Repairs vary from 84.21 to 93.33% having the highest percentage in the area "Coastal Waters" and the lowest in the area "Open+Arch".

Furthermore, regarding collision accidents, the followings should be noted:

- In the scenario of Struck-Open Sea-Coastal-LOWI- Water Ingress No: 1 accident occurred and the ship needed Major Repairs.
- In the scenario of Struck- Other-Restricted-LOWI- Water Ingress No: 1 accident occurred and the ship suffered Major Damages.
- In the scenario of Struck- Other-Restricted-LOWI-Water Ingress Yes-Sinking: 3 fatalities were recorded in one accident out of 3.

- In the scenario of Struck- Other-Restricted-LOWI-Water Ingress Yes-No Sinking-Major: 3 fatalities were recorded in one accident out of 10.
- In the scenario of Striking- Open Sea-Coastal-No LOWI-Minor: 3 fatalities were recorded in one accident out of 28.
- In the scenario of Striking- Other-Restricted-No LOWI –Major: 1 fatality was recorded in one accident out of 4.

Contact Accidents

Similarly to collision events, the area where contact accidents occurred are grouped in two (2) main categories and are presented below, Diagram 5.3.15.

The Open Sea area includes the following categories:

- Archipelagos
- Sea (open)
- Coastal (<12 nm)

The Other area includes the following categories:

- Anchorage
- At Berth
- Canal
- Inland Waters
- Port
- Port Approach
- Restricted Waters
- River

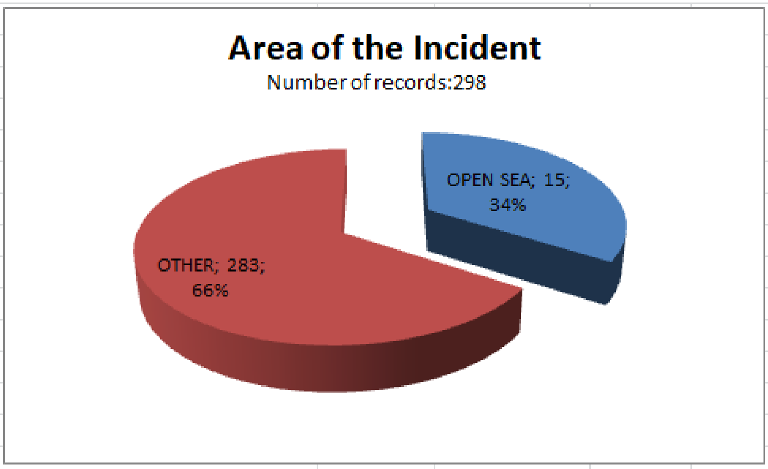


Diagram 5.3.15: Area of the Incident

It is noticed that, as expected, the highest percentage of contact accidents takes place in the area "Other" (66%, 283 cases) and a lower percentage occurs in the area "Open Sea" (34%, 15 cases).

Diagrams 5.3.15 and 5.3.16 present the percentages and the numbers of the type of the sub-areas in which contact accidents takes place.

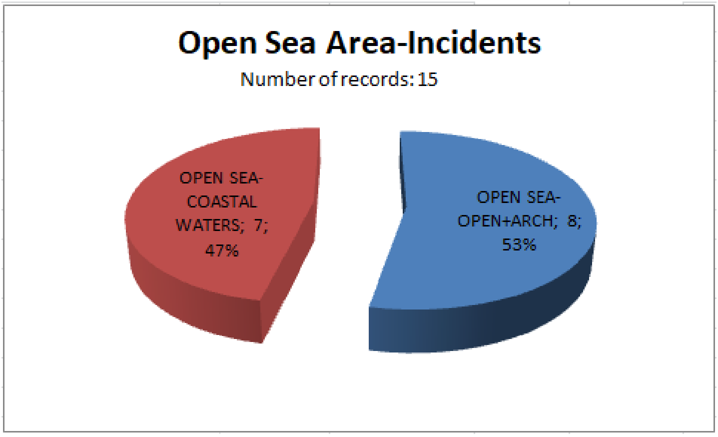


Diagram 5.3.15: Open Sea Area-Incidents

In case of accidents at Open Sea, the highest percentage of contact accidents takes place in the “Open Sea-Coastal Waters” sub-area (53 %, 8 cases) whereas the 47 % happens in the 'Open Sea-Open+Arch' sub-area (47%, 7 cases).

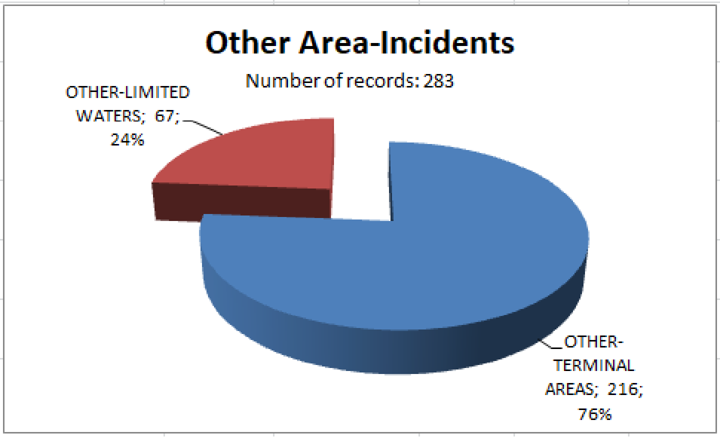


Diagram 5.3.16: Other Area-Incidents

Focusing on “Other Area”, the highest percentage of contact accidents occurs in the "Other-Terminal Areas" sub-area (76%, 216 cases) whereas 24% occurs in the "Other-Limited Waters" sub-area (24%, 67 cases).

Table 5.3.16 presents the type of object type that the vessel was in contact with due to the incident in each region/sub-region. The contact accidents refer to the impact of ship with fixed structures such as piers, docks, lighthouses, etc. (fixed construction) or floating objects such as floating platforms, buoys, etc.

The type of “Floating Object” includes the following categories:

- Floating Object

- Physical Obstacle (rocks, embankment).

Table 5.3.16: Type of contact object

Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch-Fixed	1	12.50%	100.00%	8
Open Sea-Open+Arch-Floating	7	87.50%		
Open Sea-Coastal Waters-Fixed	7	100.00%	100.00%	7
Open Sea-Coastal Waters-Floating	0	0.00%		
Other-Terminal Areas-Fixed	208	96.30%	100.00%	216
Other-Terminal Areas-Floating	8	3.70%		
Other-Limited Waters-Fixed	54	79.41%	100.00%	68
Other-Limited Waters-Floating	14	20.59%		

The majority of contact accidents, regardless the area, occurs after impact with fixed installations. The percentage of cases of ship's contact with a fixed installation varies from 79.41 to 100% where the highest percentage appears in the area "Coastal Waters" and the lowest appears in the area "Limited Waters". Only in the sub-region of "Open Sea-Open+Arch contact with floating objects is recorded in 87.5% of the cases.

Table 5.3.17 presents the percentage and the numbers of the accidents where the containership had "Loss of Watertight Integrity" (LOWI) or not due to the incident.

Table 5.3.17: LOWI Occurrence

Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch-Fixed-LOWI *Yes*	1	100.00%	100.00%	1
Open Sea-Open+Arch-Fixed-LOWI *No*	0	0.00%		
Open Sea-Open+Arch-Floating-LOWI *Yes*	3	42.86%	100.00%	7
Open Sea-Open+Arch-Floating-LOWI *No*	4	57.14%		
Open Sea-Coastal Waters-Fixed-LOWI *Yes*	0	0.00%	100.00%	7
Open Sea-Coastal Waters-Fixed - LOWI *No*	7	100.00%		
Open Sea-Coastal Waters-Floating-LOWI *Yes*	-			
Open Sea-Coastal Waters-Floating-LOWI *No*				
Other-Terminal Areas-Fixed-LOWI *Yes*	25	12.02%	100.00%	208
Other-Terminal Areas-Fixed-LOWI *No*	183	87.98%		
Other-Terminal Areas-Floating-LOWI *Yes*	6	75.00%	100.00%	8
Other-Terminal Areas-Floating-LOWI *No*	2	25.00%		
Other-Limited Waters-Fixed-LOWI *Yes*	5	9.26%	100.00%	54
Other-Limited Waters-Fixed-	49	90.74%		

LOWI *No*				
Other-Limited Waters-Floating-LOWI *Yes*	3	23.08%	100.00%	13
Other-Limited Waters-Floating-LOWI *No*	10	76.92%		

In the majority of contact cases, there is no existence of LOWI. Contact cases without LOWI vary from 57.14 to 100%, where the highest percentage appears in the area "Coastal Waters" and the lowest appears in the area "Open+Arch". Only in the cases of "Open Sea-Open+Arch-Fixed" and "Other-Terminal Areas – Floating" the highest percentage concerns LOWI occurrence (100% and 75% respectively).

Table 5.3.18 presents the percentage and the numbers of the accidents with existence of water ingress or not due to contact.

Table 5.3.18: Water ingress (LOWI Occurrence)

Scenario	Value	Percentage Of W.I.	Summary %	Summary
Open Sea-Open+Arch-Fixed-LOWI- WI *Yes*	1	100.00%	100.00%	1
Open Sea-Open+Arch-Fixed-LOWI- WI *No*	0	0.00%		
Open Sea-Open+Arch-Floating-LOWI- WI *Yes*	3	100.00%	100.00%	3
Open Sea-Open+Arch-Floating-LOWI- WI *No*	0	0.00%		
Open Sea-Coastal Waters-Fixed-LOWI- WI *Yes*	-			
Open Sea-Coastal Waters-Fixed-LOWI- WI *No*				
Open Sea-Coastal Waters-Floating-LOWI- WI *Yes*	-			
Open Sea-Coastal Waters-Floating-LOWI – WI *No*				
Other-Terminal Areas-Fixed-LOWI- WI *Yes*	14	93.33%	100.00%	15
Other-Terminal Areas-Fixed-LOWI – WI *No*	1	6.67%		
Other-Terminal Areas-Floating-LOWI- WI *Yes*	5	100.00%	100.00%	5

Other-Terminal Areas-Floating-LOWI- WI *No*	0	0.00%		
Other-Limited Waters-Fixed-LOWI-WI *Yes*	4	100.00%	100.00%	4
Other-Limited Waters-Fixed-LOWI-WI *No*	0	0.00%		
Other-Limited Waters-Floating-LOWI -WI *Yes*	3	100.00%	100.00%	3
Other-Limited Waters-Floating-LOWI – WI *No*	0	0.00%		

In the majority of contact accidents, in all regions and sub-regions, when LOWI occurs, water ingress also occurs. Water ingress occurrence varies from 93.33 to 100%. The highest percentage appears in the areas “Open+Arch” and “Limited Waters” and the lowest one in the area “Terminal Areas”.

Table 5.3.19 present the percentage and the numbers of ship’s total loss for the different scenarios of a contact event..

Table 5.3.19: Total loss of the ship (LOWI/Water Ingress Occurrence)

Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch-Fixed-LOWI-WI Yes- *Sinking Yes*	0	0.00%	100.00%	1
Open Sea-Open+Arch-Fixed-LOWI-WI Yes- *Sinking No*	1	100.00%		
Open Sea-Open+Arch-Floating-LOWI- WI Yes-Sinking *Yes*	0	0.00%	100.00%	3
Open Sea-Open+Arch-Floating-LOWI- -WI Yes- *Sinking No*	3	100.00%		
Open Sea-Coastal Waters-Fixed-LOWI-WI Yes- *Sinking Yes*	-			
Open Sea-Coastal Waters-Fixed-LOWI-WI Yes- *Sinking No*				
Open Sea-Coastal Waters-Floating-LOWI-WI Yes- *Sinking Yes*				
Open Sea-Coastal Waters-Floating-LOWI -WI Yes- *Sinking No*				

Other-Terminal Areas-Fixed-LOWI-WI Yes- *Sinking Yes*	0	0.00%	100.00%	7
Other-Terminal Areas-Fixed-LOWI - WI Yes- *Sinking No*	7	100.00%		
Other-Terminal Areas-Floating-LOWI-WI Yes- *Sinking Yes*	0	0.00%	100.00%	4
Other-Terminal Areas-Floating-LOWI-WI Yes- *Sinking No*	4	100.00%		
Other-Limited Waters-Fixed-LOWI-WI Yes- *Sinking Yes*	0	0.00%	100.00%	3
Other-Limited Waters-Fixed-LOWI-WI Yes- *Sinking No*	3	100.00%		
Other-Limited Waters-Floating-LOWI -WI Yes- *Sinking Yes*	1	33.33%	100.00%	3
Other-Limited Waters-Floating-LOWI -WI Yes- *Sinking No*	2	66.67%		

In the majority of the regions and sub-regions when LOWI occurs and water ingress takes place, the ship remains afloat due to contact. These cases vary from 66.67 to 100%. The highest percentage appears in the area “Coastal Waters”. “Open+Arch” and “Terminal Areas” and the lowest one in the area “Limited Waters”.

Tables 5.3.20 present the percentage and the numbers of the accidents where the ship under investigation with LOWI existence and water ingress occurrence needed Major Repairs or Minor Repairs due to the incident

Table 5.3.20: Major and Minor Repairs (LOWI/Water Ingress Occurrence)

Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch-Fixed-LOWI-WI Yes-Sinking No- *Major*	1	100.00%	100.00%	1
Open Sea-Open+Arch-Fixed-LOWI-WI Yes- Sinking No- *Minor*	0	0.00%		
Open Sea-Open+Arch-Floating-LOWI- WI Yes- Sinking No – *Major*	3	100.00%	100.00%	3

Open Sea-Open+Arch-Floating-LOWI-WI Yes- Sinking No- *Minor*	0	0.00%		
Open Sea-Coastal Waters-Fixed-LOWI-WI Yes- Sinking No- *Major*	-			
Open Sea-Coastal Waters-Fixed-LOWI-WI Yes- Sinking No- *Minor*				
Open Sea-Coastal Waters-Floating-LOWI-WI Yes- Sinking No- *Major*				
Open Sea-Coastal Waters-Floating-LOWI-WI Yes- Sinking No- *Minor*				
Other-Terminal Areas-Fixed-LOWI-WI Yes- Sinking No – *Major*	11	26.19%	100.00%	42
Other-Terminal Areas-Fixed-LOWI -WI Yes- Sinking No- *Minor*	31	73.81%		
Other-Terminal Areas-Floating-LOWI-WI Yes- Sinking No- *Major*	4	100.00%	100.00%	4
Other-Terminal Areas-Floating-LOWI-WI Yes- Sinking No- *Minor*	0	0.00%		
Other-Limited Waters-Fixed-LOWI-WI Yes- Sinking No- *Major*	3	100.00%	100.00%	3
Other-Limited Waters-Fixed-LOWI-WI Yes- Sinking No- *Minor*	0	0.00%		
Other-Limited Waters-Floating-LOWI -WI Yes- Sinking No- *Major*	2	100.00%	100.00%	2
Other-Limited Waters-Floating-LOWI -WI Yes- Sinking No- *Minor*	0	0.00%		

It is observed that in the majority of the accidents, in all regions and sub-regions, where LOWI and water ingress occurs, containerships needed Major Repairs due to contact except for scenarios of "Other-Terminal Areas-Fixed" where the highest percentage concerns Minor Repairs (73.81%).

Tables 5.3.21 present the cases where the ship under investigation, without existence of LOWI and water ingress, needed Major or Minor Repairs due to contact.

Table 5.3.21: Major and Minor Repairs (No LOWI/Water Ingress Occurrence)

Scenario	Value	Percentage	Summary %	Summary
Open Sea-Open+Arch-Floating- No LOWI- *Major*	-			
Open Sea-Open+Arch-Floating- No LOWI -*Minor*				
Open Sea-Coastal Waters-Fixed- No LOWI – *Major*	2	100.00%	100.00%	2
Open Sea-Coastal Waters-Fixed- No LOWI – *Minor*	0	0.00%		
Open Sea-Coastal Waters-Floating- No LOWI- *Major*	2	50.00%	100.00%	4
Open Sea-Coastal Waters-Floating- No LOWI- *Minor*	2	50.00%		
Other-Terminal Areas-Fixed- No LOWI – *Major*	-			
Other-Terminal Areas-Fixed- No LOWI- *Minor*				
Other-Terminal Areas-Floating- No LOWI- *Major*	11	20.00%	100.00%	55
Other-Terminal Areas-Floating- No LOWI- *Minor*	44	80.00%		
Other-Limited Waters-Fixed- No LOWI- *Major*	1	100.00%	100.00%	1
Other-Limited Waters-Fixed- No LOWI- *Minor*	0	0.00%		
Open Sea-Limited Waters-Fixed- No LOWI- *Major*	3	13.04%	100.00%	23
Open Sea-Limited Waters-Fixed- No LOWI- *Minor*	20	86.96%		
Open Sea-Coastal Waters-Fixed- No LOWI – *Major*	3	60.00%	100.00%	5
Open Sea-Coastal Waters-Fixed- No LOWI – *Minor*	2	40.00%		

It is observed that the highest percentage of Minor Repairs is related to ships having a contact accident in the area "Other-Terminal Areas-Fixed" (80%) while Major Repairs are most commonly noticed in ships having an accident in the areas of "Open Sea-Open+Arch-Floating" and "Other-Terminal Areas-Floating".

Furthermore, according to our analysis, in contact accidents, no fatalities or missing persons were registered for the studied time period.

Grounding Accidents

Similarly to collision and contact events, the area in which grounding accidents occurred are grouped in two (2) main categories and they are presented below, Diagram 5.3.22.

The Open sea area includes the following categories:

- Archipelagos
- Sea (open)
- Coastal (<12 nm)

The Other area includes the following categories:

- Anchorage
- At Berth
- Canal
- Inland Waters
- Port
- Port Approach
- Restricted Waters
- River

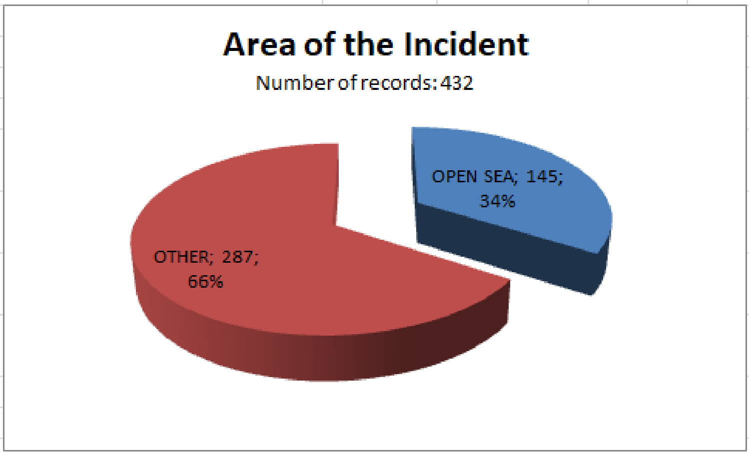


Diagram 5.3.22: Area of the Incident

It is observed that, as expected, the highest percentage of grounding accidents takes place in the area "Other" (66%, 287 cases) whereas 34% occurs in "Open-Sea" (145 cases).

Diagrams 5.3.23 and 5.3.24 present the type of the seabed in the area under investigation.

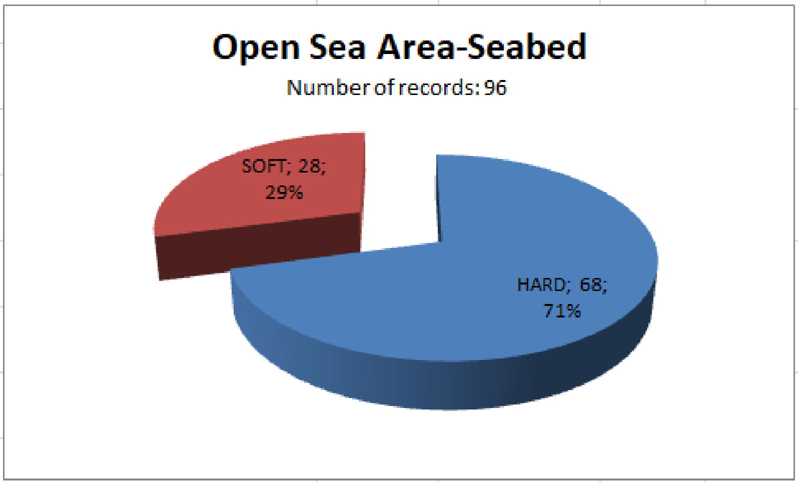


Diagram 5.3.23: Open Sea Area-Seabed

It is observed that in the area "Open sea" the highest percentage of grounding accidents occurs on hard seabed (71%, 68 cases) with a much lower percentage occurring on soft seabed (29%, 28 cases).

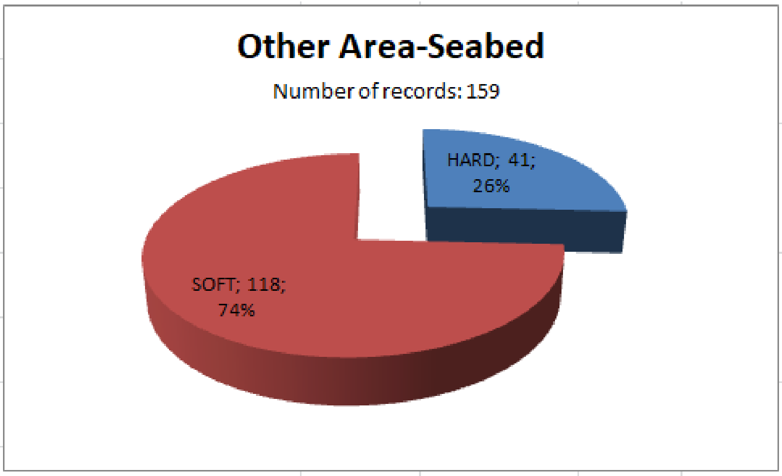


Diagram 5.3.24: Other Area-Seabed

In the area "Other", the highest percentage of grounding accidents occurs on soft seabed (74%) with a significantly lower percentage taking place on hard seabed (26%).

Table 5.3.25 presents the percentage and the numbers of the accidents in case of LOWI/water ingress existence or not due to grounding.

Table 5.3.25: Water ingress (LOWI Occurrence)

Scenario	Value	Percentage	Summary %	Summary
Open sea-Soft-LOWI/Water Ingress-*Yes*	6	21.43%	100.00%	28
Open sea-Soft-LOWI/Water Ingress-*No*	22	78.57%		
Open sea-Hard-LOWI/ Water Ingress -*Yes*	57	93.44%	100.00%	61
Open sea-Hard-LOWI/ Water Ingress -*No*	4	6.56%		
Other- Soft-LOWI/Water Ingress-*Yes*	6	6.00%	100.00%	100
Other- Soft-LOWI/Water Ingress-*No*	94	94.00%		
Other- Hard-LOWI/Water Ingress-*Yes*	22	64.71%	100.00%	34
Other- Hard-LOWI/Water Ingress-*No*	12	35.29%		

It is observed that, the highest percentage of the scenarios without LOWI/Water Ingress appears in the case "Other- Soft" (94%) and the lowest in the case "Open sea-Soft" (78.57%). The highest percentage of the scenarios with LOWI/Water Ingress existence appears in the case "Open sea-Hard" (93.44%) and the lowest in the case "Other-Soft" (6%).

Table 5.3.26 presents the percentage and the numbers of ship's total loss for the different scenarios of a grounding event.

Table 5.3.26: Total loss of the ship (LOWI/Water Ingress Occurrence)

Scenario	Value	Percentage	Summary %	Summary
Open sea-Soft-LOWI/Water Ingress Yes- *Sinking Yes*	1	20.00%	100.00%	5
Open sea-Soft-LOWI/Water Ingress Yes- *Sinking No*	4	80.00%		
Open sea-Hard-LOWI/ Water Ingress Yes- *Sinking Yes*	2	4.00%	100.00%	50
Open sea-Hard-LOWI/ Water Ingress Yes- *Sinking No*	48	96.00%		
Other- Soft-LOWI/Water Ingress Yes- *Sinking Yes*	1	16.67%	100.00%	6
Other- Soft-LOWI/Water Ingress Yes- *Sinking No*	5	83.33%		

Other- Hard-LOWI/Water Ingress Yes- *Sinking Yes*	2	9.09%	100.00%	22
Other- Hard-LOWI/Water Ingress Yes- *Sinking No*	20	90.91%		

In the majority of the regions and sub-regions and seabed types when LOWI occurs and water ingress takes place due to grounding, the ship remains afloat. These cases vary from 80 to 96%. The highest percentage appears in scenarios “Open sea-Hard” and the lowest one appears in scenarios of “Open sea-Soft”.

Tables 5.3.27 present the percentage and the numbers of the accidents where the ship under investigation, with LOWI existence and water ingress occurrence, needed Major or Minor Repairs due to the incident.

Table 5.3.27: Major and Minor Repairs (LOWI/Water Ingress Occurrence)

Scenario	Value	Percentage	Summary %	Summary
Open sea-Soft-LOWI/Water Ingress Yes-No Sinking- *Major*	3	100.00%	100.00%	3
Open sea-Soft-LOWI/Water Ingress Yes-No Sinking- *Minor*	0	0.00%		
Open sea-Hard-LOWI/ Water Ingress Yes-No Sinking- *Major*	46	97.87%	100.00%	47
Open sea-Hard-LOWI/ Water Ingress Yes-No Sinking- *Minor*	1	2.13%		
Other- Soft-LOWI/Water Ingress Yes-No Sinking- *Major*	4	100.00%	100.00%	4
Other- Soft-LOWI/Water Ingress Yes –No Sinking- *Minor*	0	0.00%		
Other- Hard-LOWI/Water Ingress Yes-No Sinking- *Major*	20	100.00%	100.00%	20
Other- Hard-LOWI/Water Ingress Yes –No Sinking- *Minor*	0	0.00%		

It is observed that, in the majority of all areas and all seabed types, ship needed Major Repairs due to grounding in cases where both LOWI and water ingress occur. Cases with ships needed Major Repairs vary from 97.87 to 100% where the highest percentage appears in the cases “Open sea-Soft”, “Other- Soft” and “Other- Hard” and the lowest one appears in the case “Open sea-Hard”.

Table 5.3.28 presents the percentage and the numbers of the accidents, where the ship under investigation, without existence of LOWI and water ingress, needed Major or Minor Repairs due to the incident.

Table 5.3.28: Major and Minor Repairs (No LOWI/Water Ingress Occurrence)

Scenario	Value	Percentage	Summary %	Summary
Open sea-Soft- No LOWI/Water Ingress- *Major*	1	9.09%	100.00%	11
Open sea-Soft-No LOWI/Water Ingress- *Minor*	10	90.91%		
Open sea-Hard- No LOWI/Water Ingress- *Major*	1	25.00%	100.00%	4
Open sea-Hard- No LOWI/Water Ingress- *Minor*	3	75.00%		
Other- Soft- No LOWI/Water Ingress- *Major*	7	23.33%	100.00%	30
Other- Soft- No LOWI/Water Ingress- *Minor*	23	76.67%		
Other- Hard- No LOWI/Water Ingress- *Major*	5	50.00%	100.00%	10
Other- Hard- No LOWI/Water Ingress- *Minor*	5	50.00%		

It is observed that ship's Minor Repairs is required in the majority of cases without LOWI and water ingress. The cases where ships needed Minor Repairs vary from 50% to 90.91% where the highest percentage appears in the case "Open sea-Soft" and the lowest one appears in the case "Other- Hard".

Furthermore, based on our analysis, in grounding accidents, no fatalities or missing persons were registered for the studied time period.

Comparative Results

The comparative results of navigational accidents are presented below:

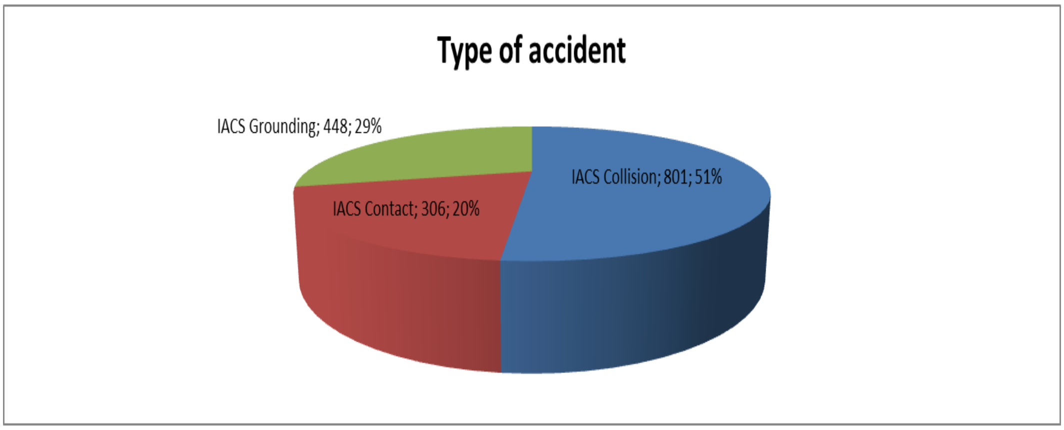
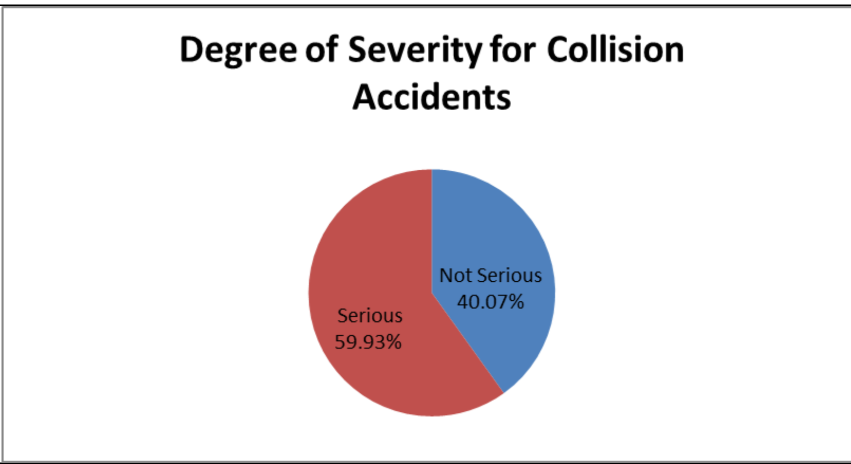
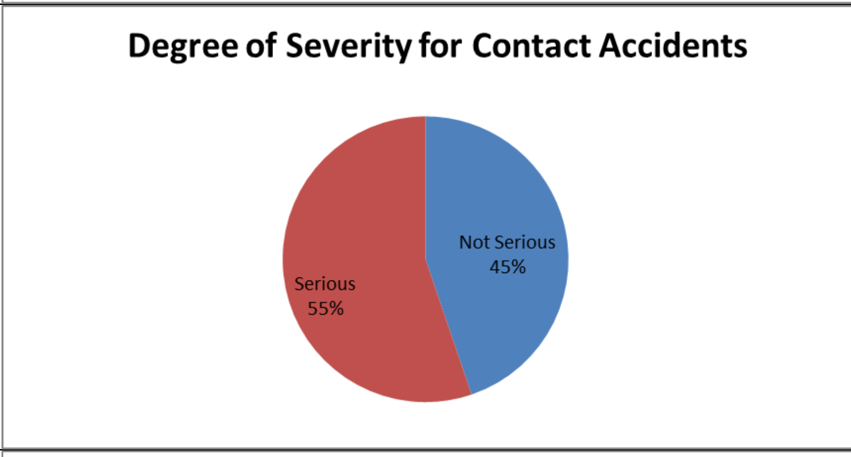
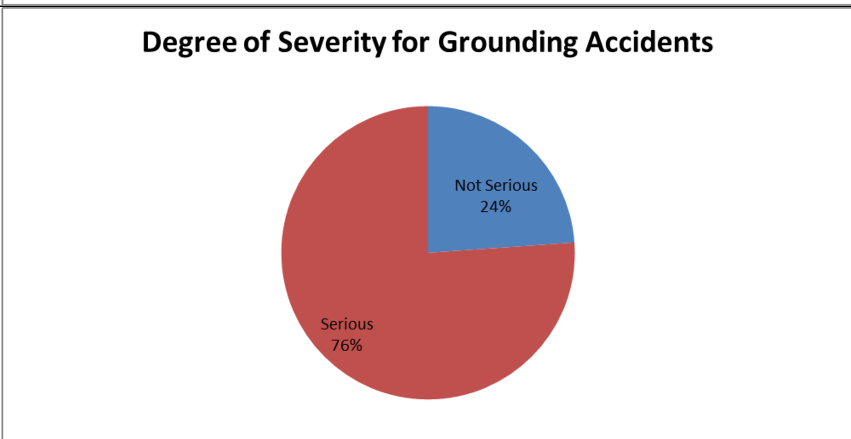
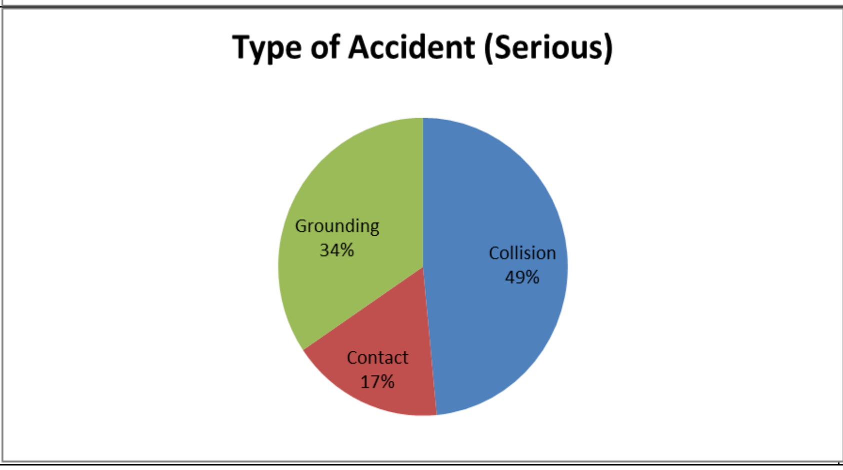


Diagram 5.3.29: Type of Accident on DCCS Database

According to our analysis, the majority of navigational accidents are collision accidents (51%). Grounding accidents represent the 29% and contact accidents the 20% of the studied sample.

Table 5.3.30 & Diagram 5.3.30, show the distribution of degree of severity (serious/not serious) for each accident category (collision, contact, grounding).

Table 5.3.30: Degree of Severity (Collision, Contact, Grounding Accidents)

<table>
<tr><td>
</td><td>Highest percentage is related to serious accidents.</td></tr>
<tr><td>
</td><td>Highest percentage is related to serious accidents.</td></tr>
<tr><td>
</td><td>Highest percentage is related to serious accidents.</td></tr>
<tr><td>
</td><td>Highest percentage related to serious accidents is coming from collision events.</td></tr>
</table>

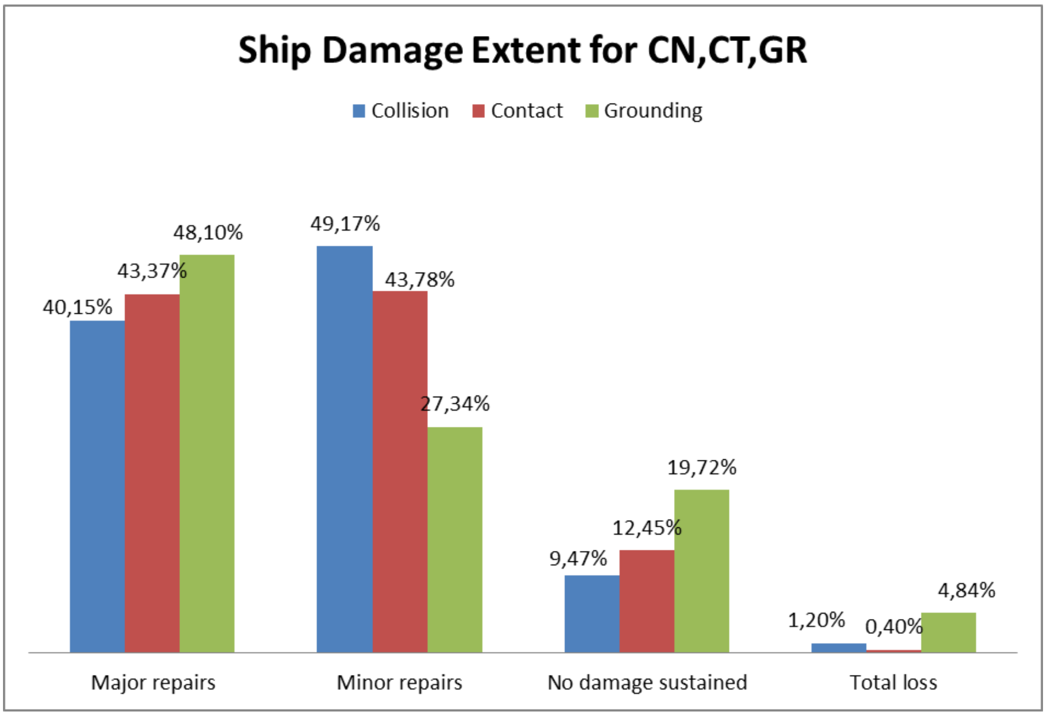


Diagram 5.3.31: Ship Damage Extent (Collision, Contact, Grounding Accidents)

Regarding collision and contact accidents, ship's Minor Repairs carried out in 49.17% and 43.78% of the cases respectively whereas in grounding accidents ship's Major Repairs required in 48.10% of the cases. Generally, a small percentage of ship sinking for all the accidents was observed i.e. collision: 1.20%, contact: 0.40% and grounding: 4.84%.

Diagrams 5.3.32 & 5.3.33 present the annual frequency of each accident (collision, contact, grounding) for the time period 1990-2020 as well as the total frequency of the three navigational accidents.

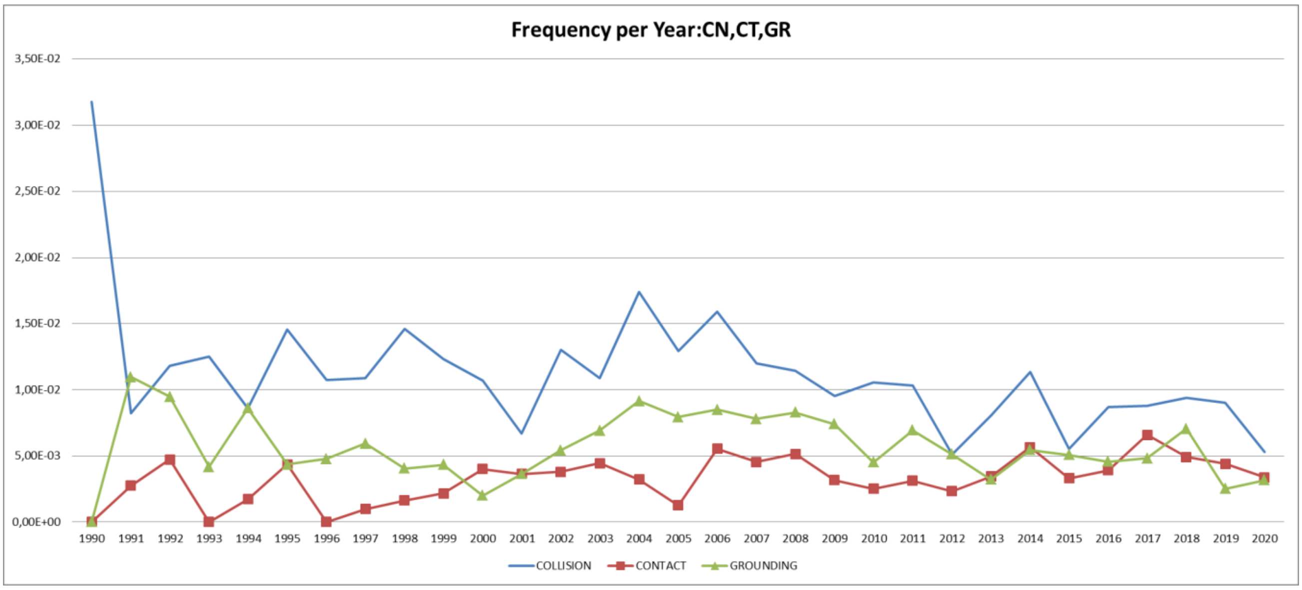


Diagram 5.3.32: Frequency per Year (Collision, Contact, Grounding Accidents)

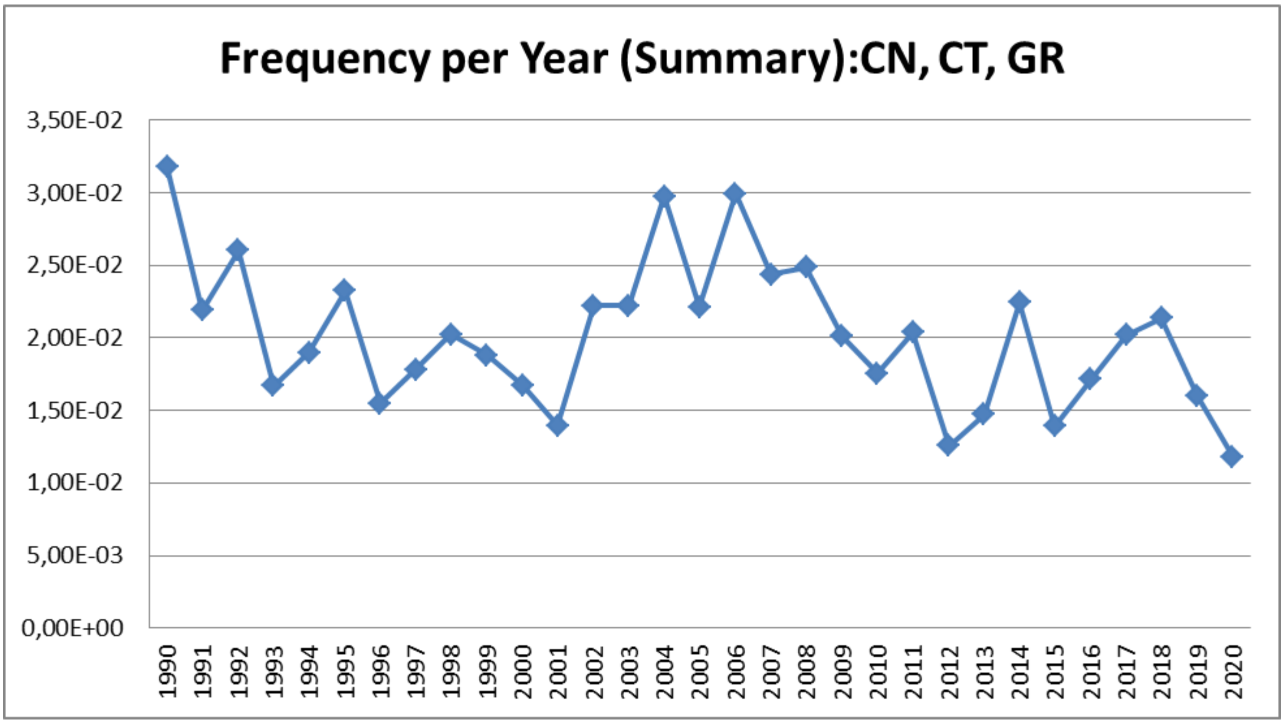


Diagram 5.3.33: Frequency per Year/Summary (Collision, Contact, Grounding Accidents)

The frequency of occurrence of each accident is presented for different decades as follows:

Collision accidents

- In the decade 1990-2000, the frequency of collision accidents is $1.25 \cdot 10^{-2}$
- In the decade 2001-2010, the frequency of collision accidents is $1.13 \cdot 10^{-2}$
- In the decade 2011-2020, the frequency of collision accidents is $7.74 \cdot 10^{-3}$

Contact accidents

- In the decade 1990-2000, the frequency of contact accidents is $2.16 \cdot 10^{-3}$
- In the decade 2001-2010, the frequency of contact accidents is $3.53 \cdot 10^{-3}$
- In the decade 2011-2020, the frequency of contact accidents is $4.81 \cdot 10^{-3}$

Grounding accidents

- In the decade 1990-2000, the frequency of grounding accidents is $4.88 \cdot 10^{-3}$
- In the decade 2001-2000, the frequency of grounding accidents is $6.67 \cdot 10^{-3}$
- In the decade 2011-2000, the frequency of grounding accidents is $4.38 \cdot 10^{-3}$

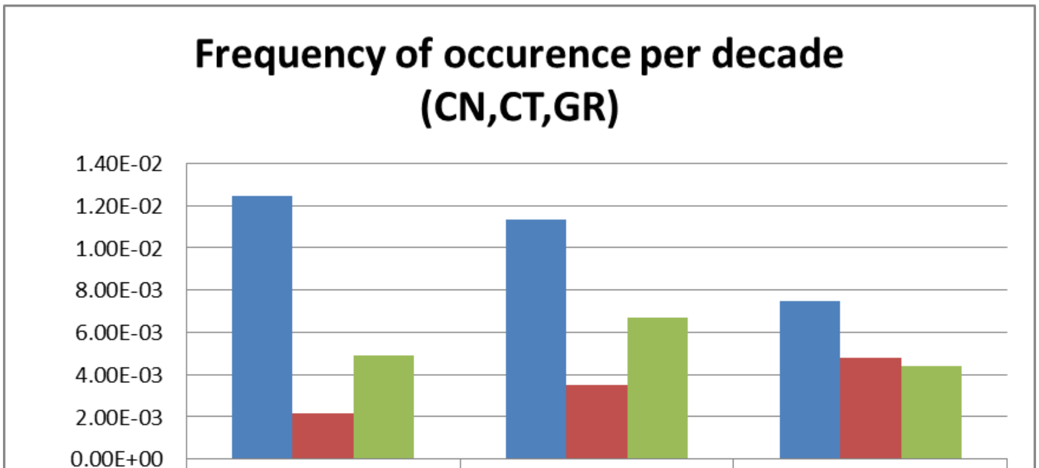
6. Conclusions and suggestions for future work

The present diploma thesis focuses on the study and the statistical analysis of collision, contact and grounding accidents of containerships which were built after 1982. In the particular thesis, 658 new records were inserted in DCCS Casualty database and were studied, covering a period from 2008 to 2020, from which 314 of them were categorized as collision accidents, 169 were assigned as contact accidents and 175 were grounding accidents. The initial database included 2629 records and, after additional accidents, the records increased to 3287. The statistical analysis of these accidents, leads to a better estimation of the main characteristics of the accident as well as the main causes and consequences of the incident.

After thorough study of accidents' investigation reports, fault trees were designed for each accident category. It is observed that for collision and grounding accidents occurred because of navigation failure, the highest percentage of the events are caused due to human error (68% and 50% respectively) in contrast to contact accidents which mainly happened due to weather conditions at the time of incident (77%). Regarding collision accidents, the highest percentage of the reasons that may lead to human error concerns wrong decisions (40%) and no proper lookout (34%) while for grounding accidents the highest percentage related to no proper action (82%). Focusing on contact accidents, the main reasons that most incidents may occur due to weather conditions are because of strong wind/wave, poor visibility, wrong actions and loss of control of the vessel.
For collision, contact and grounding accidents occurred due to machinery failure, the significantly highest percentage are coming from failure of maneuvering systems (100%, 100% and 89% respectively). Furthermore, failure of maneuvering systems are based on wrong actions/operations and unpredictable events, e.g.a block in the rudder. It is remarkable that in few collision accidents and the majority of contact incidents occurred in the ports & areas with high density traffic, the highest percentage of accidents happened by navigation failure whereas grounding accidents mainly happen due to machinery failure because this type of failure in many cases may lead to drift grounding.

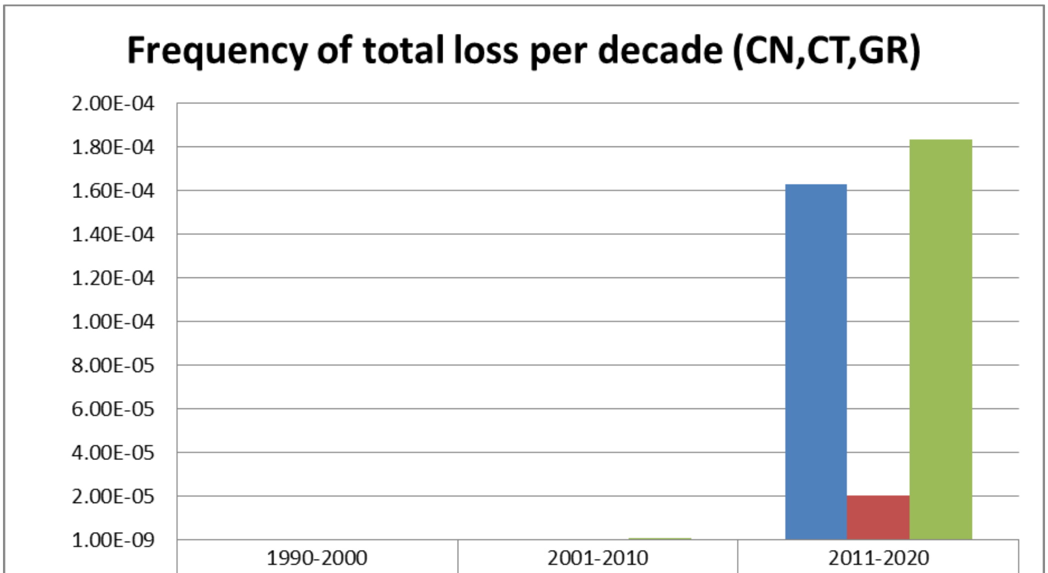
For collision, contact and grounding accidents for all the studied cases and geographical areas, when LOWI occurs and water ingress takes place, the ship in most cases does not sink. The probabilities vary from 76.92 to 100% for collision accidents, from 66.67 to 100% for contact accidents and from 80 to 96% for grounding accidents. Another significant result is that for every accident when LOWI occurs, water ingress takes place and the ship remains afloat, the ship under investigation needs major repairs due to the incident. Probabilities vary from 84.62 to 100% for collision accidents, from 97.87 to 100% for grounding accidents and for contact accidents is 100%.

Diagrams 6.1 and 6.2 present the frequency of occurrence of accidents and the frequency of total loss of the ship per decade for each category of navigational accidents.



	1990-2000	2001-2010	2011-2020
Collision	1.25E-02	1.13E-02	7.47E-03
Contact	2.16E-03	3.53E-03	4.81E-03
Grounding	4.88E-03	6.67E-03	4.38E-03

Diagram 6.1: Frequency of occurrence per Decade



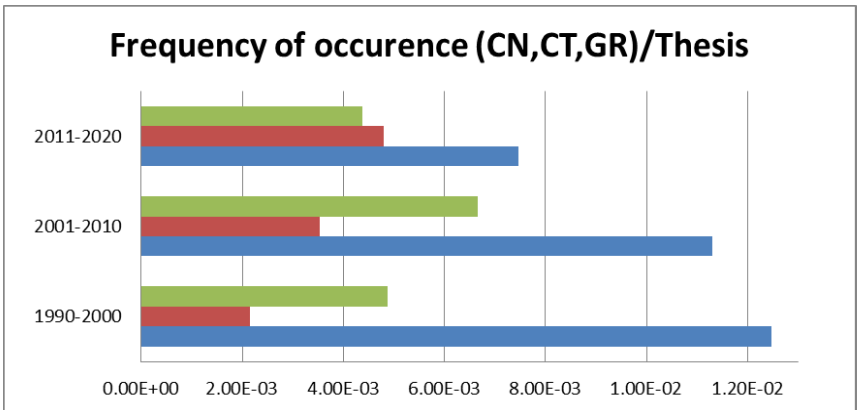
	1990-2000	2001-2010	2011-2020
Collision	0.00E+00	0.00E+00	1.63E-04
Contact	0.00E+00	0.00E+00	2.04E-05
Grounding	0.00E+00	1.13E-08	1.83E-04

Diagram 6.2: Frequency of total loss of the ship per Decade

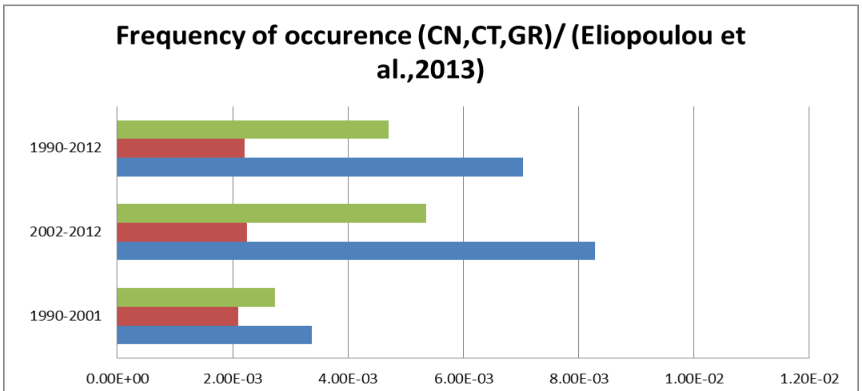
According to Diagram 6.1, collision accidents are more frequent in the first decade and they slightly decrease during the next two decades. Grounding and contact accidents are less frequent in comparison to collision events, groundings present a

higher frequency in the second decade and a slight decrease in the first and third decade whereas contact events have a lower frequency in contrast to collision and grounding in the first decade. The highest frequency of contact events is indicated in the last decade.
According to diagram 6.2, there are no total losses of the vessels during the first two decades for collision and contact accidents. Referring to grounding accidents in the first decade there is no total loss and in the second decade the frequency of total loss of the vessels is very low($1.13 \cdot 10^{-8}$). In the third decade, the highest frequency of the total losses concerns grounding accidents, collision accidents present slightly lower frequency and contact accidents present a very low frequency of ship's total loss.
Diagram 6.3 presents a comparison between the frequencies of occurrence of collision, contact and grounding accidents calculated in the present thesis and the study "Casualty analysis of Cellular Container Ships" (Eliopoulou et al., 2013) noting that the sampling plan of the studies is not exactly the same with respect to the applied filtering of ships under investigation.

Diagrams 6.3: Comparison of frequency of occurrence



	1990-2000	2001-2010	2011-2020
Grounding	4.88E-03	6.67E-03	4.38E-03
Contact	2.16E-03	3.53E-03	4.81E-03
Collision	1.25E-02	1.13E-02	7.47E-03



	1990-2001	2002-2012	1990-2012
Grounding	2.73E-03	5.36E-03	4.70E-03
Contact	2.09E-03	2.25E-03	2.21E-03
Collision	3.37E-03	8.28E-03	7.04E-03

According to our analysis, the resulted frequencies of navigational events are increased compared to (Eliopoulou et al., 2013). However, these statistical results are not directly comparable, because of the following reasons:

- Only serious events of IACS cellular containerships were selected in (Eliopoulou et al., 2013), whereas the studied sample of the present thesis includes all the casualty records regardless the accident's degree of severity.
- The sample of the present work contains all accidents except those cases where the containership does not sustain any damage.
- The used Operational Fleet at Risk presents some differences between the two studies.

Finally, some suggestions for future work are presented that can evolve the present diploma thesis. This work can be enhanced by deeper investigation in several accident cases in order to draw more consistent conclusions on the consequences of the event.

Furthermore, further research is needed on the main causes of collision, contact and grounding accidents in order to enrich the fault tree diagrams (the base level).

Further investigations focusing on the ship size could enrich the conclusions and the mechanism of navigational accidents.

The next step of this study is the performance of risk analysis in order to quantify the risk on human life, environment and cargo loss and draw conclusions on the safety of containerships.

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