MARINE ENVIRONMENT PROTECTION COMMITTEE
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Agenda item 17

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FORMAL SAFETY ASSESSMENT

FSA – Crude Oil Tankers

Submitted by Denmark

SUMMARY	
Executive summary:	This document provides information on the Formal Safety Assessment (FSA) study on crude oil tanker carried out within the research project SAFEDOR
Strategic direction:	12
High-level action:	12.1.1
Planned output:	12.1.1.1
Action to be taken:	Paragraph 2
Related documents:	MSC 83/INF.2; MSC 72/16 and MEPC 58/17/2

Introduction

1 As referred to in document MEPC 58/17/2 submitted by Denmark, a high-level FSA application on crude oil tankers has been performed. The report providing further details on this study is set out at annex to this document which contains the following:

.1 Annex I: Risk Analysis of crude oil tankers;

.2 Annex II: Risk Control Options and Cost Benefit Analysis; and

.3 Annex III: Recommendations.

Action requested of the Committee

2 The Committee is invited to note the information provided in this document in relation to its consideration of document MEPC 58/17/2.

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ANNEX

FORMAL SAFETY ASSESSMENT OF TANKERS F OIL

Contents

Annex I: Hazard Identification and Risk Analysis

1 Introduction

This annex presents steps one and two of a high-level Formal Safety Assessment (FSA) pertaining to large oil tanker ships carried out according to the FSA guidelines issued by IMO [1]. Step 1 (Hazard Identification, HAZID) relates to the identification and prioritization of the most important scenarios of large tanker accidents, whilst the purpose of Step 2 (Risk Analysis) is a detailed investigation into the causes and consequences of these scenarios.

The risk level associated with Oil Tanker shipping will be assessed, and one of the main objectives of the risk analysis is to identify high risk areas where further attention can be focused, e.g. by proposing new risk control options (RCOs).

Various methods have been employed in order to investigate the causes and consequences of the scenarios selected for further study. A risk model has been built using standard risk assessment techniques, such as construction and quantification of event trees. In order to quantify the frequencies of the incidents developing into the different scenarios, various methods have been utilized as deemed appropriate, e.g. construction of fault trees, investigation of historical accident data, calculations and simulations, comparison with similar ship types and techniques of using expert judgment.

The objective of the present study is to perform a “high-level” Formal Safety Assessment (FSA) for large oil tanker ships, i.e. to tankers with deadweight capacity over 60,000 tonnes, thus PANAMAX, AFRAMAX, SUEZMAX, VLCC and ULCC size of tankers, of double hull (DH) construction. Historical data of accidents of ships of large oil tankers of single hull (SH) construction are also considered in the study, to the extent they refer to accidents that are independent of hull type (e.g. navigational accidents) or for the purpose of comparison of their safety performance with double hull ships.

The full risk analysis problem shall consider all the different types of risk associated with the vessel herself, the environmental impact as well as the impact to third parties that directly or indirectly involved to the ship as an operating system.

The present study was limited to embrace safety environmental issues and potential loss of life. For this purpose, only the associated risk to crew’s life of the studied ship and health and to local environment was considered. Risk to crew and passengers onboard of other vessel (third parties), i.e. in case of collision, were out of the scope of the present study. Also, property risk in terms of ships’ structure and possible loss of payload is considered only in scenarios that involve possible human life loss.

The likelihood of exposure to security risks, that contains terrorist attacks or the ship being struck by missiles, is not negligible, but is considered out of the scope of the present study since it is related to other safety issues.

Occupational hazards with the potential of injuring, or in special circumstances even causing the death of individual crew members are also not within the purpose of the particular risk analysis.

Finally, the present risk analysis on Large Oil Tankers will be limited to the study of the operational phase of an Oil Tanker’s life cycle. Thus, risks associated with the vessel being in shipyards, in drydock and in the scrapping phase are also considered out of the scope. However, the frequencies of some related accidents are given in the following analysis in order to show the significance of the event location though in these cases the Event Trees analysis does not proceed further.

Section 2 of this Annex presents in brief background information on large oil tanker ships and Section 3 elaborates on the approach adopted for this study. Section 4 presents the main findings of the Hazard Identification (HAZID) work carried out, whilst Sections 5 to 10 provide full details of the risk analysis study conducted.

2 Background Information

Crude oil and petroleum products have been carried in ships for more than 100 years. The practice of carrying the oil directly inside the single hull of a ship has been common since this type of ship was first introduce in 1886. The hull provided far better security for the cargo than barrels, or casks, which could split and spill oil, creating fire and explosion hazards [3].

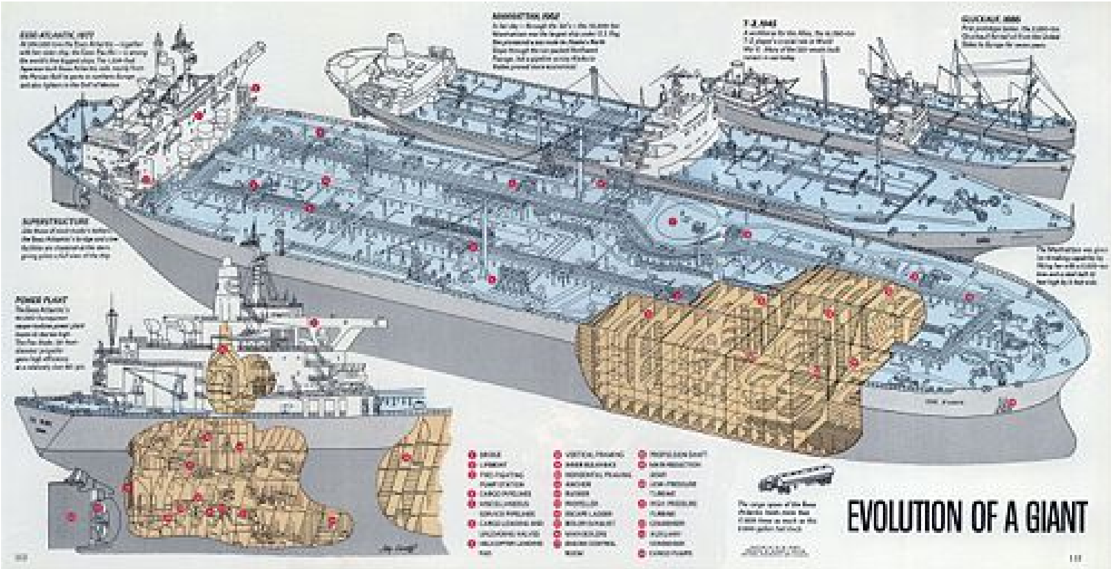


Figure 1: Tanker ships, Evolution of a giant

Tanker designs conceptually established at the end of the 19th Century remained virtually unchanged until shortly after World War II. At that time tankers were commonly of 10,000 to 15,000 DWT, with a single skin, the engine room placed astern, and multiple compartmentation with either two or three tanks across.
After WWII, the world economy expanded rapidly resulting to a huge increase in demand for energy in the form of oil. At the same time, a new shipping pattern evolved: crude oil started being transported in large quantities from distant sources, such as the Persian Gulf, to major marketing/consumers' areas, notably North America, Northern Europe, and Japan, where the crude was refined and redistributed as product. These long voyages of massive amounts of oil cargo set the stage for a dramatic increase in ship size in view of the economy of scale. Between 1950 and 1975, the largest tanker operating grew from about 25,000 DWT to over 500,000 DWT, Figure 1. The number of operating tankers in the world fleet also multiplied many times over years.
After that period and up to date, noting the effect of some spectacular oil tanker accidents, the increase of tanker ship size came practically to a stall; tanker designs underwent significant modifications, notably adopting the double skin concept; also, a series of preventive regulations and measures were introduced aiming at a reduction of the probability of accidents and mitigation of the consequences in terms of possible oil cargo release to the marine environment.

2.1 Tanker Hull Configuration

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the international convention dealing with the prevention of pollution of the marine environment by ships from operational or accidental causes, and its Annex I deals with oil pollution. As explained below, MARPOL is actually the result of a merge of two IMO treaties adopted in 1973 and 1978 and thereafter updated by various amendments. Acknowledging the importance of the USA legislation OPA90 in the introduction of modern double hull oil tanker designs, the brief review of regulatory developments below concentrates only on MARPOL because of its importance to international shipping. Furthermore, the following discussion concentrates on issues of accidental and not operational oil pollution.

The 1973 Convention, as the amended 1954 OILPOL Convention it replaced, maintained the "load on top" system which had evolved in the 1960s. Furthermore, according to the 1973 Convention new oil tankers (i.e. those whose building contract was placed after 31 December 1975) of 70,000 DWT and above, had to be fitted with segregated ballast tanks so that these ships could operate without the need to carry ballast water in cargo oil tanks. These tankers are colloquially known as pre-MARPOL tankers. In our study we refer to them as “non-SBT/PL single hull tankers”.

The Protocol of 1978 made a number of important changes to Annex I of the parent convention. Segregated ballast tanks (SBT) were required on all new tankers of 20,000 DWT and above. Furthermore, the Protocol required SBTs to be Protectively Located (PL), i.e. positioned in a way that will protect a certain percentage of cargo tanks from being exposed to the probability of collision, contact, or grounding. These tankers are known as SBT/PL, or colloquially as post-MARPOL single hull tankers. Other requirements introduced by the Protocol to tackle operational pollution but which do not affect the hull configuration of tankers are not discussed here. The following parameters defined “new oil tankers” to which the requirements of the Protocol of 1978 applied: (a) an oil tanker for which the building contract is placed after 1 June 1979; or (b) an oil tanker, in the absence of a building contract, the keel of which is laid or is at a similar stage of construction after 1 January 1980; or (c) an oil tanker the delivery of which is after 1 June 1982; or (d) an oil tanker which has undergone a major conversion (with parallel dates to those in (a)-(c) above).

As the 1973 MARPOL Convention had not yet entered into force at the time the Protocol of 1978 was adopted (in February 1978), the 1978 MARPOL Protocol absorbed the parent Convention. The combined instrument which is referred to as MARPOL 73/78, and simply as MARPOL since 2005, entered into force on 2 October 1983 (Annexes I and II).

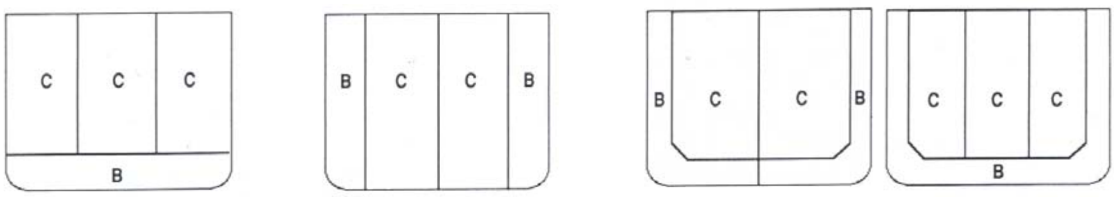
The 1992 amendments to Annex I of MARPOL entered into force on 6 July 1993 and introduced the "double hull" requirements for oil tankers, applicable to new ships (tankers ordered after 6 July 1993, whose keels were laid on or after 6 January 1994 or which are delivered on or after 6 July 1996) as well as existing ships built before that date, with a phase-in period. New-build tankers are covered by Regulation 13F which requires all new tankers of 5,000 DWT and above to be fitted with double hulls separated by a space of up to 2 metres (on tankers below 5,000 DWT the space must be at least 0.76m). Regulation 13G applies to existing crude oil tankers of 20,000 DWT and product carriers of 30,000 DWT and above. Regulation 13G came into effect on 6 July 1995 and required compliance with the double hull requirements (or more likely, withdrawal from service) when an oil tanker became 25 years old; unless it complied with PL requirements, or unless it operated under the hydrostatically balanced loading method, in which cases the tanker could continue operating as a single hull tanker until its 30th anniversary. As an alternative to the double hull configuration, tankers may incorporate the "mid deck" concept of design under which the pressure within the cargo tank does not exceed the external hydrostatic water pressure. Tankers built to this design have double sides but not a double bottom. Instead, another deck is installed inside the cargo tank with the venting arranged in such a way that there is an upward pressure on the bottom of the hull. Other methods of design and construction may be accepted as alternatives "provided that such methods ensure at least the same level of protection against oil pollution in the event of a collision or stranding” and are approved in principle by the Marine Environment Protection Committee based on guidelines developed by the Organization. It must be noted however that, to the authors’ knowledge, no mid-deck or alternative designs have been built to date, most probably because such oil tankers are not accepted for trading to the USA where regulation 13F has not been adopted but where OPA90 is the relevant regulation controlling double hull tankers.

The 2001 amendment to Annex I brought in a new timetable for accelerating the phase-out of single-hull oil tankers which was subsequently revised and further accelerated again by the 2003 amendments which entered into force in April 2005. The currently applicable timetable for the phasing out of single-hull tankers is as follows:

- For non-SBT/PL single hull oil tankers: 5 April 2005 for ships delivered on 5 April 1982 or earlier; and delivery anniversary date in 2005 for ships delivered after 5 April 1982.
- For SBT/PL single hull oil tankers: 5 April 2005 for ships delivered on 5 April 1977 or earlier; 2005 for ships delivered after 5 April 1977 but before 1 January 1978; 2006 for ships delivered in 1978 and 1979; 2007 for ships delivered in 1980 and 1981; 2008 for ships delivered in 1982; 2009 for ships delivered in 1983, and 2010 for ships delivered in 1984 or later.

The revised regulation allows a flag State to permit continued operation of post-MARPOL oil tankers beyond 2010 up to 2015 or to the date on which the ship reaches 25 years of age, whichever is earlier. Also, for post-MARPOL oil tankers fitted with only double bottoms or double sides the flag State may allow continued operation beyond 2010, up to the date on which the ship reaches 25 years of age. Nevertheless, the regulation also provides that these exemptions may not be accepted by port States, some of which may therefore ban such oil tankers from operating it their waters.

As a result of all the above regulatory developments a variety of alternative hull configurations have been introduced over the last two and a half decades. Figure 2, shows some typical modern tanker hull type configurations, representing the major part of today's tanker fleet at risk.



DB concept DS concept DH concept with "L" and "U" arrangement

Figure 2: Typical Tanker Hull Designs

2.2 IMO Regulations and Major Tanker Accidents

Investigations into some tragic tanker accidents have provided an in-depth knowledge and experience governing the change in the safety regime in the past years. Significant outcomes of some catastrophic casualties that were investigated, led to improvements of IMO's regulatory framework and eventually of maritime safety and operation. In the following, some spectacular tanker casualties are listed that led to the adoption of new regulations or/and amendments of the existing ones ([5], [6], [7]):

1. The catastrophe of "*Torrey Canyon*", in 1967, triggered the introduction of MARPOL 1973, STCW 1978 and parts of SOLAS 1974 (fire safety provisions for tankers).
2. The groundings of "*Argo Merchant*", in 1976, and of "*Amoco Cadiz*", in 1978, led to the Protocol 1978 of MARPOL. The "*Amoco Cadiz*" casualty had one little note effect. It was the basis for the introduction of Paris Memorandum Of Understanding on Port State Control (PARIS MOU).
3. The "*Exxon Valdez*" casualty, in 1989, led to the adoption of the first major regional agreement (introduction of double-hull tanker concept, application to US waters), OPA 90.
4. The "*Erika*" disaster, in 1999, contributed to the revision of MARPOL 73/78 (Reg. 13G), which regulated an accelerated phase-out of single hull tankers (MEPC - IMO). Furthermore, this particular accident led the European Union to the adoption of the ERIKA I and ERIKA II regulatory packages.
5. Following the "*Prestige*" accident in 2002, the European Union adopted Regulation 1726/2003 (accelerated single hull tanker phase-out, carriage of heavy grade oils in double hull tankers, hull

Condition Assessment Scheme). This regulation took effect within EU in October 2003. The IMO's Marine Environment Protection Committee (MEPC) adopted in December 2003 amendments to Regulation 13G and produced Regulation 13H to Annex I of MARPOL [Resolution MEPC.111(50) and Resolution MEPC.112(50)].

A study was carried out within the EU-funded project POP&C [8] in order to identify the key regulations and other preventive measures that contributed most to the *reduction of oil tankers accident occurrence*. Figure 3, [9], presents the navigational accident rates of AFRAMAX tankers for the period 1978-2003 along with the introduced relevant key regulations and measures that could be held responsible for the observed declining trends of the accidental rates. Similar declining trends were also observed for the other large tankers categories. Note that relevant regulations/measures are herein presented according to their year of implementation, thus it can be expected that their effect should be noticeable with some phase lag, depending on the nature of each regulation.

In the following, these basic regulations and measures (coded) are listed:

- *COLREG*: Convention of the international regulations for preventing collisions at sea.
- *SOLAS*: International Convention for the safety of life at sea (Routeing systems, Fire safety provisions)
- *MOU*: Memorandum of Understanding
- *STCW*: International Convention on Standards of Training, Certification and Watchkeeping
- *ARPA*: Automatic Radar Plotting Aid
- *VETTING* measure
- *MARPOL:* Enhanced Special inspection Program
- *OPA90*: Oil Pollution Act
- *GMDSS*: Global Maritime Distress and Safety System
- *ETS*: European Telecommunications Standard
- *ISM*: International Safety Management Code
- *CAP*: Condition Assessment Program
- *ILO*: International Labour Organisation

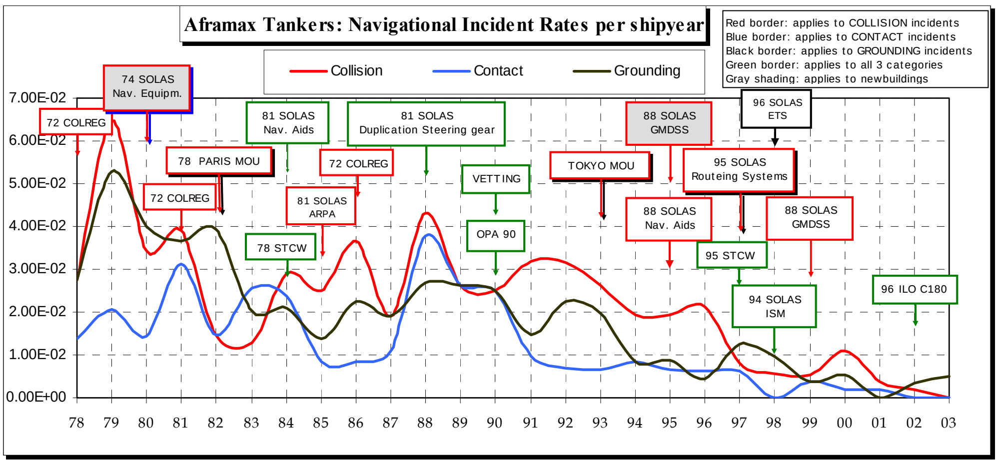


Figure 3: Navigational Accident rate vs. regulations [9]

2.3 Major Oil Movements

In general, oil tankers follow routes from the major centres of production to the industrialised centres of demand. Production is presently centred on: Middle East, North Sea, West Africa, Northern South

America, Eastern Europe, Indonesia, Mexico and North Africa. Figure 4 presents the major oil trade movements worldwide [10].

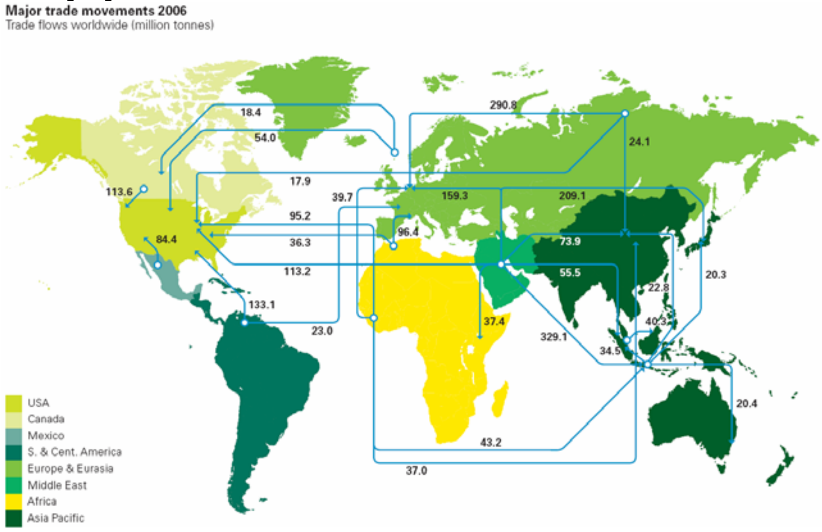


Figure 4: Major oil trade movements

2.4 Pollution of Marine Environment

Oil is released to the marine environment via a number of different sources. The most obvious one is oil pollution from tanker accidents that attract great public attention. However, this proves to be one of the least significant causes of marine pollution (merely 4.7% of the entire pollution quantity). Industrial waste, tanker loading/offloading, dry docking, marine terminals bilge and fuel oils, the decommissioning of ships, offshore oil production, urban river run-off and atmospheric inputs all contribute to the marine environment pollution by petroleum hydrocarbons. These spills are usually less than 50 barrels and attract less public attention. Figure 5 presents the different sources of oil pollution of the marine environment [11].

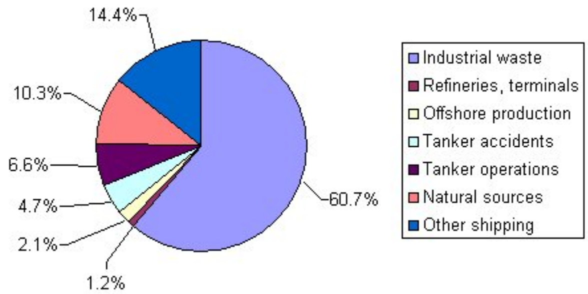


Figure 5: Relative inputs of oil from different sources [11]

Figure 6 shows the worldwide geographic locations of most severe oil pollution caused by AFRAMAX-SUEZMAX-VLCC-ULCC tanker accidents over the period 1978-2003 along with the routes of major worldwide oil movements [38].

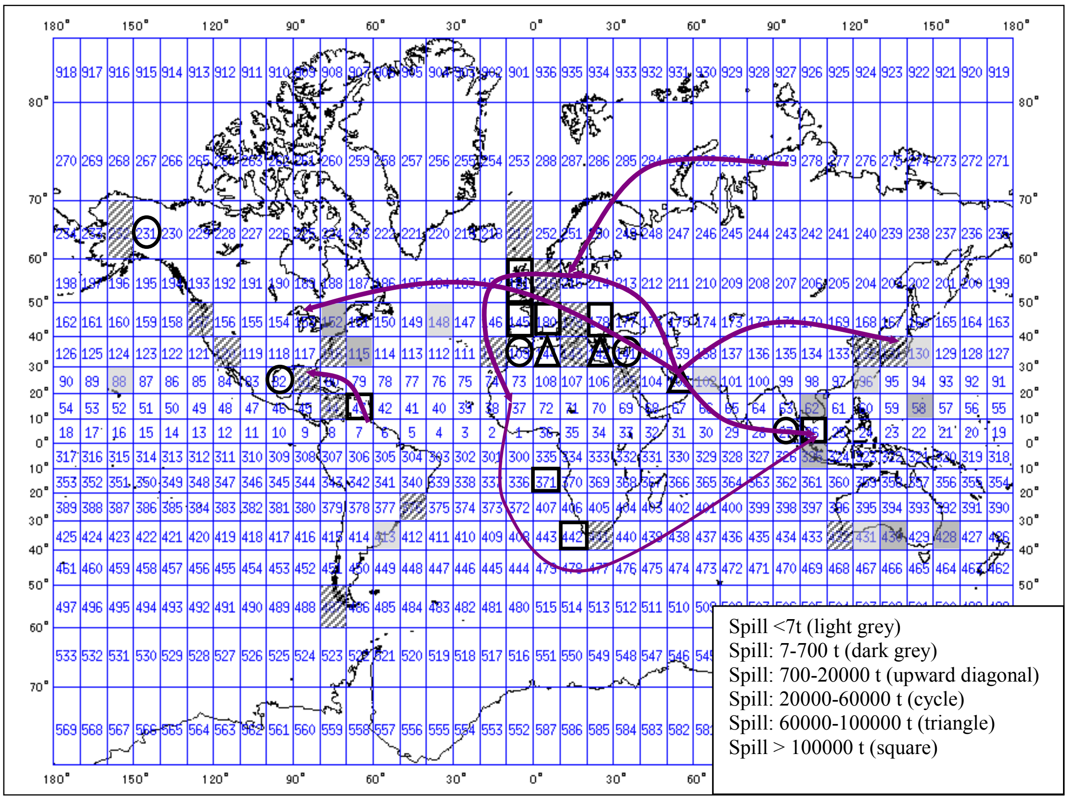


Figure 6: World map of main oil transport routes and marine pollution due to large tankers accidents over the period 1978-2003 [38]

2.5 Background FSA Studies

Two related FSA studies on oil tanker ships greater than 10,000 tonnes DWT have been carried out earlier with significant findings ([12], [13]). Synoptically, with respect to Double Hull oil tankers, the following findings may be highlighted:

- In the period 1990-2003, no total loss accidents were recorded for DH tankers larger than 10,000 tonnes DWT built after 1980.
- One serious accident, of any type, can be expected every 120 shipyears.
- One single fatality has been recorded in the period, one person deceased in a terrorist attack off the Yemen coast in 2002 (occupational accidents excluded).
- One oil spill accident can be expected to occur in about every 700 shipyears with an average spill size of about 400 tonnes.

3 Approach and Methodology

3.1 Casualty Databases

Casualty databases are potentially important tools for gauging the safety and the environmental performance of the industry. They can be used to study and analyse the historic accident scenarios and to find the vulnerable operational or design problems. They can be used also to guide the regulatory process so that the regulations that are being produced may be focused so as to address the weakest links in the safety and environmental prevention chain, and also they can be used to provide alerts for areas of design, operation and training which may be in need of additional attention or of a new approach.

There are many casualty databases, most well-known the Lloyds Register Fairplay (LRFP) and Lloyds Maritime Intelligent Unit (LMIU) which are and will be the largest international ships' accident database for the foreseeable future. Unfortunately, the marine incident/accident databases, which have evolved over the years, were not designed with the application of a possible risk assessment in mind, and therefore suffer from a number of serious limitations which make their usage in risk assessment and engineering projects quite problematic. A critical review of such databases was done in [14].

The necessity of using ship's casualty data in risk assessment methodologies led to the development of a new casualty database within the EU-funded project POP&C [8]. The construction of the POP&C database was based on the Fault Trees (FTs) and Event Trees (ETs) developed by the project [15] [16]. In comparison to the existing casualty databases, namely the LRFP and LMIU casualty databases which were the starting point for this new database, the POP&C database introduces the following basic alterations:

- *Possibility to categorise properly the main incident category and further describe the initiative event.* For example, "Fire and explosions" are treated as one category in LRFP/LMIU and in other data sources. Upon examining the causes and consequences of fire and of explosion accidents, it was realised that these differ considerably and because the scope of the analysis is to use this information on risk-based methodologies, it was considered essential to define accurately the first, initiating event. Furthermore, LRFP/LMIU databases has also a category called "Hull and Machinery" which incorporates structural failures, failures of machinery and propulsion devices, and failures of hull and deck fittings, all of which should be rationally examined under separate categories as they are associated with different causes (Fault Trees) and consequences (Event Trees).
- *Information within the complementary texts.* LRFP/LMIU databases contain information regarding the causes and consequences of the incident within complementary texts. This information is not very useful in the way it is registered. For this purpose, POP&C database was further developed in order to register the information of the complementary texts in a proper manner (using checklists, pull-down menus, etc.) so that the information could be easily retrieved and systematically analysed in the way required in a rational risk analysis.

Some specific weaknesses of the LRFP/LMIU databases that affected the proper population of POP&C database are outlined below:

- *Quality of Information within the complementary texts* The quality of information within the complementary texts was sometimes found questionable and incomplete for filing properly data to all relevant fields of the developed Fault and Event Trees. In the vast majority of the initial LRFP/LMIU records, the first initiative event is registered properly. It should be noted, however, that in very some cases, the LRFP/LMIU main accident categorisation coding did not keep up with the initiative event described in the complementary texts. For example, although the LRFP/LMIU main categorisation of the accident in some cases was "Hull and Machinery", from the complementary texts it was clear that the initiative event of the incident/accident was "Contact" or "Explosion". Also,

  1. In some cases, the quality of text is very poor without any technical information in the way that the Fault Trees cannot be filled or filled up to a certain level.
  2. The description of the consequences is very qualitative. In several cases, it is stated that with respect to severity of ship damage or/and pollution occurrence (because of the accident),

information was “not reported”. This does not mean that the ship did not sustain damage or there was no pollution occurrence [17].

3. Degree of accidents’ severity: LRFP/LMIU has a certain definition of coding the “severity” of accidents [18]. Comparing the coded degree of severity with what is written in the complementary text, the coded degree of severity is not evident in all cases.
4. Regarding the oil spill quantity of the accident, in some cases although it is stated that an oil spill occurred, there is no information regarding the amount quantity released to sea environment. In general, the oil spilt quantity needs to be checked before use, especially for major accidents.

In view of the above, the initial POP&C database was further developed by NTUA-SDL [19], with the aim to extract more detailed information useful for the risk assessment techniques and to verify filed information by cross-checking with other sources. Briefly, the followings aspects have been considered:

- Case of second major event after the initiative main event (i.e. Fire after collision).
- In case of collision, to consider if the ship is the struck or the striking one.
- In case of collision, to consider if there is “Tanker to Tanker” collision and also if the other tanker is registered to the database.
- To consider Ship-To-Ship Transfer operation, or transfer to other installation at the time of accident.
- To consider information on poor visibility and rain at the time of incident
- To consider ship loading information at the time of incident (ship loaded or in ballast condition).
- To consider enhanced hull type sub-form information.
- For Non-accidental structural failures, the basic damage is characterised, namely deck damage, hull damage, internal structural damage, etc.
- Where it is stated that oil pollution occurred in the initial LRFP/LMIU records but there is no information regarding the amount quantity, a notional oil spill is registered of 1-5 tonnes of oil spilt.

Part of the work presented herein and conducted within the project SAFEDOR was dedicated to enhancing the dataset by entries covering tanker accidents that were recorded in the period 2003-2007 [20]. In line with the aforementioned alterations, while entering the data, information was verified and enhanced by information from reliable secondary sources, as far as available.

For the purpose of the present study, the latest version of NTUA-SDL casualty database (ver. 5, April 2008) was used in the statistical analysis of historical data.

3.2 Applied Risk Assessment Methodology

The general methodology consists of the linking the fault tree with the event tree analysis in order to represent a full accident scenario. A scenario of accident is a sequence of events starting with a perturbation from the normal course of events. This initial perturbation is called “basic event”. This perturbation will trigger a response from the vessel systems and/or crew in an effort to bring the vessel back to a normal state. These responses constitute the “pivotal events” in the accident sequences. While most of the pivotal events will serve to protect the vessel or mitigate the consequences, a few events may actually exacerbate the sequence. Finally, each sequence will end with a certain level of damage (from no damage to total vessel loss for example). These consequences are called “end states”. The combination of the fault tree and event tree techniques can be symbolised as a bow tie. The scenario of accident is then represented as a complete path from the initiating event to the end event [21]. The risk assessment methodology is illustrated in Figure 7.

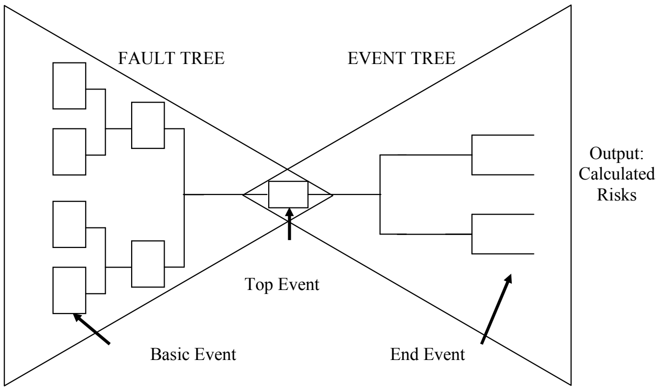


Figure 7: Risk assessment methodology

3.3 Boundaries of the Study

3.3.1 Major Hazards

This high level risk assessment comprises a limited number of identified major hazards and accident scenarios. The particular risk assessment study is focused on incidents/accidents that potentially lead to Loss Of Watertight Integrity (LOWI), namely:

Collision: striking or being struck by another ship, regardless of whether under way, anchored or moored. This category does not include striking underwater wrecks.

Contact: striking any fixed or floating objects other than those included under collision or grounding.

Grounding: being aground or hitting/touching shore or sea bottom or underwater objects (wrecks, etc.)

Fire: incidents where fire is the initial event.

Explosion: incidents where explosion is the initial event

Non-accidental structural failure: when the hull presents cracks and fractures, affecting ship's seaworthiness.

Note that scenarios due to failure of hull fittings or machinery failure as well as incidents associated with piracy or war losses are not considered in the study. The used accident statistics reflect a limited time period and input frequency figures are taken as average figures for time period.

This risk assessment addresses crude oil tanker ships of specific subtypes, as they are defined in [2], in the range of deadweight greater than 60,000 tonnes. Details on the sampling plan of casualty records are given in the Appendix of this Annex.

3.3.2 Operational State

The characteristics of different seaways and port environments are considered essential for the chain of Event Tree Analysis. In the setup database, the registration of casualty's location is based on the IMO relevant description on event location [22], namely *at Berth*, *Anchorage*, *Port*, *Port Approach*, *Inland waters*, *Canals*, *Rivers*, *Archipelagos*, *Coastal (<12 miles off)* and *Open Sea*.

Based on the above categorisation, four different operational states –associated with four different operational speed ranges- were identified as the basic categorisation for the risk analysis of different events. One more category of operational state is indicated, namely Shipyards & Drydocks, for which only the probability of having the studied event in this state is given and the event tree analysis is not continued.

The four different operational states are further related to different type of sea areas with different conditions for rescue efforts and environmental pollution, namely:

- *Terminal areas*. (Port, Anchorage, Port Approach and at Berth). The ship lies at berth/ port or is operating at low speed because of port or berth approaching or anchorage operations. The low speed generally reduces the severity of the consequences. Manoeuvring operations during pilot boarding are also related with increased collision probability.
- *Operation in congested waters.* (Coastal (<12 miles off) or restricted waters). Areas within congested waters are characterised by high density traffic.
- *En route at sea.* (Open Sea (≥12 miles off) & Archipelagos). Ship has her full operational speed.
- *Operation in limited waters* (Rivers, Canals and Inland waters).
- *Shipyards & Drydocks*

3.3.3 Loss of Watertight Integrity (LOWI)

The probability of hull breaching in case of an accident is considered essential for the sequence of events and consequences of the accident. For the purpose of this study, the NTUA-SDL database is used to determine this probability with respect to the navigational accidents. In some cases, it is clear from the complementary texts of the database that LOWI was occurred.

In some collision incidents, LOWI was not occurred because the other involved ship was small in comparison to the tanker ship (i.e. a fishing vessel) or it is clearly stated that the tanker ship does not sustain damage.

In some contact or grounding incidents, the tanker ship came accidentally in contact with a bridge or sustained propeller damage due to the contact or grounding. Both cases are considered as incidents with no LOWI occurrence.

When there was no clear statement, the following assumptions were taken into consideration in order to calculate the probability of hull breaching.

<u>No LOWI occurrence:</u>

- When it is stated "No damage reported".
- When the point of impact is above the main deck plating (i.e. superstructure, rails).
- When there is no relevant information regarding renewal of side shell plating.
- When the tanker ship sustains only minor or slight damage in relation to non-serious degree of accident's severity.

LOWI occurrence:

- When it is stated that "extent of damage was not known", it is assumed LOWI occurrence.
- When it is stated that the damage is below or above waterline.

3.3.4 Double Hull & Non-DH Construction

This study will be focusing on double-hull constructed ships with respect to the sequence of events and consequences assessment because this hull type is nowadays exclusively applicable to all newbuildings. Non-Double hull ships have a phase-out scheme to be converted to double-hull construction or to be removed (para 2.1).

The proportion of relevant Fleet at Risk (large oil tankers, as defined over 60,000 tonnes DWT) for the year 2007 is 77% (Double Hull) vs. 23% (Non-Double Hull). Detailed statistics of relevant Fleet at Risk considering the period 1980-2007 are given in Appendix of this Annex.

3.4 Generic Oil Tanker – common assumptions for the event trees

Four representative generic large oil tanker vessels – one PANAMAX, one AFRAMAX, one SUEZMAX and one VLCC ship were selected to serve as reference ships. Due to the large amount of data to be processed, this high-level FSA study will be conducted for all 4 tanker types/sizes together, though in some identified cases the analysis might be refined for the four generic sub-categories. The four reference designs [23] are briefly described below.

3.4.1 PANAMAX tanker ship

In this section a representative PANAMAX tanker ship is described. The basic ship characteristics are given in Table 1 and the typical general arrangement is presented in Figure 8.

Table 1: Basic characteristics of the PANAMAX tanker

Ship size	PANAMAX
Length, oa	228.00m
Length, bp	219.00m
Breadth, moulded	32.20m
Depth, moulded (main deck)	19.80m
Width of double skin sides	2.075m
Double bottom height	2.040m
Draught, moulded, scantling	13.60m
Deadweight, scantling draught (comparable with design proposed)	69,684dwt
Capacities (100%) Liquid volume, heavy oil, diesel oil, Water ballast	 80,659m^3 (of which 1,445m^3 are Slops), 1,419m^3, 195m^3 29,687m^3 (of which 2,377m^3 are peak tanks)
Classification	Lloyd's Register
Propeller Diameter	6,700 mm
Number of Cargo tanks	12 plus 2 slop tanks
Typical cargo tank volumes	No.1 P/S each 4,926m^3, No.2 P/S each 7,009m^3 No.3 P/S each 7,078m^3, No.4 P/S each 7,078m^3 No.5 P/S each 7,059m^3, No.6 P/S each 6,458m^3 Slop Tanks P/S each 722.6m^3
Cargo Tanks block length	170.52 m

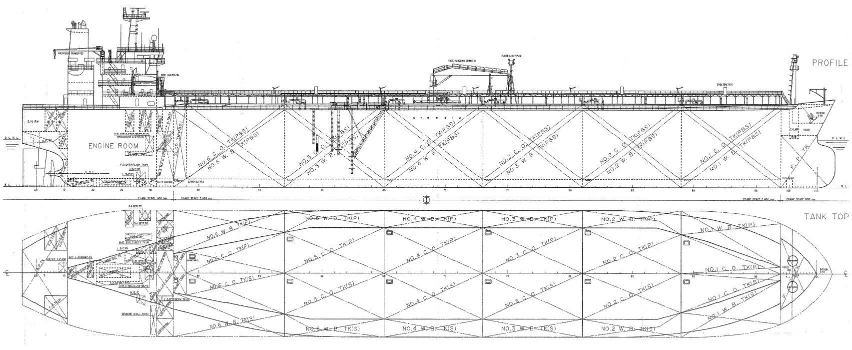


Figure 8: PANAMAX Tanker, General arrangement, side and top view

3.4.2 AFRAMAX tanker ship

In this section a representative AFRAMAX tanker ship is described. The basic ship characteristics are given in Table 2 and the typical general arrangement is presented in Figure 9.

Table 2: Basic characteristics of the AFRAMAX tanker	
Ship size	AFRAMAX
Length, oa	248.00m
Length, bp	238.00m
Breadth, moulded	43.00m
Depth, moulded (main deck)	21.00m
Width of double skin sides	2.18m
Double bottom height	2.30m
Draught, moulded, scantling	14.30m
Deadweight, scantling draught (comparable with design proposed)	105,357dwt
Capacities (100%) Liquid volume, heavy oil, diesel oil, Water ballast	 125,203m^3 (of which 2,424m^3 are Slops), 3,339m^3, 231m^3 39,783m^3 (of which 3,218m^3 are peak tanks)
Classification	Lloyd's Register
Propeller Diameter	8,000 mm
Number of Cargo tanks	12 plus 2 slop tanks
Typical cargo tank volumes	No.1 P/S each 8,003m^3, No.2 P/S each 10,796m^3 No.3 P/S each 10,872m^3, No.4 P/S each 10,872m^3 No.5 P/S each 10,872m^3, No.6 P/S each 9,976m^3 Slop Tanks P/S each 1212m^3
Cargo Tanks block length	184.90 m

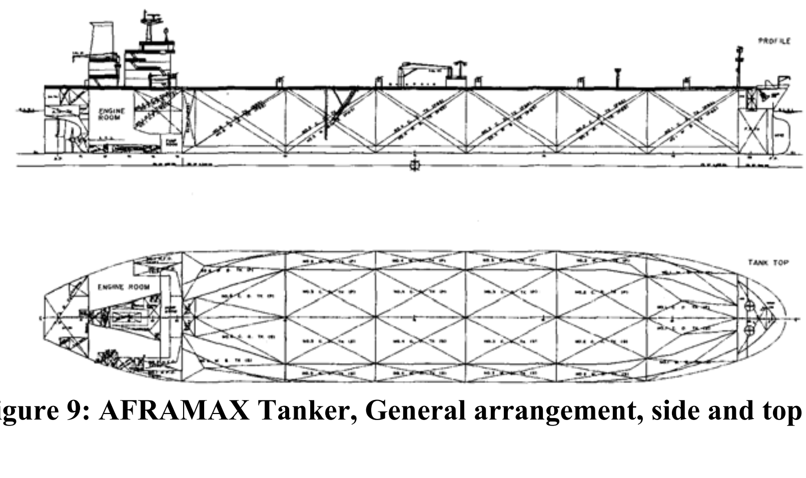


Figure 9: AFRAMAX Tanker, General arrangement, side and top view

3.4.3 SUEZMAX tanker ship

In this section a representative SUEZMAX tanker ship is described. The basic ship characteristics are given in Table 3 and the typical general arrangement is presented in Figure 10.

Table 3: Basic characteristics of the SUEZMAX tanker	
Ship size	SUEZMAX
Length, oa	274.07m
Length, bp	264.00m
Breadth, moulded	48.00m
Depth, moulded (main deck)	23.10m
Width of double skin sides	2.50m
Double bottom height	2.80m
Draught, moulded, scantling	17.05m
Deadweight, scantling draught (comparable with design proposed)	158,982dwt
Capacities (100%) Liquid volume, heavy oil, diesel oil, Water ballast	 174,846m^3 (of which 3,837m^3 are Slops), 4,566m^3, 260m^3 54,350m^3 (of which 3,306m^3 are peak tanks)
Classification	ABS
Propeller Diameter	8,200 mm
Number of Cargo tanks	12 plus 2 slop tanks
Typical cargo tank volumes	No.1 P/S each 11,136m^3, No.2 P/S each 14,988m^3 No.3 P/S each 15,089m^3, No.4 P/S each 15,089m^3 No.5 P/S each 15,089m^3, No.6 P/S each 14,113m^3 Slop Tanks P/S each 1,918.6m^3
Cargo Tanks block length	213.14 m

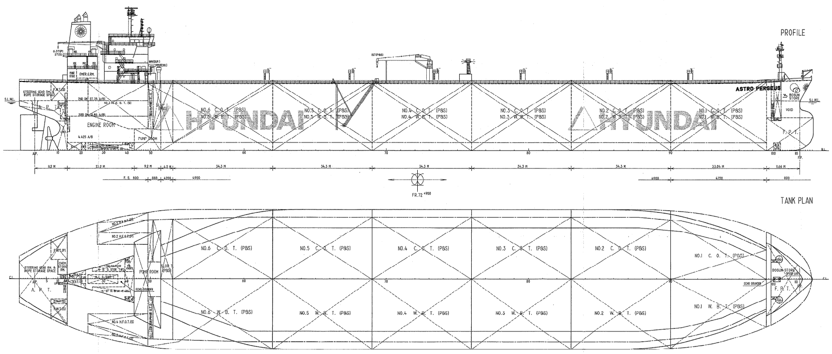


Figure 10: SUEZMAX Tanker, General arrangement, side and top view

3.4.4 VLCC tanker ship

In this section a representative VLCC tanker ship is described. The basic ship characteristics are given in Table 4 and the typical general arrangement is presented in Figure 11.

Table 4: Basic characteristics of the VLCC tanker	
Ship size	VLCC
Length, oa	333.277m
Length, bp	318.00m
Breadth, moulded	58.00m
Depth, moulded (main deck)	31.25m
Width of double skin sides	3.38m
Double bottom height	3.00m
Draught, moulded, scantling	22.50m
Deadweight, scantling draught (comparable with design proposed)	309,020dwt
Capacities (100%) Liquid volume, heavy oil, diesel oil, Water ballast	 350,100m^3 (of which 10,085m^3 are Slops), 8,602m^3, 372m^3 98,996m^3 (of which 6,841m^3 are peak tanks)
Classification	Built with DNV, currently ABS
Propeller Diameter	10,000 mm
Number of Cargo tanks	15 plus 2 slop tanks
Typical cargo tank volumes	No.1 C 29,625m^3, No.1 P/S each 16,404m^3 No.2 C 32,410m^3, No.2 P/S each 20,556m^3 No.3 C 32,410m^3, No.3 P/S each 20,556m^3 No.4 C 32,410m^3, No.4 P/S each 20,556m^3 No.5 C 30,307m^3, No.5 P/S each 13,354m^3 Slop Tanks P/S each 5,042.6m^3
Cargo Tanks block length	254.00 m

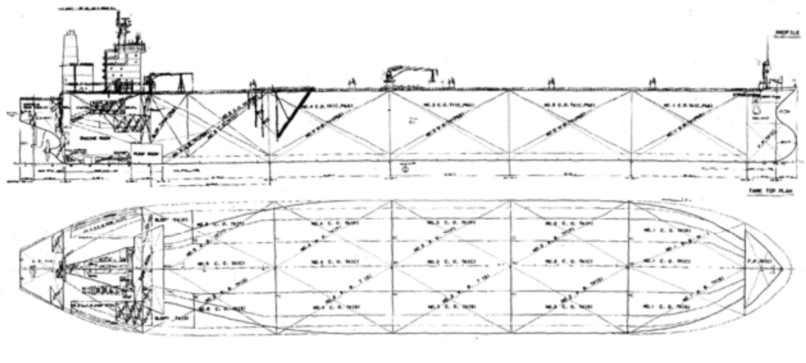


Figure 11: VLCC Tanker, General arrangement, side and top view

3.5 Oil Cargo and Hazards

Petroleum (Latin Petroleum derived from Greek πέτρα (Latin petra) - rock + Greek έλαιον (Latin oleum) - oil) or crude oil is a naturally occurring liquid found in formations in the Earth consisting of a complex mixture of hydrocarbons (mostly alkanes). Petroleum is used mostly (by volume) for producing fuel oil and gasoline (petrol), both important "primary energy" sources. Due to its high energy density, easy transportability and relative abundance, it has become the world's most important source of energy since the mid-1950s. Petroleum is also the raw material for many chemical products, including pharmaceuticals, solvents, fertilizers, pesticides, and plastics; by volume, about 16% of the crude oil not used for energy production are converted into these other materials.

Behaviour of oil which has been spilled at sea:
Oil is a general term used to denote petroleum products which mainly consist of hydrocarbons. Crude oils are made up of a wide spectrum of hydrocarbons ranging from very volatile, light materials such as propane and benzene to more complex heavy compounds such as bitumens, asphaltenes, resins and waxes. Refined products such as petrol or fuel oil are composed of smaller and more specific ranges of these hydrocarbons. Oil, when spilled at sea, will normally break up and be dissipated or scattered into the marine environment over time. This dissipation is a result of a number of chemical and physical processes that change the compounds that make up oil when it is spilled. The processes are collectively known as weathering [24].

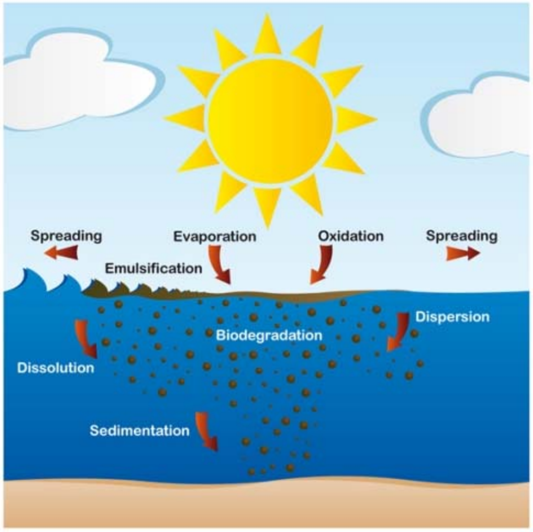


Figure 12: Fate of oil spilled at sea showing the main weathering processes [24]

Most of the weathering processes, such as evaporation, dispersion, dissolution and sedimentation, lead to the disappearance of oil from the surface of the sea, whereas others, particularly the formation of water-in-oil emulsions ("mousse") and the accompanying increase in viscosity, promote its persistence. The speed and relative importance of the processes depend on factors such as the quantity and type of oil, the prevailing weather and sea conditions, and whether the oil remains at sea or is washed ashore. Ultimately, the marine environment assimilates spilled oil through the long-term process of biodegradation. The eight main processes that cause oil to weather are presented in Figure 12. More detailed information can be found in [25].

4 Hazard Identification (HAZID) and Accident Scenarios

4.1 Hazard Identification Process

A structured Hazard Identification process was adopted, comprising two stages, namely an analysis of statistical data aimed to identify the main hazardous processes/operations from historical experience (reference is made to the statistical report of Appendix A.3) followed by Hazard Identification expert sessions in which hazards relating to the mentioned processes/operations were identified and prioritised.

The expert sessions were performed by means of Failure Modes, Effects and Criticality Analysis (FMECA). The task of the FMECA is the detection of hazards and a ranking of these hazards to select the main risk contributors to be investigated in the course of the quantitative analysis. The following four processes/operations were investigated:

1. Loading/unloading operations; including tank cleaning and crude oil washing(COW)
2. Ship-to-ship transfer (STS) at open sea
3. Operations in coastal and restricted waters, including navigation under pilotage
4. Maintenance tasks

The analysis was performed in two separate FMECA sessions held in Athens on 26 and 27 June 2007. The first session dealt with phases operations 1 and 2 above, whilst the second session dealt with operations 3 and 4. The table of Appendix A.1 lists participants in the FMECA sessions with their professional background and experience.

Hazards were identified with respect to safety (effect on human life) and the environment. In the course of the FMECA analysis, connections between causes and consequences of identified hazards are elicited and presented in a standardised format.

The basic process is to establish a description of the steps and tasks of a system or process, and list the consequences if a task fails. In a further step the participants evaluate the consequences with respect to two criteria; frequency of occurrence and severity of consequence. Here, severity was ranked separately for human life and environmental damage. In order to ensure that experts make their judgements on a common scale, frequencies and consequences index were defined:

- frequency index, FI ε {1..8}
- severity index, SI ε {1..5}

These indices relate to a logarithmic scale, so that the risk index RI is calculated by addition: RI=FI+SI. The risk index is used to prioritize all potential failures with the ultimate goal to decide upon actions leading to a risk reduction, usually by either reducing the frequency, by reducing severity and / or improving controls for detecting the failure. The rating was performed in the same group setting immediately after the hazard identification phase, with the aim of reaching expert consensus on the assigned frequencies and consequences.

4.2 Outcome of HazId and Identification of Prioritised Risk Scenarios

Hazard Identification Process

The undertaken Hazard Identification Process [2] identified in total 81 hazards which are distributed among the defined operational phases of a tanker as shown in Table 5. The highest assigned risk index, RI, was 8.

Table 5: Number of identified hazards

Scenario	No of hazards
Navigation	36
Loading/Unloading	30

STS[1]	8
Maintenance	7
Total	81

Prioritisation criteria
Hazards were evaluated using pre-defined frequency and severity scales. A hazard is considered to be serious if the risk index RI>=6 and/or the severity is catastrophic (SI=4).

The top-ranked hazards with respect to human life were:

- Explosion during loading/unloading in harbour after mooring breaks because vessel passing with high speed
- Fire/explosion after collision due to communications problem during navigation
- Fire/explosion after breach of manifolds/pipelines caused by drift of vessel during SP mooring (communications problem or pilot fatigue)
- Fire/explosion during loading/unloading due to failure/absence of vapour emission control system
- Fire/explosion during weld repairs due to insufficient cleaning of pipes

The top-ranked hazards with respect to environmental damage were:

- Explosion during loading/unloading in harbour after mooring breaks because vessel passing with high speed.
- Loss of cargo after high-energy impact due to human communications problem leading to a collision.
- Loss of cargo after high-energy impact due to technical communications problem leading to a collision.
- Breach of cargo tank due to stuck pressure valve during ballasting.
- Damaged bunker tanks due to collision during preparation of STS.

4.3 Selected Risk Scenarios

The following generic accident scenarios have been selected based on a balanced consideration of the hazard identification process and to the historical accident analysis for tanker ships greater than 60,000 DWT compiled within the *period 1980-2007* and presented in Appendix of this Annex.

Collision
Collision scenarios represent 30% of all registered initial causes in the historical accidents database. In total, 4 hazards with RI ≥ 7, with respect to human life or/and the environment, were identified in the HazId phase. In general, most collision scenarios occur within congested waters while the ship is sailing or during berth/port approach.
Contact
Contact scenarios represent 13% of all registered initial causes in the set-up database. No hazards with RI ≥ 7, with respect to human life or the environment, were identified in the HazId phase. In general, most contact scenarios occur within congested waters while the ship is sailing or during manoeuvring operations.

Grounding

[1] Note that Ship To Ship transfer (STS) and Maintenance scenarios were not analysed exhaustively. For STS, only aspects were considered that go beyond to what was already covered in Loading/Unloading. For Maintenance only selected activities were looked at, which were judged by experts to be particularly likely and critical. Experts agreed that the information that is available on maintenance-related hazards is insufficient to be considered in detail in the quantitative analysis.

Grounding scenarios represent 21% of all registered initial causes in the set-up database. In total, 6 hazards with RI ≥ 7, with respect to human life or the environment, were identified in the HazId phase. In general, most grounding scenarios occur within congested waters while the ship is sailing or during berth/port approach.

Fire
Fire scenarios represent 11% of all registered initial causes in the set-up database. In total, 2 hazards with RI ≥ 7, with respect to human life or the environment, were identified in the HazId phase. In general, most fire scenarios occur while the ship is sailing, during berth/port approach and when it is under repair or construction.

Explosion
Explosion scenarios represent 6% of all registered initial causes in the set-up database. In total, 4 hazards with RI ≥ 7, with respect to human life or the environment, were identified in the HazId phase. In general, most explosion scenarios occur while the ship is sailing, during berth/port approach, while discharging and when it is under repair or construction.

Non-accidental structural failure (NASF)
Non-accidental structural failure scenarios represent 19% of all registered initial causes in the set-up database. No hazard with RI ≥ 7, with respect to human life or the environment, was identified in the HazId phase. In general most non-accidental structural failure scenarios occur while the ship is sailing, while loading or discharging.

5 Frequency Assessment

The full risk model could include except LOWI accidents, also "machinery failures", "failures of hull fittings" and "unknown reasons. For the scope of the particular study, only the six (6) events that potentially lead to LOWI (Loss Of Watertight Integrity) are taken into consideration, Figure 13.

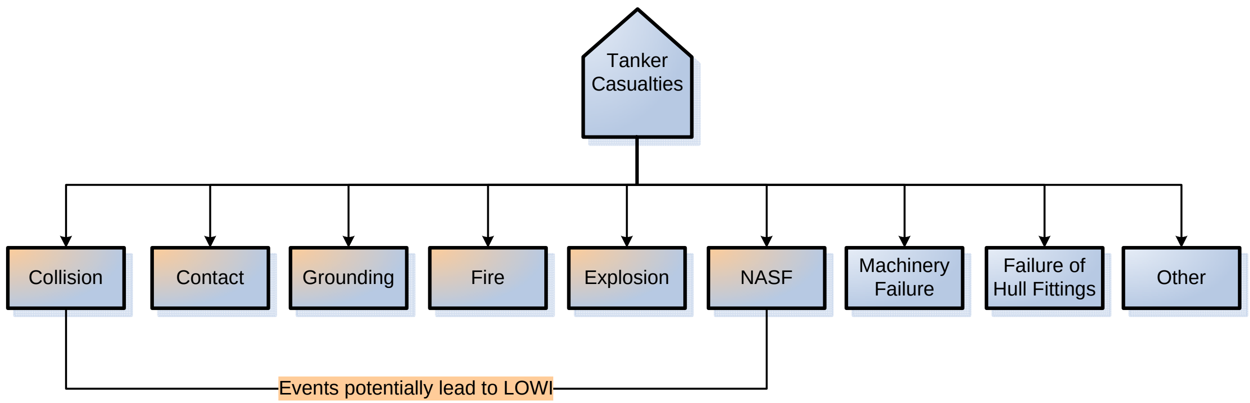


Figure 13: Tanker Casualties Distribution

5.1 Historical Probability and Consequence Data Assessment

Based on the set-up database [19] for large oil tankers and the statistical analysis presented in the Appendix A.3 of this Annex, the frequency of occurrence of the different accident categories was calculated. Table 6 summarises the number of casualties, sum of live vessels, the frequency of casualties, and also indicates consequences in terms of dead/ missing and injured people for each accident category, within the period 1980-2007.

Table 6: Historical data, *Studied Period 1980-2007*, Fleet at Risk = 38211.20 shipyears All recorded incidents, independent the degree of severity.												
					Frequency			**Injured**			**Fatalities/ Missing**	
Initial event	**No of accidents**	**No of accidents with pollution**	**Tonnes Spilt**		**All accidents**	**Accidents with pollution**		**No of persons**	**No of events**		**No of persons**	**No of events**
Collision	606	39	213,574		1.59E-02	1.02E-03		2	1		55	7
Contact	269	26	37,548		7.04E-03	6.80E-04		0	0		0	0
Grounding	424	40	360,962		1.11E-02	1.05E-03		0	0		1	1
Fire	225	4	397,174		5.89E-03	1.05E-04		100	16		61	19
Explosion	115	6	441,446		3.01E-03	1.57E-04		30	10		119	31
NASF	394	51	212,407		1.03E-02	1.33E-03		0	0		8	2
Total[2]	**2033**	**166**	**1,663,111**					**132**			**244**	

5.2 Trends and Representative Frequency for Today's Situation

Figure 14 presents the frequency of the 6 studied accident categories per shipyear within the studied period 1980-2007. A downward trend of frequencies is noted within the studied period. Significant reduction of accident occurrence is shown in the post-90 period.

The representative frequency for today's situation is selected to be the average of annual frequencies in the post-90 period because of the significant reduction of accident occurrence in the particular period, taken into consideration that a series of introduced key regulations was found to be related to the significant decrease and prevention of accidents [9].

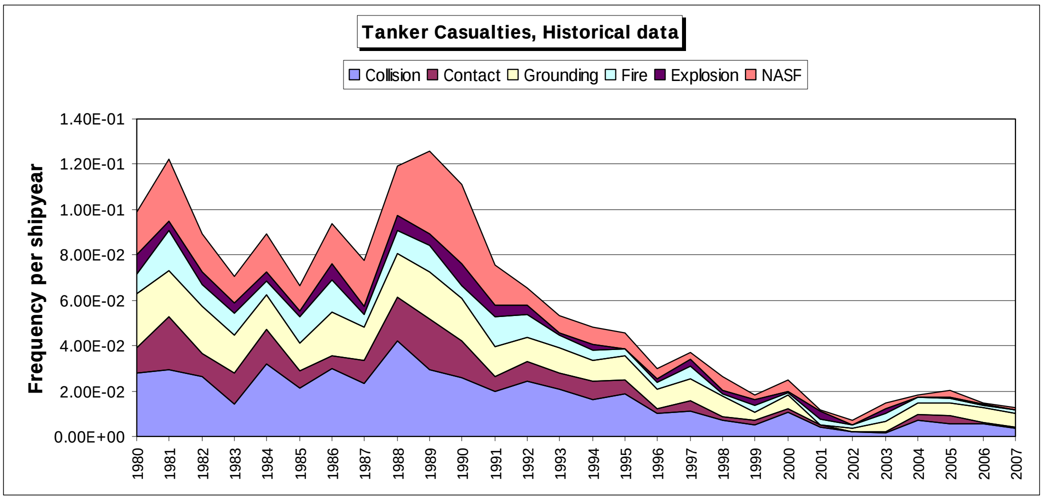


Figure 14: Frequency per shipyear

[2] Incidents in Shipyards & Drydock are included.

5.3 *Input Frequencies for the Event Scenario Models*

Overall frequency of the six incident events: ***3.28E-02***[3]
Table 7 presents the assumed, input frequencies for each event tree scenario model.
With respect to the navigational events (collision, contact and grounding) as well as fire and explosion events, the full sample of accident data independently of the involved ship's hull type was used for the statistical analysis. This was decided because of the statistical sufficiency of the sample data; it is also supported by the fact that frequencies of these events are not related to the ship's basic hull type construction.

In case of non-accidental structural failure, only events of Double Hull ships were considered in the frequency assessment because the particular event category is highly related to the ship's internal structure.

Table 7: Frequency by incident category, Covered period 1990-2007 All incidents independent the degree of severity	
Fleet at Risk of all ships = 25780.22 shipyears Fleet at Risk of DH ships=10377.87 shipyears	
Initial event	**Frequency of accident**
Collision	***1.03E-02***
Contact	***3.72E-03***
Grounding	***7.49E-03***
Fire	***3.65E-03***
Explosion	***1.90E-03***
NASF	***DH ships: 1.93E-03, All ships: 5.74E-03***

6 Consequences Assessment

At a high level, the total risk associated with the operation of large oil tanker ships is assumed to be the sum of the risk contributions from the six (6) selected accident scenarios. The risk contributions from all other scenarios are assumed to be negligible in comparison. Thus, the overall risk model can be illustrated as in Figure 15. The risk contribution from each of the accidents scenarios will be estimated based on more detailed risk models and event trees.

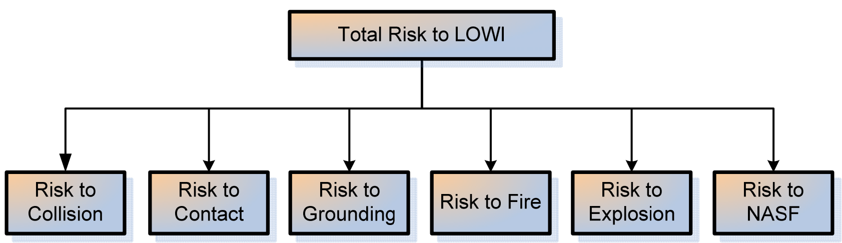


Figure 15: Risk contributors

- <u>**Consequences on crews' life**</u>

[3] Corresponding frequency to all ships involved, independently of the hull type & degree of severity.

The expected number of fatalities for each identified scenario is presented as the Potential Loss of Life, PLL, per shipyear. The related estimation of PLL is derived from historical data on the basis of a *typical crew number of 30 persons*.

Note that according to [26], a typical crew number for international trading patterns is given next:

PANAMAX	26 persons
AFRAMAX	28 persons
SUEZMAX & VLCC	32 persons

The above crew numbers may vary depending on the trading pattern, e.g. for short voyages in the North Sea, these numbers are increased by 2-3 persons.

- **Environmental impact**

The consequences to the environment for each identified scenario are presented as the expected cargo oil tonnes released to the sea.

Table 8 presents the statistical values (mean and standard deviation) for one typical tank size in tonnes that is based on actual data of 1450 ships (Panamax to ULCC ships), registered in LRFP database [27]. For the purpose of this study, the average size of one tank[4] is taken into consideration for the calculation of expected oil outflow in those scenarios, where *given the accident and the ship is assumed loaded, the inner hull is breached and there is a severe damage without ship sinking.*

Table 8: Average of tank size for SH and DH ships

	SH ships		DH ships	
	Mean (t)	Stdw(t)	Mean(t)	Stdw(t)
PANAMAX	6450.9	1813.5	5285.8	1372.3
AFRAMAX	9298.5	2424.5	8145.8	1654.4
SUEZMAX	10947.9	2622.3	11365.7	2255.4
VLCC&ULCC	19828.4	2443.2	18106.5	2924.2
Average of typical tank sizes, in tonnes			**10726**	

Based on the characteristics of the reference vessels, the total cargo volume is presented in Table 9 for each reference vessel along with the total oil cargo carried based on the assumption of 98% fully loaded and oil specific weight 0.85 t/m^3. For the purpose of this study, the average value of total oil cargo weight[5] is used in the consequences assessment, in those scenarios where *given the accident, the ship is loaded and the accident results to ship's total loss.*

Table 9: Reference ships, Oil cargo carried

Reference Vessel	100%Volume (m^3)	Oil cargo (in tonnes) *(98% full, 0.85 t/ m^3)*
PANAMAX	80,659	67,189
AFRAMAX	125,203	104,294
SUEZMAX	174,846	145,647
VLCC	350,100	291,633
	182,702	***152,191***

[4] Note that using a weighted average for the generic ship's tank size based on Fleet at Risk tanker size distribution the obtained results are quite similar, see Appendix of this Annex.

[5] Note that using a weighted average for the generic ship's tank size based on Fleet at Risk tanker size distribution the obtained results are quite similar, see Appendix of this Annex.

- **Economic impact**

Economic impact is calculated only in terms of ship property in cases of expected loss of human life. Table 10 presents the assumed values, used for the purpose of this study [26].

Table 10: Ship & oil cargo typical values		
	Ship value*[6] in $	**Oil cargo ($ /tonne)**
PANAMAX	50,000,000	***923[7]***
AFRAMAX	65,000,000	
SUEZMAX	85,000,000	
VLCC	130,000,000	
Average value	***82,500,000***	

7 Risk Assessment

7.1 Risk Model - Collision

Collision events consist of scenarios where two vessels accidentally come into contact with each other. The investigated scenarios contain collisions when the tanker vessel 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. Because not all collisions took place between two tankers, in the determination of the risk for tankers it is necessary to consider only one incident as tanker accident, e.g. if the collision is between a tanker and a container vessel. However, if the frequency of collisions involving tankers needs to be determined, the number of collisions between tankers has to be divided by a certain number, reflecting the probability of the tanker to be striking or being struck by another tanker vessel.

Collision scenarios present 32% of all registered initial causes in the setup databases involving tanker ships during the studied period 1990-2007. In total, 265 recorded accidents were registered as collisions.

Concerning the degree of event's severity as coded in LRFP/LMIU databases, in 64 cases the event characterised by serious degree of severity, in 191 cases there were of non serious degree of severity and in 10 cases there was no relevant registration.

In 8 accidents, there were 2 non-serious injuries and 55 fatalities (39 missing persons and 16 deaths). Furthermore, in 27 collision accidents (10% of registered collision accidents), oil spill occurred because of the accident, resulting to 126,532 tonnes of oil spilt within the studied period. In 5 cases out of 27, the degree of severity was "not-serious" though in some cases the amount of oil spill was considerable (case A: 144 tonnes, case B: 1074 tonnes, case C: 121 tonnes).

In 11 cases out of the 265 recorded accidents (4%), fire was occurred because of the accident. In all these cases, except for 1, the accident was characterised by serious degree of severity.

[6] Based on an assumed age of about 5 years.
[7] Assumed $/tonne oil value as of March, 2008

7.1.1 Qualitative Risk Modelling

The collision probability is highly related to the traffic density. According to the statistics, most collisions take place within congested waters with dense ship traffic, crossing routes and areas with large ship speed variations. The basic causes are bad visibility, navigational or technical failures.

A typical collision scenario involving a tanker ship starts with the event occurrence. The tanker vessel might be struck by another vessel or it might be the striking one. If the tanker vessel is the striking ship, the likelihood of further escalation of the incident for the tanker vessel can be considered as small as it will receive the collision impact in the bow.

The tanker operating condition at the time of collision might be fully loaded or in ballast condition and this fact will influence the further escalation of the event.

Focusing on the tanker as the struck ship, the collision might or might not cause damage that breaches the hull and if it is so, there is a possibility to penetrate the inner hull in case of Double Hull construction. If the collision damage penetrates the inner hull, it might cause leakage of cargo. Possible Fire/Explosion initiation after the collision affects the consequences of event scenario possibly resulting to fatalities. Penetration of the hull or/and the inner hull might also cause loss of stability and hence cause the ship to sink.

Figure 16 presents the event sequence in the collision risk model.

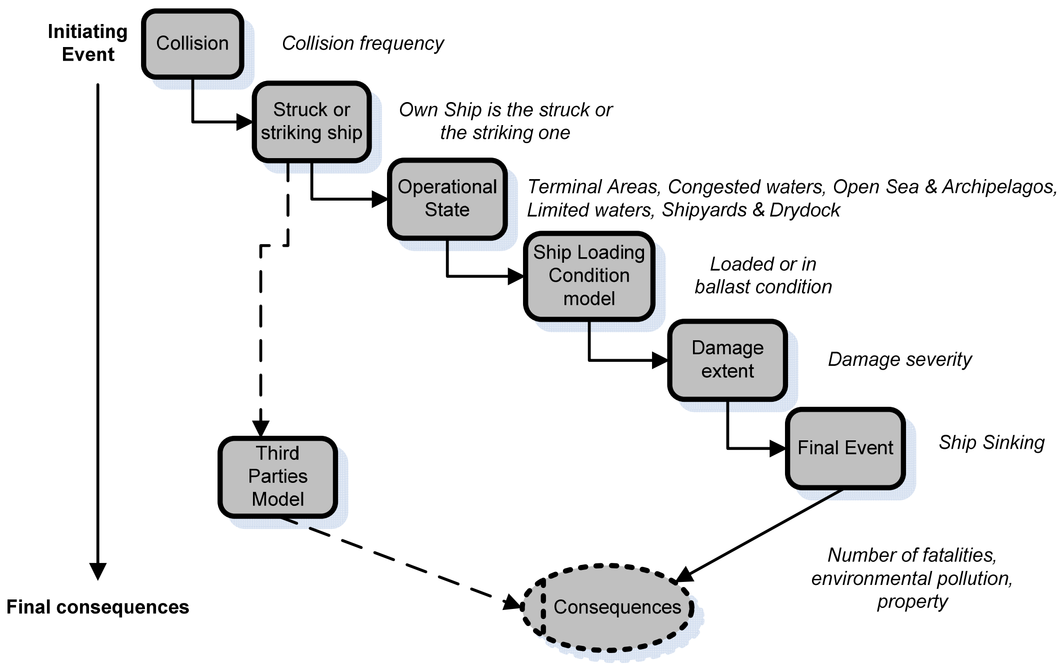


Figure 16: Event sequence in collision risk model of an Oil Tanker

7.1.2 Quantitative Input for Collision Risk Model

Frequency of collision scenarios

For the risk analysis of oil tankers, the frequency of collision events is calculated in terms of oil tankers involved in the particular casualties (265 incidents).

Estimated frequency of collision occurrence *in terms of ships involved* in collisions per shipyear:

1.03E-02.

The frequency of collision events based *on the number of collision events*, is slightly different because it refers only to the number of events. In the setup database, there are only 24 cases (out of 265 incidents) for which both ships involved in collisions are of the studied tanker size and are registered in separate records. Based on this, the estimated frequency of collision occurrence in terms of collisions per shipyear is **9.35E-03.**

Struck or striking vessel

In [28], probabilities of the struck ship encountering specific ship types are given. These probabilities are based on the fraction of each ship type in the worldwide ship population in 1993 (Lloyds 1993). Concerning tankers, the study includes crude and product tankers, ore/oil carriers, LPG tankers, chemical tankers, LNG tankers, and oil/bulk/ore carriers and the calculated probability of a struck ship to be in collision with a tanker (striking ship type probability) is *0.252*. In the same study, it is mentioned that it is more likely a particular ship to meet ships of the same type since they travel the same routes, but this relationship could not be quantified.

Given the fact that the tanker ship has relatively low operational speed it is expected that it is related to a higher probability that a tanker is the struck ship than to be the striking one. Discussions with the experts [26], resulted to a ratio of 80% (struck) to 20% (striking) for the studied ship type and size.

For the purpose of this study, *the probability of a tanker to be the struck ship or be the striking one in a collision event is assumed as 80%(struck)-20%(striking).*

Concerning events where the tanker ship is the striking vessel, the probability of receiving a critical damage is assumed to be negligible; therefore these scenarios will not contribute to the collision risk.

Operational state

Assumed probabilities of different operational states are based on historical data.

Table 11

Operational state	Collision Events Probability of Operational State	
Terminal areas	$P_{TERM\|COLL}$	0.30
Operation in congested waters	$P_{CONG\|COLL}$	0.37
En route at open sea	$P_{OSEA\|COLL}$	0.26
Operation in limited waters	$P_{LIMW\|COLL}$	0.07
Shipyards & Drydocks	$P_{YARDS\|COLL}$	0.00

Ship Loading Condition Model

The probability of the ship to be in a specific loading condition is used as a fixed value for the evaluation of collision events (independent of the operational state). Details on the assumed probability are given in the Appendix of this Annex.

Probability of ship in loading condition: ***0.60***
Probability of ship in ballast condition: ***0.40***

Hull Breaching

The probability of hull breaching is estimated from historical data and is calculated on the basis of each given operational state in case of a collision event.

Table 12

Operational state	Probability of hull breaching
Terminal areas	0.46

Operation in congested waters	0.36
En route at open sea	0.46
Operation in limited waters	0.42

Damage penetration

Several studies have been carried out concerning the collision damage for different ship types [29], [30]. An extensive study on the development of damage extent modelling concerning oil tankers was carried out in [31]. This study concluded that with respect to collision and grounding events, the MARPOL damage extent distributions fit better historical data than other simplified models such as Resolution A.265, SOLAS Part B-1, or the new harmonised stability regulations, SOLAS 2009.

For collision scenarios, the damage extent is highly related to the penetration of ship's damage. Thus, for the purpose of this study, the probability of damage penetration the inner hull is calculated on the basis of [32]-Regulation 23: Accidental oil outflow performance, taken into account only the transverse extent.

Table 13

Probability of damage will lie entirely outboard of the tank, [32]-Regulation 23				
Ref. Ships (para 3.4)	**Bs (m)**	**y (m)**	**y/Bs**	**P (y < Y)**
PANAMAX	32.2	2.075	0.0644	0.812
AFRAMAX	43	2.18	0.0507	0.753
SUEZMAX	48	2.5	0.0521	0.759
ULCC	58	3.38	0.0583	0.787
			Average P (y < Y)	*0.778*

The probability of penetrating the inner hull structure is calculated on the basis of the average value:

$P(y > Y) = 1 - P(y < Y) = \mathbf{0.22}$

Damage severity

The appearance of fire in case of a collision event is considered significant and is taken into consideration in the event sequence. This probability is deduced from the historical data as a conditional probability of the particular basic scenario.

Table 14

Operational State	**Fire/Explosion after collision with LOWI**	**Fire/Explosion after collision without LOWI**
Terminal areas	0.03	0.00
Operation in congested waters	0.06	0.00
En route at open sea	0.23	0.03
Operation in limited waters	0.00	0.00

Furthermore, the probability of ship's damage to be severe or not severe is calculated as a conditional probability of having or not LOWI occurrence in a given operational state in case of collision and is in accordance to accident's degree of severity according to LRFP/LMIU coding.

Final event

<u>Ship survivability</u>

For the struck ship two final outcomes were identified, each with completely different consequences with respect to rescue and evacuation conditions:

· The struck ship remains afloat and continues to sail by her own means or towed away: *No Sinking*

· Total loss of the struck ship: *Sinking*

<u>Consequences on crew life or/and to the local environment</u>

In case of collision events, non-serious and serious injuries as well as fatalities could occur. The expected number of fatalities is calculated from the historical data and is summarised below:

Table 15

Collision events - Consequences on human life	
Typical crew number = 30 persons	
Collision Scenarios	**Expected number of fatalities (% of crew number)**
Existence of fire and ship total loss	44%
Existence of fire with ship's severe damage	14%
No fire and ship's severe damage	7%
Non-severe damage	0%
No LOWI occurrence	0%

The environmental consequences of the risk modelling consider the release of oil cargo from the damaged tanker. For scenarios resulting to ship's severe damage, the expected oil outflow is described in Section 6, namely the release of oil cargo of one tank. According to the setup database, for scenarios with non-severe ship's damage the expected oil outflow was calculated as a % of DWT of the ships involved in the particular collision scenarios and is given next:

Table 16

For non-serious accidents *Average DWT = 160,761 (ref. ships, para 3.4)*	
expected oil outflow	*184.6 tonnes*

Property risk is evaluated only in scenarios with expected number of fatalities. This calculation is based on typical average values of Table 9. For severe collision damages, it is assumed that *the ship damage cost is 5% of the ship value*.

7.1.3 Event Tree Model

A high-level event tree model for collision accidents with large oil tankers has been elaborated on the basis of the qualitative and quantitative considerations presented in the previous sections. The event tree structure has a total of 82 sequential scenario branches with non-zero frequency.

- 44 scenario sequence branches are associated with single or multiple crew fatalities.
- 20 scenario sequence branches are associated with oil spill occurrence.

For crew member: $PLL_{Collision\text{-}Crew}$ *= 4.91E-03 per ship year*
For environment: $PLC_{Collision\text{-}Envi}$ *= 1.30E+01 tonnes per ship year*

Characteristic figures for environmental damage, expected quantity of released oil spillage are also derived and summarised in the event tree model.
The event tree is graphically presented in the Appendix of this Annex.

7.2 Risk Model – 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.

Contact scenarios present 11% of all registered initial causes in the setup database involving tanker ships during the studied period 1990-2007. In total, 96 recorded accidents were registered as contacts, from which 68% was contacts with a fixed installation and 32% with a floating object.

Concerning the degree of event's severity as coded in LRFP/LMIU database, in 24 cases the event is characterised by serious degree of severity, in 69 cases there were of not serious degree of severity and in 3 cases there was no relevant registration.

No accident with injuries or fatalities was recorded during the studied period. Furthermore, in 16 contact accidents (17% of registered contact accidents), oil spill occurred because of the accident, resulting to 13,162 tonnes of oil spilt within the studied period.

7.2.1 Qualitative Risk Modelling

The presence of objects likely to be struck in contact scenarios is higher in congested waters than at open sea. The majority of the contact scenarios take place during manoeuvring operations or approach/sailing in rivers and canals.

Contacts with a fixed installation contains scenarios where the tanker ship contacts an offshore terminal, a quay, pier, canal's locks, shore cranes, rocks etc. Contacts with floating objects contain scenarios where the tanker ship contacts an iceberg, a buoy, a floating fender, a submerged object etc. The basic causes are because of bad visibility, navigational or technical failures. Figure 17 presents the event sequence in contact risk model.

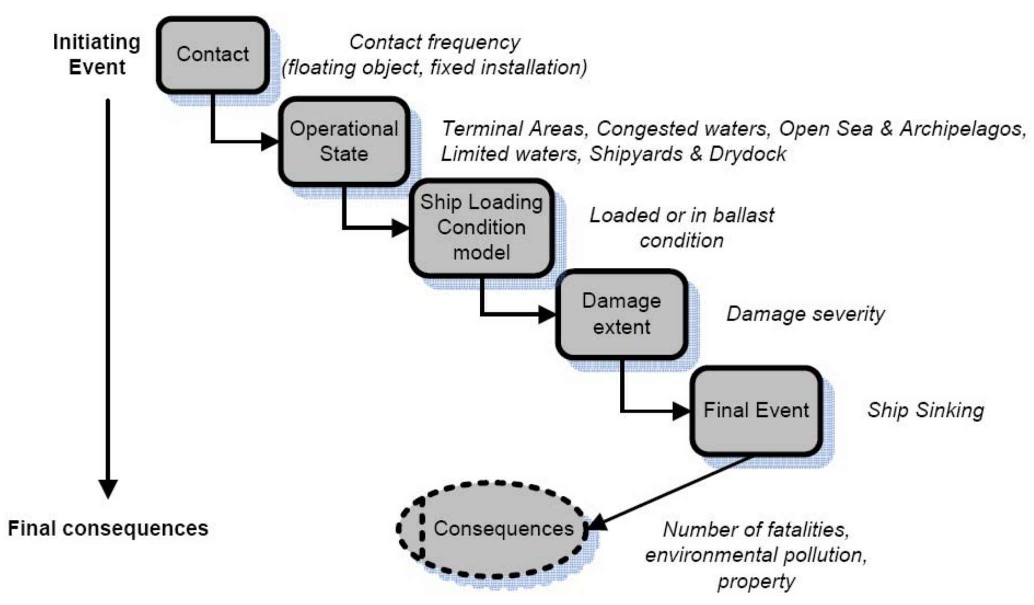


Figure 17: Event sequence in contact risk model of an Oil Tanker

7.2.2 Quantitative Input for Contact Risk Model

Frequency of contact scenarios
Estimated frequency of contact in terms of contacts per ship year: ***3.72E-03***

Probability of contact with a floating object: $P_{FLOAT|CONT}$ = ***0.32***
Probability of contact with fixed installation: $P_{FIXED|CONT}$ = ***0.68***

Operational state
Probabilities of different operational states are based on historical data.

Table 17

Operational state	Contact with a floating object Probability of Operation State		Contact with Fixed Installation Probability of Operation State	
Terminal areas	$P_{TERM|FLOAT|CONT}$	0.21	$P_{TERM|FIXED|CONT}$	0.56
Operation in congested waters	$P_{CONG|FLOAT|CONT}$	0.42	$P_{CONG|FIXED|CONT}$	0.02
En route at sea	$P_{OSEA|FLOAT|CONT}$	0.08	$P_{OSEA|FIXED|CONT}$	0.00
Operation in limited waters	$P_{LIMW|FLOAT|CONT}$	0.29	$P_{LIMW|FIXED|CONT}$	0.38
Shipyards & Drydocks	$P_{YARDS|FLOAT|CONT}$	0.00	$P_{YARDS|FIXED|CONT}$	0.04

Ship Loading Condition Model
The probability of a ship to be in a specific loading condition is used as constant value for the evaluation of contact events (independent the Operational state). Details on the assumed probability are given in the Appendix of this Annex.

Probability of ship in loading condition: ***0.60***
Probability of ship in ballast condition: ***0.40***

Hull breaching
The probability of hull breaching is deduced from historical data and is calculated on the basis of each given operational state in case of contact with a fixed installation or a floating object.

Table 18

Probability of hull breaching		
Operational state	**Contact with fixed installation**	**Contact with floating object**
Terminal areas	0.57	0.40
Operation in congested waters	1.00	0.30
En route at sea		0.00
Operation in limited waters	0.50	0.43

Damage penetration: Same as collision events.

Damage severity
The probability of ship's damage to be severe or non severe is calculated as a conditional probability of having or not LOWI occurrence in a given operational state in case of contact with a floating object or a fixed installation and is in accordance to accident's degree of severity according to LRFP/LMIU coding.

Final event
Ship survivability
With respect to ship's survivability, no ship sinking has happened in case of contact events according to the setup database and this was adopted in the particular risk analysis.

Consequences on crew life or/and to the local environment
In case of contact events, no injuries or fatalities were considered in the risk analysis process.
The environmental consequences of the risk modelling consider the release of oil cargo from the damaged tanker. For scenarios resulting to ship's severe damage, the expected oil outflow is described in Section 6, release of oil cargo of one tank. According to the setup database, for scenarios with non-severe ship's

damage the expected oil outflow was calculated as a % of DWT of the ships involved in the particular contact scenarios and is given next:

Table 19

For non-serious accidents *Average DWT = 160,761 (ref. ships, para 3.4)*	
Contact scenarios	**Expected oil outflow**
Fixed installation	*912.5 tonnes*
Floating object	*0.0 tonnes*

7.2.3 Event Tree Model

A high-level event tree model for collision accidents with large oil tankers has been elaborated on the basis of the qualitative and quantitative considerations presented in previous sections. The event tree structure has a total of 52 sequential scenario branches with non zero frequency.

- No scenario sequence branches are associated with single or multiple crew fatalities.
- 7 scenario sequence branches are associated with oil spill occurrence.

For crew member: $PLL_{Contact\text{-}Crew}$ = *0.00E+00 per ship year*
For environment: $PLC_{Contact\text{-}Envi}$ = *1.41E+00 tonnes per ship year*

Characteristic figures for environmental damage, expected quantity of released oil spillage are also derived and summarised in the event tree model.
The event tree is graphically presented in the Appendix of this Annex.

7.3 Risk Model – 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 tanker ship 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. The ship can either lodge on the ground or floats free. The accident evolution can lead to sinking, loss of structural integrity or the ship will remain afloat.

Grounding scenarios present 23% of all registered initial causes in the setup database involving tanker ships during the period 1990-2007. In total, 193 recorded accidents were registered as groundings, 83% were powered groundings and 17% were drift groundings.

Concerning the degree of event's severity as coded in LRFP database, in 78 cases the event characterised by serious degree of severity, in 111 cases there were not serious degree of severity and in 4 cases there was no relevant registration.

Concerning all grounding scenarios, in only 1 accident, there was 1 fatality (missing person). Furthermore, in 17 grounding accidents (9% of registered grounding events), oil spill occurred because of the accident, resulting to 245,942 tonnes of oil spilt within the studied period. In all cases, the accidents were characterised by serious degree of severity except for 1 case that there was no relevant registration.

7.3.1 Qualitative Risk Modelling

Grounding scenarios mainly happen in congested waters. The majority of the grounding scenarios take place while the tanker ship is en-route.

Drift grounding can happen due to loss of propulsion or steering system and drift to shallow water/shore. Powered grounding can happen due to squat effect, because ground is detected but not avoided or it is not detected.

The main causes for grounding related to:

- Ground topology and environmental conditions,
- Technical failures (steering or machinery failures)
- Human factors.

Figure 18 presents the event sequence in grounding risk model.

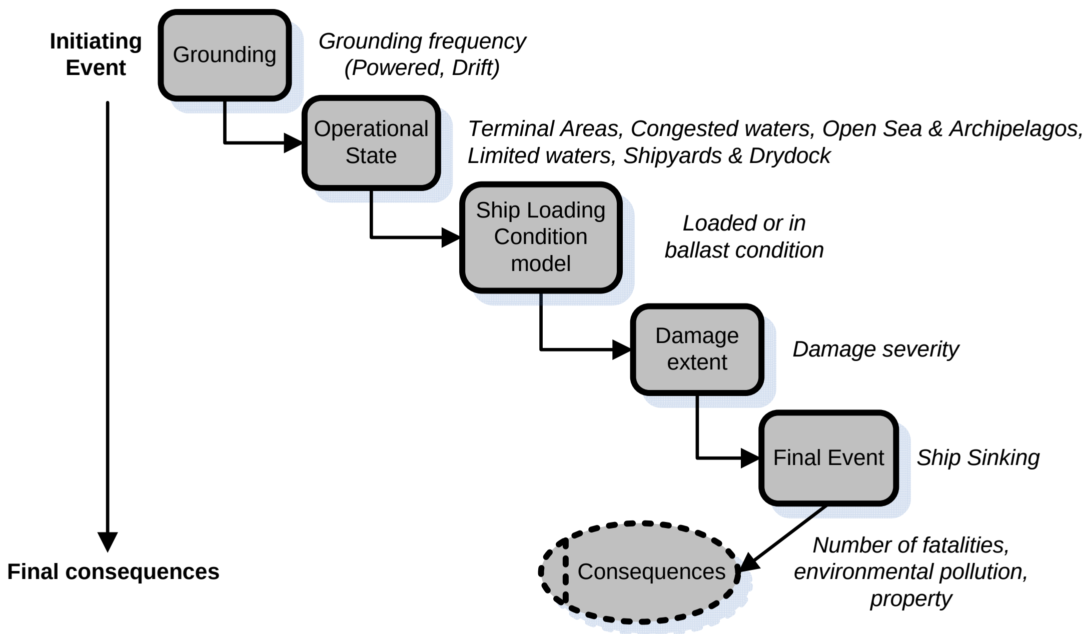


Figure 18: Event sequence in grounding risk model of an Oil Tanker

7.3.2 Quantitative Input for Grounding Risk Model

Frequency of grounding scenarios
Estimated frequency of grounding in terms of groundings per ship year: ***7.49E-03***

Probability of powered grounding: ***0.83***
Probability of drift grounding: ***0.17***

Operational state
Probabilities of different operational states are based on historical data.

Table 20

Operational state	Powered Grounding Probability of Operation State	Drift Grounding Probability of Operation State
Terminal areas	0.14	0.28
Operation in congested waters	0.42	0.28
En route at sea	0.09	0.03
Operation in limited waters	0.35	0.41
Shipyards & Drydocks	0.00	0.00

Ship Loading Condition at the time of accident

The probability of ship to be in a specific loading condition is used as constant value for the evaluation of contact events (independent the Operational state). Details on the assumed probability are given in the Appendix of this Annex.

Probability of ship in loading condition: ***0.80***

Probability of ship in ballast condition: ***0.20***

Hull breaching

The probability of hull breaching is received from historical data and is calculated on the basis of each given operational state in case of powered or drift grounding.

Table 21

Probability of Hull breaching		
	Powered Grounding	Drift Grounding
Terminal areas	0.32	0.25
Operation in congested waters	0.27	0.50
En route at sea	0.50	1.00
Operation in limited waters	0.15	0.33

Damage penetration

Concerning grounding damages, there are different approaches leading to slightly different results. In [29], the probability of damage that extend through the double bottom, assuming a double bottom height of 2.0m for passenger ships, was found to be: $P_{DAMAGE,\ DB} = 0.12$.

For grounding scenarios, the damage extent is highly related to the vertical extent of ship's damage. Thus, the probability of damage penetration is considered as the probability of penetrating the double bottom structure. For the purpose of this study, the particular probability is calculated according to [32]-Regulation 23: Accidental Oil outflow performance, taken into account only the vertical extent.

Table 22

Probability damage will lie entirely below the tank, [32]-Regulation 23				
Ref. Ships (para 3.4)	**Z_{DB} (m)**	**Ds (m)**	**z/Ds**	**$P(z < Z_{DB})$**
PANAMAX	2.04	19.80	0.1030	0.783
AFRAMAX	2.30	21.00	0.1095	0.784
SUEZMAX	2.80	23.10	0.1212	0.803
VLCC	3.00	31.25	0.0960	0.776
			Average P (z < Z)	*0.78*

The probability of penetrating the double bottom structure is calculated based on the average value:

$P(z > Z_{DB}) = 1 - P(z < Z_{DB}) = \mathbf{0.22}$

Damage severity
The probability of ship's damage to be severe or non severe is calculated as a conditional probability of having or not LOWI occurrence in a given operational state in case of powered or drift grounding and is in accordance to accident's degree of severity according to LRFP/LMIU coding.

Final event
Ship survivability
Two final outcomes were identified, each with completely different consequences with respect to rescue and evacuation conditions:
· Ship remains afloat and continues to sail by her own means or towed away. *No Sinking*
· Total loss of the ship. *Sinking*
Consequences on crew life or/and to the local environment
In case of powered grounding events, a slight probability of fatalities was estimated. The expected number of fatalities is calculated from the historical data and is summarised below:

Table 23

Grounding events - Consequences on human life	
Typical crew number = 30 persons	
Powered Grounding Scenarios	**Expected number of fatalities (% of crew number)**
In case of ship's total loss	3%

The environmental consequences of the risk modelling consider the release of oil cargo from the damaged tanker. For scenarios result to ship's severe damage, the expected oil outflow is described in Section 6, release of oil cargo of one tank. According to the setup database, for scenarios with non-severe ship's damage there is no expectation of oil outflow.

7.3.3 Event Tree Model

A high-level event tree model for grounding accidents with large oil tankers has been elaborated on the basis of the qualitative and quantitative considerations presented in previous sections. The event tree structure has a total of 86 sequential scenario branches with no zero frequency.

- 10 scenario sequence branches are associated with single or multiple crew fatalities.
- 15 scenario sequence branches are associated with oil spill occurrence.

For crew member: $PLL_{Grounding\text{-}Crew}$ = *1.32E-04 per ship year*
For environment: $PLC_{Grounding\text{-}Envi}$ = *2.48E+01 tonnes per ship year*

Characteristic figures for environmental damage, expected quantity of released oil spillage are also derived and summarised in the event tree model.
The event tree is graphically presented in the Appendix of this Annex.

7.4 Risk Model – Fire

Fire events consist of scenarios where the fire is the first initiative event. Thus, other events such as collision that subsequently lead to fire are not included herein. Fire can start due to internal source, external source (unlawful act, spread of fire from other ship) or due to atmospheric conditions (by lighting).

Fire scenarios present 11% of all registered initial causes in the set-up database involving tanker ships during the studied period 1990-2007. In total, 94 recorded accidents were registered as fire, 97% of them started due to internal source, 1% by external source (i.e. migration of fire from harbour installations and other vessels, for instance) and 2% by lightning.

Concerning the degree of event's severity as coded in LRFP/LMIU database, in 29 cases the event characterised by serious degree of severity, in 57 cases there were not serious degree of severity and in 8 cases there was no relevant registration.

In 17 accidents, there were 66 injuries (42 serious and 24 non-serious injuries) and 30 fatalities (7 missing persons and 23 deaths). From these 17 accidents, 8 accidents were occurred in Shipyards & Drydocks (para 9).

Furthermore, in one fire accident (1% of registered fire accidents), oil spill occurred because of the accident, resulting to 144,000 tonnes of oil spilt within the studied period. The registered degree of severity of this case was catastrophic (ship's total loss). In 4 cases out of the 94 recorded accidents (4%), fire was followed by explosion.

7.4.1 Fire/Explosion Casualty Recording

Fire, and Explosion incidents are typically registered as one common categorisation, thus it is not straight forward the comparison of statistical data among the different sources. For the purpose of this study, these two events are investigated separately because the consequences of each event have significant differences.

A statistical analysis was performed concerning fire/explosion accidents [33] and the main findings are briefly discussed herein.

Sample data contains tankers (oil, chemical, OBO and ore/oil carriers) classed with Lloyds' Register of 30,000 DWT and above. The studied casualties consist of 51 serious cases of fire/explosion events initiating within the cargo tank area including the pump room.

In 12 cases out of 51, fire/explosion resulted in breaching the hull envelop and in 6 cases out of these 12 incidents resulted to ship's total loss. Focusing on the 6 accidents resulted to ship's total loss, it was found that all involved tanker ships were large ships over the 180,000 DWT bracket, the smallest of them being 210,000 DWT. The study indicates that fire/explosion incidents in large tankers tend to be more severe than those in smaller tankers where the effects of an explosion are better contained by the tank structure. Furthermore, in 3 cases out of 6 ship's total losses, the involved vessel was tank cleaning.

The resulted incident rates indicate that a tanker of greater than 180,000 DWT will be an actual loss every 756 shipyears, with a 50% probability of this vessel being in the loaded condition.

7.4.2 Qualitative Risk Modelling

Fire due to internal source can be initiated in ship's aft area, on deck, in Cargo/Slop tanks area, in Ballast/Void spaces or in the Fore Peak area. Fire in the aft area can occur in the accommodation area (above main deck) because of electrical faults, heating equipment failure, smoking etc., or below the main deck in Engine Room or in the Pump Room.
The accident evolution depends on the early/late detection and the rate of fire spreading.

Fire because of an external source includes scenarios when the fire was spread to tanker ship by other ship. Also, fire can be started due to atmospheric conditions (by lighting). Figure 19 presents the event sequence in the fire risk model.

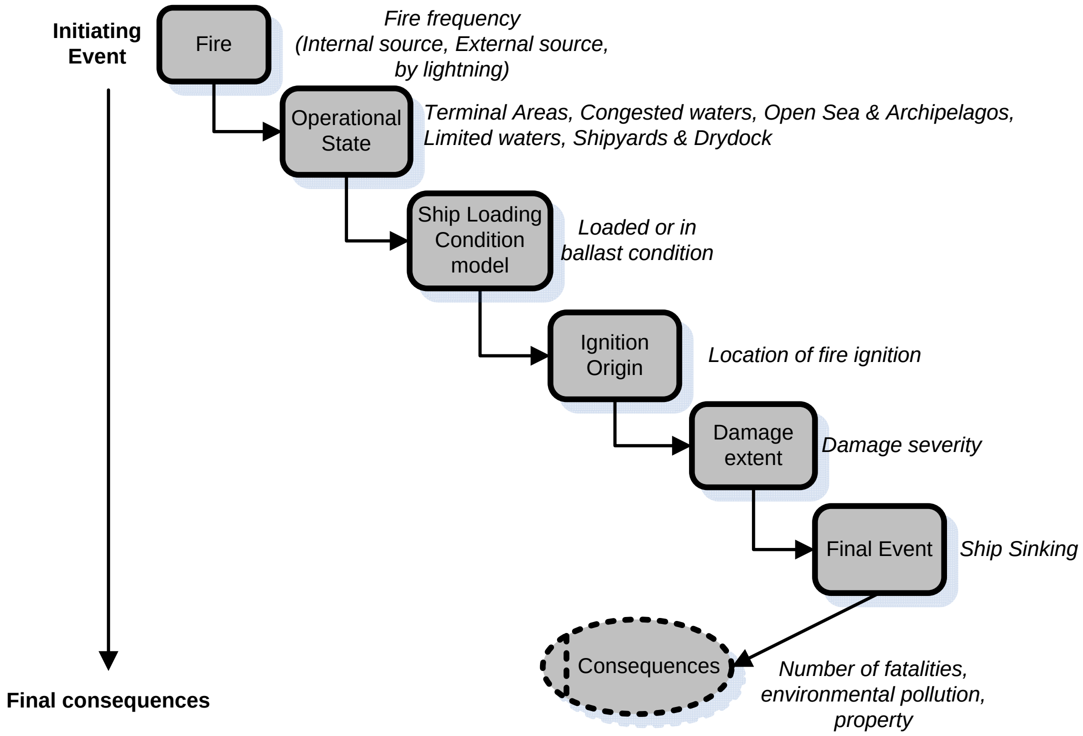


Figure 19: Event sequence in fire risk model of an Oil Tanker

7.4.3 Quantitative Input for Fire Risk Model

Frequency of fire events
Estimated frequency of fire in terms of fires per shipyear: ***3.65E-03***

With respect to the source of fire initiation, three sources are distinguished, probabilities of which are based on historical data.

- Fire due to internal source contains scenarios that fire started inside the vessel.
- Fire due to external source contains scenarios that fire spread to tanker ship from other vessels nearby her or from the shore.
- Fire by lighting

For the purpose of this study, the analysis will be focused on fire events due to internal source assuming that events of fire due to external source and by lighting will not contribute to fire risk.

Probability of internal source: ***0.97***
Probability of external source: ***0.01***
Probability of lighting: ***0.02***

Operational state
Probabilities of different operational states are based on historical data.

Table 24

Operational state	Fire due to internal source

	Probability of Operational State
Terminal areas	0.35
Operation in congested waters	0.17
En route at sea	0.25
Operation in limited waters	0.04
Shipyards & Drydocks	0.19

Ship Loading Condition at the time of accident
The probability of ship to be in a specific loading condition is used as constant value for the evaluation of contact events (independent the Operational state). Details on the assumed probability are given in the Appendix of this Annex.

Probability of ship in loading condition: ***0.50***
Probability of ship in ballast condition: ***0.50***

Fire ignition origin
Focusing on fire events due to internal source, the probability of starting the fire in a specific ship location is based on historical data and is calculated as the conditional probability of a given operational state in case of fire due to internal source.

Table 25

Fire Ignition origin due to ignition source			
	Terminal Areas	**Congested waters**	**Open Sea**
In Aft Area	0.84	0.91	0.94
In Cargo/Slop Tanks	0.08	0.09	0.00
In Ballast Tanks/Void Spaces	0.08	0.00	0.00
On deck	0.00	0.00	0.06
In Fore peak area	0.00	0.00	0.00

Damage severity
The probability of having an explosion as a second major event is considered significant and is taken into consideration in the event sequence. This probability is received from the historical data as a conditional probability of particular basic scenario.

The probability of ship's damage to be severe or non severe is calculated as a conditional probability and is in accordance to accident's degree of severity according to LRFP/LMIU coding.

Final event
Ship survivability
Two final outcomes were identified, each with completely different consequences with respect to rescue and evacuation conditions:
· Ship remains afloat and continues to sail by her own means or towed away. *No Sinking*
· Total loss of the ship. *Sinking*

Consequences on crew life or/and to the local environment
In case of fire events, a probability of fatalities was estimated. The expected number of fatalities is basically calculated from the historical data and is summarised below:

Table 26

Fire events - Consequences on human life	
Typical crew number = 30 persons	
Fire Scenarios (fire initiated in Aft Area, Cargo/ Slop tanks, Ballast/Void spaces) in Terminal Areas, Congested waters and Open Sea	**Expected number of fatalities (% of crew number)**
Cases where Fire followed by Explosion (cases of severe damage)	7%

Congested and Terminal areas (not followed by Explosion, cases of severe damage)	3%
Open Sea (not followed by Explosion, cases of severe damage)	7%
Cases of non-severe damage	2%

The environmental consequences of the risk modelling consider release of oil cargo from the damaged tanker. The expected oil outflow is described in Section 6, release of oil cargo of one tank.

Property risk is evaluated only in scenarios with expected number of fatalities. This calculation is based on typical average values of Table 9. For severe damages, it is assumed that *the ship damage cost is 10% of ship value*. For not severe damages, it is assumed that *the ship damage cost is 2.5% of ship value* [26].

7.4.4 Event Tree Model

A high-level event tree model for fire accidents with large oil tankers has been elaborated on the basis of the qualitative and quantitative considerations presented in previous sections. The event tree structure has a total of 36 sequential scenario branches resulted to non-zero frequency.

- 32 scenario sequence branches are associated with single or multiple crew fatalities.
- 10 scenario sequence branches are associated with oil spill occurrence.

For crew member: $PLL_{Fire\text{-}Crew}$ = *2.34E-03 per ship year*
For environment: $PLC_{Fire\text{-}Envi}$ = *2.35E+01 tonnes per ship year*

Characteristic figures for environmental damage, expected quantity of released oil spillage are also derived and summarised in the event tree model.
The event tree is graphically presented in the Appendix of this Annex.

7.5 Risk Model – Explosion

Explosion events consist of scenarios where the explosion is the first initiative event. Thus, other events such as collision or fire that subsequently lead to explosion are not included herein. Explosion scenarios present 6% of all registered initial causes in the setup database involving tanker ships during the studied period 1990-2007. In total, 49 recorded accidents were registered as explosions.

Concerning the degree of event's severity as coded in LRFP/LMIU database, in 30 cases the event characterised by serious degree of severity, in 14 cases there were not serious degree of severity and in 5 cases there was no relevant registration.

In 25 accidents, there were 16 injuries (11 serious and 5 non-serious injuries) and 92 fatalities (7 missing persons and 85 deaths). From these 25 accidents, 7 of them where occurred in Shipyards and Drydock (para. 8)

Furthermore, in 3 explosion accidents (6% of registered explosion accidents), oil spill occurred because of the accident, resulting to 278,770 tonnes of oil spilt within the studied period. All these three accidents had serious degree of severity (in 2 cases there was ship's total loss).
In 21 cases out of the 49 recorded accidents (43%), explosion was followed by fire.

7.5.1 Qualitative Risk Modelling

Explosion can be initiated in ship's aft area, on deck, in Cargo/Slop tanks area, or in Ballast/Void spaces.
The explosion in aft area can be due to an explosion of the fuel tank, the boiler, an explosion in the accommodation or in the pump room.

The explosion in Cargo/Slop tanks area can occur because of the combination of the presence of an explosive atmosphere and the presence of an ignition source. The presence of an explosive atmosphere can be due for instance to human error or air inlet in the cargo tank and to the presence of an ignition source.

In Ballast/Void spaces, the explosion can occur due to the combination of the presence of an explosive atmosphere and the presence of an ignition source. The presence of an explosive atmosphere can be due for instance to a gas leak in the double hull, and to the presence of an ignition source. Figure 20 presents the event sequence in explosion risk model.

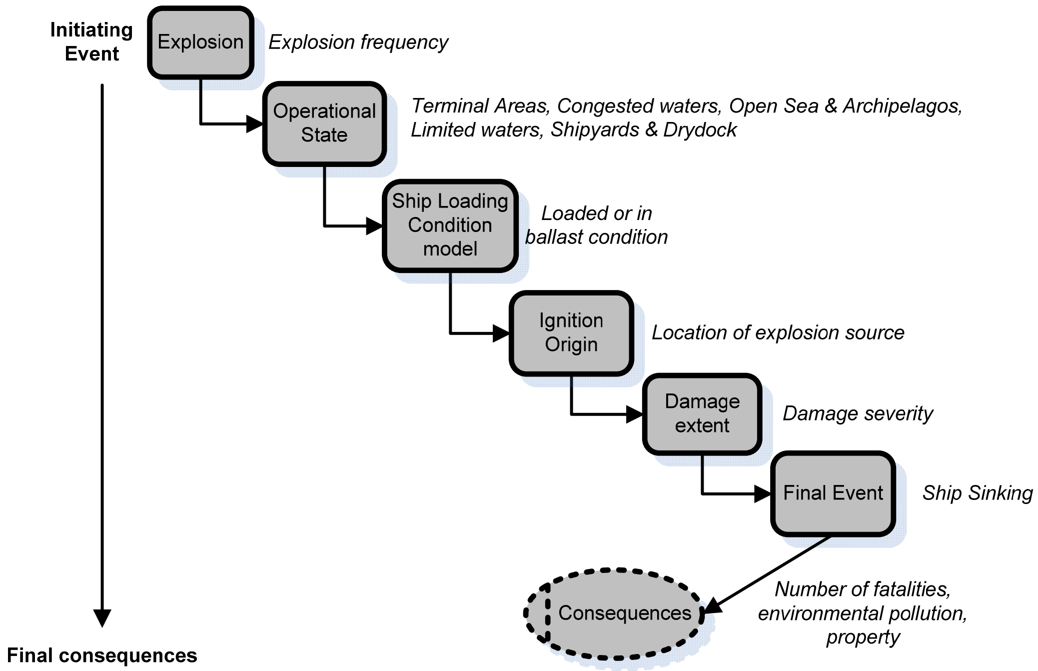


Figure 20: Event sequence in explosion risk model of an Oil Tanker

7.5.2 Quantitative Input for Explosion Risk Model

Frequency of explosion event:
Estimated frequency of explosion in terms of explosions per shipyear: ***1.90E-03***

Operational state
Probabilities of different operational states are based on historical data.

Table 27

Operational state	Explosion, Probability of Operational state
Terminal areas	0.34
Operation in congested waters	0.09
En route at sea	0.33
Operation in limited waters	0.02
Shipyards & Drydocks	0.22

Ignition Location

The probability of explosion initiation at a specific ship location is based on historical data.

Table 28

Ship Location	Terminal Areas	Open Sea	Congested waters
In Aft Area	0.36	0.59	0.25
In Cargo/Slop Tanks	0.64	0.33	0.50
In Ballast Tanks/Void Spaces	0.00	0.00	0.00
On deck	0.00	0.08	0.25

Ship Loading Condition at the time of accident

The probability of ship to be in a specific loading condition is used as constant value for the evaluation of contact events (independent the Operational state). Details on the assumed probability are given in the Appendix of this Annex.

Probability of ship in loading condition: ***0.20***
Probability of ship in ballast condition: ***0.80***

Damage severity

The probability of having a fire as a second major event is considered significant and is taken into consideration in the event sequence. This probability is received from the historical data as a conditional probability of particular basic scenario.

The probability of ship's damage to be severe or non severe is calculated as a conditional probability and is in accordance to accident's degree of severity according to LRFP/LMIU coding.

Final event

<u>Ship survivability</u>

Two final outcomes were identified, each with completely different consequences with respect to rescue and evacuation conditions:

· Ship remains afloat and continues to sail by her own means or towed away. *No Sinking*
· Total loss of the ship. *Sinking*

<u>Consequences on crew life or/and to the local environment</u>

In case of explosion events, a probability of fatalities was estimated. The expected number of fatalities is calculated from the historical data and is summarised below:

Table 29

Explosion events - Consequences on human life	
Typical crew number = 30 persons	
Explosion Scenarios	**Expected number of fatalities (% of crew number)**
Terminal Areas	
Fire after explosion, ship's severe damage	12%
No fire after explosion, ship's severe damage	10%
No fire after explosion, ship 's not-severe damage	7%
Open Sea	
Fire after explosion, ship's total loss	42%
Fire after explosion, ship's severe damage	12%
No fire after explosion, ship's severe damage	7%
No fire after explosion, ship 's not-severe damage	3%

Congested waters	
Ship's severe damage & cases of total loss	7%

The environmental consequences of the risk modelling consider release of oil cargo from the damaged tanker. The expected oil outflow is described in Section 6, release of oil cargo of one tank.

Property risk is evaluated only in scenarios with expected number of fatalities. This calculation is based on typical average values of Table 9. For severe damages, it is assumed that *the ship damage cost is 10% of ship value*. For not severe damages, it is assumed that *the ship damage cost is 2.5% of ship value* [26].

7.5.3 Event Tree Model

A high-level event tree model for explosion accidents with large oil tankers has been elaborated on the basis of the qualitative and quantitative considerations presented in previous sections. The event tree structure has a total of 42 sequential scenario branches resulted to no zero frequency.

- 38 scenario sequence branches are associated with single or multiple crew fatalities.
- 17 scenario sequence branches are associated with oil spill occurrence.

For crew member: $PLL_{Explosion\text{-}Crew}$ = *5.07E-03 per ship year*
For environment: $PLC_{Explosion\text{-}Envi}$ = *1.23E+01 tonnes per ship year*

Characteristic figures for environmental damage, expected quantity of released oil spillage are also derived and summarised in the event tree model.
The event tree is graphically presented in the Appendix of this Annex.

7.6 Risk Model – NASF

Non-accidental structural failure events consist of scenarios where the hull presents cracks and fractures, affecting ship's seaworthiness. Damage to a vessel rudder, or rudder-adjoining parts are considered as structural damage. Damages to ship's hull-fitting equipments, like vessel propeller, propeller portion or propeller adjoining parts are not included in the particular categorisation.

Historical data based on all ships regardless the hull type
Non-accidental structural failure scenarios present 18% of all registered initial causes of incidents involving tanker ships during the studied period 1990-2007. In total, 148 recorded incidents were registered as non-accidental structural failures.

Concerning the degree of event's severity as coded in LRFP/LMIU database, in 51 cases the event is characterised by serious degree of severity, in 92 cases there was non serious degree of severity and in 5 cases there was no such registration.

According to the registered data, the weather condition was an important factor in 52 cases out of 148.
In 1 accident, there were 2 fatalities.

Furthermore, in 38 non-accidental structural failures (26% of registered non-accidental structural failures), oil spill occurred because of the accident, resulting to 170,538 tonnes of oil spilt within the studied period.

Historical data based on DH ships
Focusing on DH ships, 20 non-accidental structural failures were registered in the period 1990-2007.

Concerning the degree of event's severity as coded in LRFP/LMIU database, in 11 cases the event is characterised by serious degree of severity and in 9 cases there were non serious degree of severity.

According to the data, the weather condition was an important factor in 6 cases out of 20.
No injuries or fatalities were registered in these incidents.
Practically, no oil spill occurred due to these incidents as evident from the investigated records (in 1 case there was a slight release of oil, typically 1 tonne).

Weather related incidents
Based on all ships regardless the hull type, many incidents happened in heavy weather conditions (about 35%, 52 cases out of 148 incidents). This does not mean that the weather condition is the only cause of non-accidental structural failures. Tanker hulls are typically designed to handle a wide range of weather conditions. In case of poor hull structural design or maintenance (corrosion), however, the structure becomes weak to handle such weather conditions and this could result to non-accidental structural failures.

Focusing on the DH ships, the relationship of the particular accident category to weather conditions was found to be almost the same as with the SH ships (about 30%, 6 cases out of 20 incidents). Considering, however, that the DH tanker fleet is relatively young up to date, this implies more structural design and proper construction problems, rather than maintenance. *In particular, according to the setup database, considering all weather related NASF accidents of DH ships, the majority of them fell in the group age of less than 5 years.* Next Table presents the age distribution of Double Hull ships involved in the NASF incidents during the studied period 1990-2007.

Table 30

DH ships, NASF, Period 1990-2007	
Group age	**Number of ships**
up to 5 years	15
6-10 years	1
11-15 years	2
>16 years	2
	20

7.6.1 Qualitative Risk Modelling

Non-accidental structural failures that may potentially lead to the Loss Of Watertight Integrity (LOWI), can occur because of structural degradation, overstressing due to excessive loading and structure overstressing due to poor design or construction.

Such accidents mainly happen while the tanker ship in en-route in Open Sea/Archipelagos, or during loading or discharging operations.

In general, the nature of non-accidental structural damages can be categorised into four main categories, namely internal structural damage, hull damage, rudder damage and deck plating damage.
Figure 21 presents the event sequence in NASF risk model.

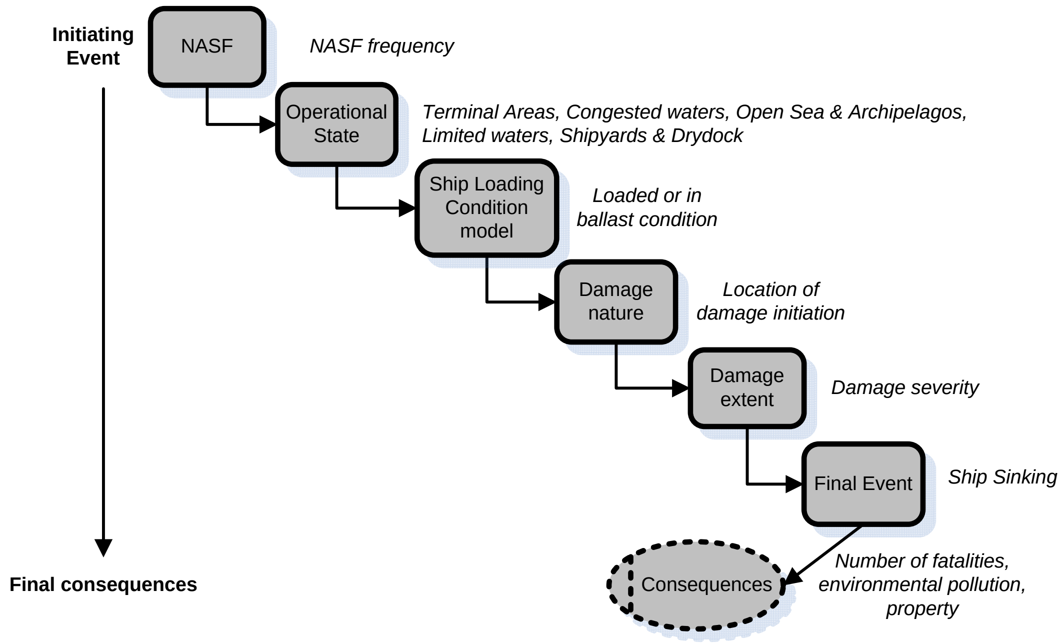


Figure 21: Event sequence in NASF risk model of an Oil Tanker

7.6.2 Quantitative Input for NASF Risk Model

For the purpose of this study, the particular risk analysis of NASF will be focused on Double-Hull ships also in terms of frequency estimation.

Frequency of Non-accidental structural failure event:
Estimated frequency of Non-accidental structural failure in terms of NASFs per shipyear: ***1.93E-03.***

Weather related scenarios
The probability of weather condition relation to NASF is given next and it is based on historical data.

Table 31

	Probability of weather related incidents
yes	0.30
no	0.70

Operational state
Probabilities of different operational states are based on historical data.

Table 32

Operational state	Probability of operational state, in weather related events	Probability of operational state, in non-weather related events
Terminal areas	0.00	0.29
Operation in congested waters	0.33	0.14
En route at sea	0.67	0.50
Operation in limited waters	0.00	0.07
Shipyards & Drydocks	0.00	0.00

Ship Loading Condition at the time of accident
The probability of ship to be in a specific loading condition is used as constant value for the evaluation of contact events (independent the Operational state). Details on the assumed probability are given in the Appendix of this Annex.

Probability of ship in loading condition: ***0.70***
Probability of ship in ballast condition: ***0.30***

Damage nature
Probabilities of damage nature are based on historical data.

Table 33

Damage Nature	Weather related		No weather related			
	Open Sea	Congested	Terminal	Congested	Open Sea	Limited
Hull damage	0.25	0.00	0.00	0.00	0.14	0.00
Internal damage	0.00	0.00	0.75	1.00	0.43	0.00
Rudder damage	0.25	0.00	0.00	0.00	0.29	1.00
Deck damage	0.25	0.50	0.25	0.00	0.14	0.00
Other	0.25	0.50	0.00	0.00	0.00	0.00

Damage severity
The probability of ship's damage to be severe or non severe is calculated as a conditional probability and is in accordance to accident's degree of severity according to LRFP/LMIU coding.

Final event
Ship survivability
No ship total loss is considered based on historical data.
Consequences on crew life or/and to the local environment
In case of NASF events, a probability of fatalities was estimated. The expected number of fatalities is calculated from the historical data containing all ships (not only DH ships) and is summarised below:

Table 34

NASF events - Consequences on human life	
Typical crew number = 30 persons	
NASF Scenarios	**Expected number of fatalities (% of crew number)**
In case of deck damage in Open Sea, given a weather related scenario	7%

The environmental consequences of the risk modelling consider release of oil cargo from the damaged tanker, concept of one tank Section 6, in cases of severe hull damage.

Property risk is evaluated only in scenarios with expected number of fatalities. This calculation is based on typical average values of Table 9. For not severe damages, it is assumed that *the ship damage cost is 1% of ship value*.

7.6.3 Event Tree Model

A high-level event tree model for NASF events with large oil tankers has been elaborated on the basis of the qualitative and quantitative considerations presented in previous sections. The event tree structure has a total of 32 sequential scenario branches.

- 2 scenario sequence branches are associated with single or multiple crew fatalities.
- 2 scenario sequence branches are associated with oil spill occurrence.

For crew member; $PLL_{NASF\text{-}Crew}$ = 1.94E-04 per ship year
For environment: $PLC_{NASF\text{-}Envi}$ = *1.44E+00 tonnes per ship year*

Characteristic figures for environmental damage, expected quantity of released oil spillage are also derived and summarised in the event tree model.
The event tree is graphically presented in the Appendix of this Annex.

7.7 Risk Consideration with Respect to Ship To Ship Transfer (STS)

A Ship-to-ship (STS) Transfer operation is a state where cargo, usually crude oil, liquefied gas (LPG, LNG), bulk, or petroleum products are transferred between seagoing ships moored alongside each other. This may take place when the ships are stationary or underway.

The collision risk between the two vessels is low due to the fact that the mother vessel will be stationary and the daughter vessel will be approaching at a very low speed assisted by local tugs and pilot. In the unlikely event of a collision, structural damage to both vessels may occur.

A range of potential oil spill causes exists from STS operations that may result in a release of hydrocarbon into the marine environment. These are mainly due to oil handling and tanker loading operations.

Although there are no IMO regulations on STS operation, in general all transfer operations are in compliance with the current OCIMF (Oil Companies International Marine Forum) STS Transfer Guide and the approved company STS procedures.

7.7.1 Relevant Studies on Ship-To-Ship Transfer Operation

In [34], the requirement to have an Oil Spill Contingency Plan for Harbours, Ports and Oil Handling Terminals around UK waters has been formalised by the Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998, which implement the International Convention on Oil Pollution Preparedness, Response and Co-operation, 1990 (OPRC, 1990). The Convention, adopted by the International Maritime Organisation (IMO) is aimed to "mitigate the consequences of major oil pollution incidents involving, in particular, ships, offshore units, sea ports and oil handling facilities".

The purpose of this plan is to guide response personnel through the processes required to manage an oil spill originating from ship to ship transfer operations at two locations, in the Firth of Forth in accordance with UK legislation.

The plan takes account of the spill risks associated with the ship to ship transfer operations, the nature of the hydrocarbons that could be spilt; the prevailing meteorological and hydrographical conditions and the environmental sensitivity of the surrounding area in order to ensure that resources available during Ship to Ship (STS) transfers are sufficient and the mechanism for calling upon assistance in the event of a major incident is clearly defined.

7.7.2 Historical Data

According to the set-up database, 13 accidents are registered as accidents during ship to ship transfer operation. Note that due to limited number of recorded accidents an extended period (1980-2007) was firstly selected despite that fact that the whole analysis is based on the period 1990-2007.

Covered period 1980-2007
13 accidents were occurred during ship-to-ship transfer operation in the covered period 1980-2007.

- Collision events
  10 out of 13 accidents were registered as collision accidents. Pollution was occurred in one case resulting an oil spill of 121 tonnes. Only one accident was characterised as accident with serious degree of severity. No injuries or fatalities were registered.
- Explosion events
  The rest 3 accidents out of 13 were registered as explosion accidents. In one case the accident characterised as serious degree of severity and in the other 2 cases there were ship's total loss. Furthermore, in 1 case the explosion caused an oil spill of the amount quantity of 17,000 tonnes. In that case, 4 fatalities (2 deaths and 2 missing) were registered.

Covered period 1990-2007
9 accidents were occurred during ship-to-ship transfer operation in the covered period 1990-2007.

- Collision events: 6 out of 9 accidents were registered as collision accidents.
- Explosion events: The rest 3 accidents out of 13 were registered as pollution accidents.

7.7.3 Discussion

The original setup database was upgraded to capture the case of ship-to-ship transfer operation. In the initial data (*LMIU* and *LRFP* recording) there is no specific information about this specific tanker operation. Studying the database records, the above pre-described cases were identified.
Ship-to-ship transfer operation is nowadays considered significant for the oil tankers risk assessment and further study is required in order to model and quantify this risk properly. However, the limited number of recorded data makes such a study on ship-to-ship transfer operation by the presently available data very difficult.

8 Casualties in Shipyards & Drydocks

In the studied period 1990-2007, the followings are observed with respect to the casualties took place in Shipyards and Drydocks. No oil spill occurrence is expected because the ship in the particular event location is not loaded.

- Three contact events

In one case, the ship was in drydock when the drydock gate was struck by a tsunami (bad weather conditions). In the other two cases, the ship was under manoeuvring to enter the drydock with pilot onboard. No injuries or fatalities were registered.

- One grounding event

Ship was under repair, when due to bad weather conditions, the moorings broke and ship drifted and stranded. No injuries or fatalities were registered.

- Eighteen (18) fire events

In 8 cases out of 18 fire events, there is a significant number of injuries and fatalities as indicated to the next table. In the 4 cases out of these 8, there is a clear statement that fire started due to "hot works".

Table 35

Fire events in Shipyards & Drydocks			
ID1	**Serious Injuries**	**Non Serious Injuries**	**Fatalities**
Case 1	14	0	0
Case 2	4	9	0
Case 3	3	6	1
Case 4	0	0	7
Case 5	0	1	3
Case 6	0	0	7
Case 7	0	0	1

Case 8	0	7	0
	21	**23**	**19**

- Ten (10) explosion events

In 7 cases out of 10 explosion events, there are a significant number of injuries and fatalities as indicated to the next table.

Table 36

Explosion events in Shipyards & Drydocks			
	Serious Injuries	**Non Serious Injuries**	**Fatalities**
Case 1	0	0	10
Case 2	1	0	1
Case 3	0	0	2
Case 4	0	0	4
Case 5	8	0	0
Case 6	0	0	6
Case 7	0	0	4
	9	**0**	**27**

9 Risk Summation

Based on the risk modelling outlined in the previous sections, the contributions from the various scenarios to the total **P**otential **L**oss of **L**ives (PLL) and **L**oss of **C**argo (PLC) from Oil tanker shipping operations can be extracted and presented in Table 37.

Table 37: Potential Loss of Life & Oil Cargo			
Event	**Frequency per shipyear**	**PLL persons per shipyear**	**PLC tonnes per shipyear**
Collision-Struck ship	8.24E-03	4.91E-03	1.30E+01
Collision-Striking ship	2.06E-03		
Contact with fixed installation	2.43E-03		1.09E+00
Contact with floating object	1.19E-03		3.17E-01
Powered Grounding	6.22E-03	1.32E-04	1.86E+01
Drift Grounding	1.27E-03		6.16E+00
Fire Due to internal source	2.86E-03	2.34E-03	2.35E+01
Fire Due to external source	3.65E-05		
Fire By lightning	7.29E-05		
Fire Internal source - Shipyards	6.43E-04		
Explosion-Operational phase	1.48E-03	5.07E-03	1.23E+01
Explosion-Shipyards	4.18E-04		
NASF	1.93E-03	1.94E-04	1.44E+00
TOTALS		***1.26E-02***	***7.63E+01***

Relatively high PLL values are coming from explosion and collision events, Figure 22.

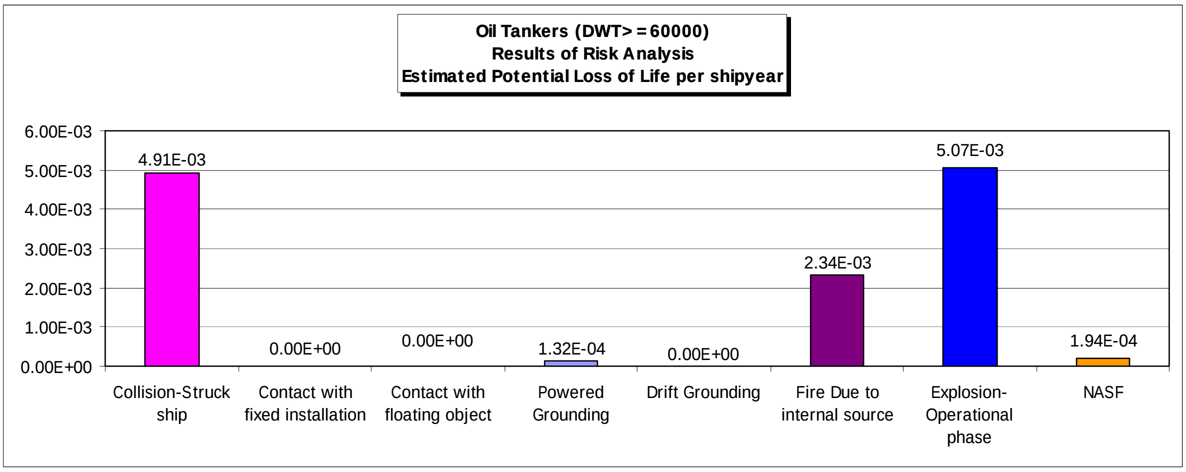


Figure 22: Estimated Potential Loss of Life per shipyears

Relatively high PLC values are coming from fire, powered grounding, collision and explosion events, in that order, Figure 23.

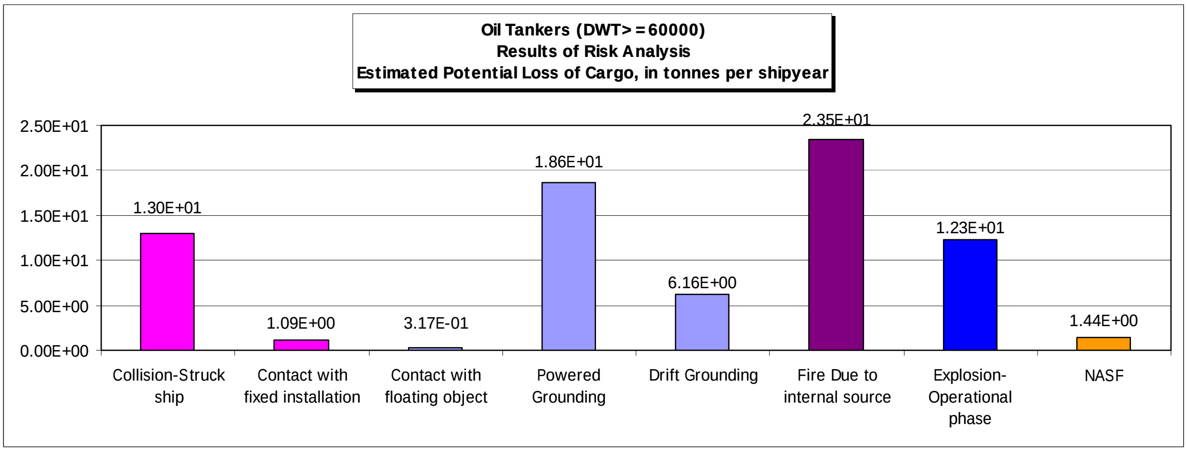


Figure 23: Estimated Potential Loss of Cargo per shipyears

The results from this particular study can also be used to estimate the individual risk for crew and to develop FN-curves reflecting the societal risk picture.

9.1 Individual Risk for Crew

Intentionally, individual risks of 3rd parties or passengers were not an issue in the context of this study, and only the individual risk for the tanker crew will be considered. It is assumed that all members of the crew are equally exposed to the risk.
Assuming a crew of 30 on a typical crude oil tanker, a fatality rate of 1.26E-02 per shipyear corresponds to an individual risk of 4.21E-04 per year. However, more than one complete crew is needed for continuous operation of a tanker. With a 50-50 rotation scheme, two complete crews are needed, and in the case of a one-on/two-off scheme, there will be three crews. This would correspond to an individual risk for crew of 2.1E-04 per year and 1.4E-04 per year respectively. A 50-50 rotation scheme is assumed to be most widespread and hence, the individual risk for tanker crew members is taken to be 2.1E-04 per year.

Table 38: Individual risk acceptance criteria for crew	
Boundary between negligible risk and the ALARP area	10^{-6} per year
Maximum tolerable risk for crew members (risks below this limit should be made ALARP)	10^{-3} per year

9.2 F-N Curve for Crew

According to MSC72/16 and [35], the societal risk acceptance criteria for tanker ships based on economic importance are given in Table 39.
Based on historical data, for the period 1990-2007, the F-N curve is produced for the overall risk to crew, Figure 24. Compared to the above established criteria, it is clearly indicated that also the presently *calculated societal risk lies within the defined ALARP region.*

Table 39: Societal risk acceptance criteria for tanker ships based on economic importance	
Boundary between negligible and tolerable risk	$(10, 2x10^{-5})$
Boundary between tolerable and intolerable risk	$(10, 2x10^{-3})$

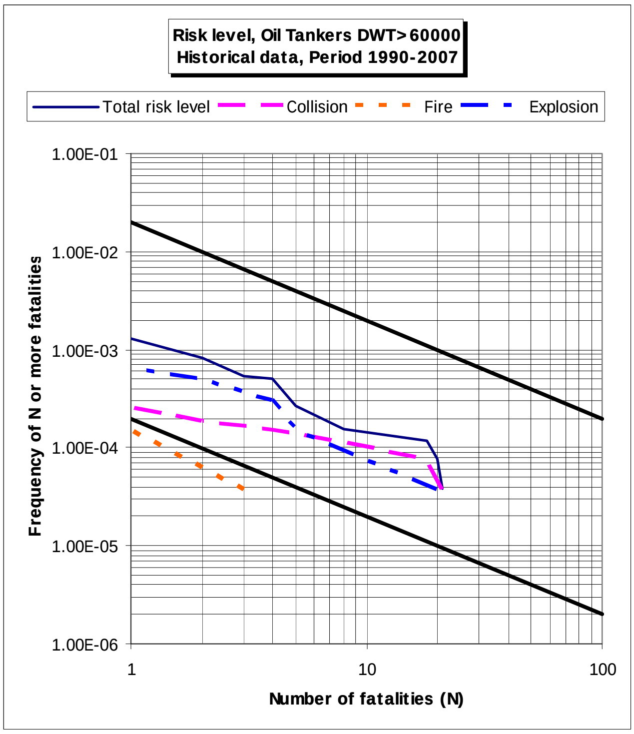


Figure 24: F-N curve for total risk to crew of Oil Tankers

9.3 Potential Loss of Oil Cargo

9.3.1 Tanker Size

This high level risk analysis gives an overview of risk issues of large size oil tankers (over 60,000 tonnes DWT). Due to time limitations, the present study focused on an average size of these large tanker ship categories.

In the risk assessment of oil tankers, the Potential Loss of oil cargo is an essential parameter of risk evaluation. This parameter as well as the ship's damage cost varies significantly among the reference tanker ships. For example,

- Breaching one tank of a SUEZMAX is more or less equal to two PANAMAX size tanks.
- The total loss of a fully loaded PANAMAX ship in terms of environmental impact potentially corresponds to about 70,000 tonnes of oil, whereas the average used value in this high level risk analysis is about 150,000 tonnes (Table 8).
- In terms of ship's damage cost evaluation, the cost of ship's damage is calculated as a percentage of ship's value that considerably varies among the different tanker sizes, Table 9.

For this purpose, it is considered valuable to do a more realistic approach in terms of the consequences assessment.
Keeping the same frequencies, the consequence model was changed in terms of environmental and economic impact for each reference vessel, by using the corresponding values of Tables 7-9. This resulted to the production of four event trees (per tanker size) for each studied event.
Based on this procedure, Potential Loss of Cargo was estimated for each reference category vessel and is presented in Table 40 and Figure 25 (bars) along with PLC derived from the unified calculations for all tankers of DWT≥ 60,000 tonnes (line).

Table 40: Estimated Potential Loss of Cargo, tonnes per shipyear

	PANAMAX	AFRAMAX	SUEZMAX	VLCC
Collision-Struck ship	5.85E+00	9.07E+00	1.27E+01	2.44E+01
Contact with fixed installation	5.34E-01	8.22E-01	1.15E+00	1.86E+00
Contact with floating object	1.56E-01	2.40E-01	3.36E-01	5.35E-01
Powered Grounding	8.34E+00	1.29E+01	1.81E+01	3.51E+01
Drift Grounding	2.76E+00	4.28E+00	5.97E+00	1.16E+01
Fire Due to internal source	1.06E+01	1.64E+01	2.29E+01	4.41E+01
Explosion-Operational phase	5.49E+00	8.52E+00	1.19E+01	2.32E+01
NASF	7.08E-01	1.09E+00	1.52E+00	2.42E+00

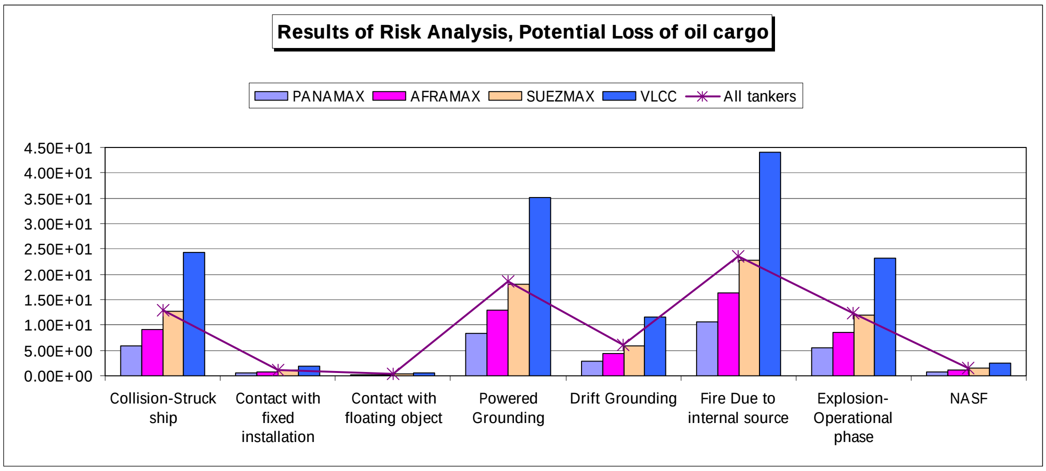


Figure 25: Estimated Potential Loss of Cargo, per tanker size

9.3.2 Double Hull Ships

A separate statistical analysis was performed [36] in order to evaluate the oil cargo release to the sea in case of a tanker accident. Frequency-Tonnes (F-T) curves were produced for Double Hull and Non-Double Hull ships for the period 1997 to 2007 (Figure 26) for visualisation of the societal environmental risk. The comparison shows a significant lower societal risk for Double Hull tankers. However, the Double Hull fleet is relatively young and thus conclusions based only on historical accidental data shall be treated at this stage very carefully.

Unlike the F-N diagrams used in the risk evaluation of a FSA, no ALARP area is expressed in Figure 26. Several proposals for a definition of ALARP boundaries exist [40], [41], however at IMO such boundaries are not agreed or even discussed yet. Thus, the authors decided not to consider the ALARP limits in the F-T-diagram.

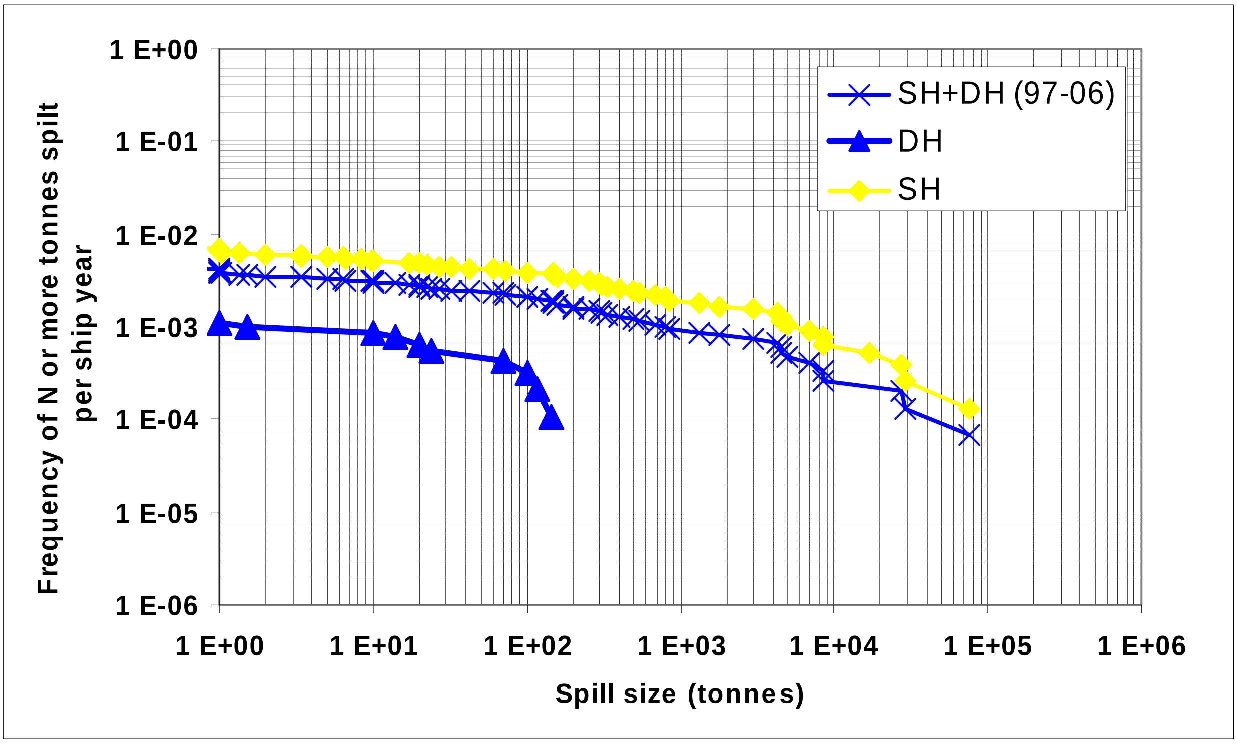


Figure 26: Estimated Potential Loss of Cargo, per tanker size [36]

10 Conclusions and Recommendations

This report has presented the risk analysis and assessment of large oil tankers that forms the second step of a high level, generic FSA on the current fleet of oil tankers with DWT ≥ 60,000 tonnes. The conclusions and recommendations from this study are below highlighted. Some areas of improvements are suggested where further studies can be focused in order to bridge the gaps in available statistics and fundamental knowledge about hazards and risks related to large Oil tankers shipping. Finally, high risk areas are identified, where it is recommended that future efforts in risk reduction should be focused.

10.1 Identified High Risk Areas

In terms of potential loss of crew life, three areas or generic accident scenarios were identified, Figure 22:

- Collision scenarios of the struck ship
- Fire scenarios due to internal source initiation
- Explosion scenarios.

In terms of potential loss of oil cargo, four areas or generic accident scenarios were identified, Figure 23:

- Collision scenarios of the struck ship

- Powered grounding
- Fire scenarios due to internal source initiation
- Explosion scenarios.

By studying the risk models associated with these scenarios, the following general issues are discussed in order to give feedback to step 3 (Risk Control Options and Cost Benefit Analysis) of this FSA study.

10.2 General Issues of Risk Control Options

In this paragraph, some general issues are discussed in terms of the prevention undesirable events and the mitigation of the consequences.

- In case of collision and contact events, if the inner hull of the struck ship breaches, it will result to the release of at least one cargo tank's oil, when the struck ship is loaded. Due to the fact that large tankers carry a considerable amount of oil in each tank, an effective measure to mitigate the consequences could be a more enhanced subdivision in terms of number of tanks (or limitation of maximum tank size in terms of volume). This measure will result to an increase of ship's lightweight.
- One of the most important causes of accidents is related to the Rules of the Roads. Except for the cases for which such events are related to ship's manoeuvrability, in the majority these events are based on communication problems among the ships. In order to prevent such events, communication activities and responsibilities shall be enforced. It must be noted, that the continuously spread of English language along with some regulations such as GMDSS (Global Maritime Distress and Safety System), SOLAS 81 (ARPA requirements) SOLAS 95 (Routeing systems) have significantly reduced the navigational incidents [9].
- Events related to navigational/guidance (pilot) errors have been reduced by the use of GPS/ECDIS (Global Positioning System/Electronic Chart Display and Information Systems). Twin screw and more power redundancy would help significantly by drastically improving low speed manoeuvrability and the pilot's ability to correct a mistake.
- From the held brainstorming session of the project experts for Risk Control Options (meeting of March 2008, Athens) it was suggested to extend inerting to double hull ballast tanks. Inerting double hull ballast tanks is neither difficult nor expensive [7]. Furthermore,
    - In case of cargo leakage into a ballast tank, there will be a considerable lower probability of a fire and explosion initiation.
    - Even if in the VLCC ships, the ballast area must be coated, it is inevitable to avoid breaking the coating locally.

Note that according to [7], the double sides result to a very large amount of coated ballast tank area which must be maintained, about twice as much as a MARPOL tanker and roughly six times that of a Pre-MARPOL one.

10.3 Recommendations - The Way Ahead

- This high level risk analysis gives an overview of risk issues pertaining large oil tankers. Due to time limitations, the study focused on an average size of these large tanker ships. The consequence model, however, was evaluated in terms of each reference tanker size due to the necessity of a more realistic overall risk assessment approach. Frequency models need, however, to be rechecked in order to identify possible significant deviations for each reference vessel, if any.
- The present state of risk levels of large oil tankers of double hull construction with respect to the potential loss of crew and oil cargo (with damage to the marine environment) appears satisfactory and within ALARP. This, however, might be sensitive to negative changes, if sizable oil spills of double hull tankers occur, what did not happen with large oil tankers after their introduction in the early 90ties. Thus, present results should be taken into account with care.

- A parallel study on the risk levels of large oil tankers of single hull construction [36] showed that corresponding levels for the potential loss of oil cargo were outside ALARP, what is a strong justification for the introduction of the double hull concept in the early 90ties by the USA and later on worldwide.
- Furthermore, with respect to the smaller tanker ships, namely oil tankers of less than 60,000 DWT, a separate FSA study is required, because the nature of smaller tankers' accidents appears different in comparison to the larger ones. This is also supported by two other known studies, namely:
    - According to [33], fire/explosion incidents of large tankers tend to be more severe than those of smaller tankers where the effects of an explosion are better contained by the tank structure.
    - In [37], it is stated that a larger ship has a higher probability of a larger relative damage length than that of a smaller ship in case of a grounding event. On the other hand, the damages to the side structure caused by ship collisions are found to be relatively smaller for large ships.
- A summary of this Large Oil Tankers Risk Analysis report was presented and discussed in [39].

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Appendices to Annex I

A.1: HAZID Sessions Participants

Name	Affiliation	Background
Batistatos, Nikolaos	Alpha Marine Services Ltd	Naval Architect & Marine Engineer
Daskalakis, Capt. Themistoklis	European Maritime Pilots Association, Vice-President	Master Mariner, Chief pilot in Piraeus port authority areas in Attica Prefecture
Dausendschön, Kay	GL	Mechanical Engineer
Eliopoulou, Eleftheria	NTUA	Naval Architect & Marine Engineer
Ellinikiotis, Nikolaos	Euronav Shipping	Master (Oil and product tankers)
Hamann, Rainer	GL	Mech.Eng., safety analyst
Hatzigrigoris, Stavros	Kristen Navigation Inc / Maran Gas Maritime Inc.	General Manager Naval Architect & Marine Engineer
Iordanidis, Antonios	Alpha Marine Services Ltd.	Naval Architect & Marine Engineer
Kodovas, Ch.	NTUA	Naval Architect & Marine Engineer
Loer, Karsten	GL	Safety Engineer
Lyras, Dimitris	Director of Lyras Shipping Ltd., member of Intertanko's Information Technology Committee, Advisor to the Board of Directors for Ulysses Systems	Engineer
Maroussis, Capt. Anastassios	Alpha Marine Services Ltd	Master Mariner
Moustaka, Despina	Kristen Navigation Inc / Maran Gas Maritime Inc.	Analyst / Programmer; ISM ISO Manager
Papanikolaou, A.D.	NTUA Professor	Naval Architect & Marine Engineer
Touliatos, Petros	Kristen Navigation Inc.	Safety Officer, Operations Dept., Marine Superintendent
Tsichlis, Philip	Alpha Marine Services Ltd.	Naval Architect & Marine Engineer

A.2: Event Trees

Event Tree: Collision

Collision	Struck	Operational state	Loaded	No breach in hull	No breach inner hull	Fire/Explosion	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
Collision **1.03E-02**	Struck 0.80	Terminal areas 0.30	loaded 0.60	No breach 0.54		No	severe damage 0.07	No sinking	1	5.68E-05	1.5							
							no severe damage 0.93	No sinking	2	7.54E-04	19.4							
				Breach hull 0.46	No breach inner 0.78	Yes 0.03	severe damage 1	Sinking 0.5	3	8.08E-06	0.2		13.33	152191	82,500,000	1.08E-04	1.23E+00	6.67E+02
								No sinking 0.5	4	8.08E-06	0.2		4.33		4,125,000	3.50E-05		3.34E+01
						No 0.97	severe damage 0.29	Sinking 0	5	0.00E+00								
								No sinking 1	6	1.52E-04	3.9		2.02		4,125,000	3.06E-04		6.25E+02
							no severe damage 0.71	No sinking	7	3.71E-04	9.6							
					Breach inner hull 0.22	Yes 0.03	severe damage 1	Sinking 0.5	8	2.28E-06	0.1		13.33	152191	82,500,000	3.04E-05	3.47E-01	1.88E+02
								No sinking 0.5	9	2.28E-06	0.1		4.33	10726	4,125,000	9.88E-06	2.45E-02	9.41E+00
						No 0.97	severe damage 0.29	Sinking 0	10	0.00E+00								
								No sinking 1	11	4.28E-05	1.1		2.02	10726	4,125,000	8.64E-05	4.59E-01	1.76E+02
							no severe damage 0.71	No sinking	12	1.05E-04	2.7			184.6			1.93E-02	
			ballast 0.40	No breach 0.54		No	severe damage 0.07	No sinking	13	3.79E-05	1.0							
							no severe damage 0.93	No sinking	14	5.03E-04	13.0							
				Breach hull 0.46	No breach inner hull 0.78	Yes 0.03	severe damage 1	Sinking 0.5	15	5.39E-06	0.1		13.33		82,500,000	7.19E-05		4.45E+02
								No sinking 0.5	16	5.39E-06	0.1		4.33		4,125,000	2.34E-05		2.22E+01
						No 0.97	severe damage 0.29	Sinking 0	17	0.00E+00								
								No sinking 1	18	1.01E-04	2.6		2.02		4,125,000	2.04E-04		4.17E+02
							no severe damage 0.71	No sinking	19	2.47E-04	6.4							
					Breach inner hull 0.22	Yes 0.03	severe damage 1	Sinking 0.5	20	1.52E-06	0.0		13.33		82,500,000	2.03E-05		1.25E+02
								No sinking 0.5	21	1.52E-06	0.0		4.33		4,125,000	6.59E-06		6.27E+00
						No 0.97	severe damage 0.29	Sinking 0	22	0.00E+00								
								No sinking 1	23	2.85E-05	0.7		2.02		4,125,000	5.76E-05		1.18E+02
							no severe damage 0.71	No sinking	24	6.98E-05	1.8							
		Congested 0.37	loaded 0.60	No breach 0.64		No	severe damage 0.03	No sinking	25	3.47E-05	0.9							
							no severe damage 0.97	No sinking	26	1.12E-03	28.9							
				Breach hull 0.36	No breach inner hull 0.78	Yes 0.06	severe damage 1	Sinking 0.5	27	1.52E-05	0.4		13.33	152191	82,500,000	2.03E-04	2.32E+00	1.26E+03
								No sinking 0.5	28	1.52E-05	0.4		4.33		4,125,000	6.59E-05		6.28E+01
						No 0.94	severe damage 0.59	Sinking 0.05	29	1.41E-05	0.4		2.02	152191	82,500,000	2.84E-05	2.14E+00	1.16E+03
								No sinking 0.95	30	2.67E-04	6.9		2.02		4,125,000	5.40E-04		1.10E+03
							no severe damage 0.41	No sinking	31	1.95E-04	5.0							
					Breach inner hull 0.22	Yes 0.06	severe damage 1	Sinking 0.5	32	4.29E-06	0.1		13.33	152191	82,500,000	5.72E-05	6.53E-01	3.54E+02
								No sinking 0.5	33	4.29E-06	0.1		4.33	10726	4,125,000	1.86E-05	4.60E-02	1.77E+01
						No 0.94	severe damage 0.59	Sinking 0.05	34	3.97E-06	0.1		2.02	152191	82,500,000	8.01E-06	6.04E-01	3.27E+02
								No sinking 0.95	35	7.54E-05	1.9		2.02	10726	4,125,000	1.52E-04	8.09E-01	3.11E+02
							no severe damage 0.41	No sinking	36	5.51E-05	1.4			184.6			1.02E-02	

Operational state	Loaded	No breach in hull	No breach inner hull	Fire/Explosion	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
	ballast 0.40	No breach 0.64		No	severe damage 0.03	No sinking	37	2.31E-05	0.6							
					no severe damage 0.97	No sinking	38	7.48E-04	19.3							
		Breach hull 0.36	No breach inner hull 0.78	Yes 0.06	severe damage 1	Sinking 0.5	39	1.01E-05	0.3		13.33		82,500,000	1.35E-04		8.37E+02
						No sinking 0.5	40	1.01E-05	0.3		4.33		4,125,000	4.40E-05		4.18E+01
				No 0.94	severe damage 0.59	Sinking 0.05	41	9.38E-06	0.2		2.02		82,500,000	1.89E-05		7.74E+02
						No sinking 0.95	42	1.78E-04	4.6		2.02		4,125,000	3.60E-04		7.35E+02
					no severe damage 0.41	No sinking	43	1.30E-04	3.4							
			Breach inner hull 0.22	Yes 0.06	severe damage 1	Sinking 0.5	44	2.86E-06	0.1		13.33		82,500,000	3.82E-05		2.36E+02
						No sinking 0.5	45	2.86E-06	0.1		4.33		4,125,000	1.24E-05		1.18E+01
				No 0.94	severe damage 0.59	Sinking 0.05	46	2.64E-06	0.1		2.02		82,500,000	5.34E-06		2.18E+02
						No sinking 0.95	47	5.03E-05	1.3		2.02		4,125,000	1.02E-04		2.07E+02
					no severe damage 0.41	No sinking	48	3.68E-05	0.9							
Open Sea 0.26	loaded 0.60	No breach 0.54		Yes 0.03	severe damage 1	Sinking 0	49	0.00E+00								
						No sinking 1	50	2.06E-05	0.5							
				No 0.97	severe damage 0.1	Sinking 0	51	0.00E+00								
						No sinking 1	52	6.67E-05	1.7							
					no severe damage 0.9	No sinking	53	6.01E-04	15.5							
		Breach hull 0.46	No breach inner hull 0.78	Yes 0.23	severe damage 0.83	Sinking 0.2	54	1.75E-05	0.4		13.33	152191	82,500,000	2.33E-04	2.66E+00	1.44E+03
						No sinking 0.8	55	6.98E-05	1.8		4.33		4,125,000	3.03E-04		2.88E+02
					no severe damage 0.17	No sinking	56	1.79E-05	0.5							
				No 0.77	severe damage 0.5	Sinking 0	57	0.00E+00								
						No sinking 1	58	1.76E-04	4.5		2.02		4,125,000	3.56E-04		7.26E+02
					no severe damage 0.5	No sinking	59	1.76E-04	4.5							
			Breach inner hull 0.22	Yes 0.23	severe damage 0.83	Sinking 0.2	60	4.92E-06	0.1		13.33	152191	82,500,000	6.56E-05	7.49E-01	4.06E+02
						No sinking 0.8	61	1.97E-05	0.5		4.33	10726	4,125,000	8.53E-05	2.11E-01	8.12E+01
					no severe damage 0.17	No sinking	62	5.04E-06	0.1			184.6			9.31E-04	
				No 0.77	severe damage 0.5	Sinking 0	63	0.00E+00								
						No sinking 1	64	4.96E-05	1.3		2.02	10726	4,125,000	1.00E-04	5.32E-01	2.05E+02
					no severe damage 0.5	No sinking	65	4.96E-05	1.3			184.6			9.17E-03	
	ballast 0.40	No breach 0.54		Yes 0.03	severe damage 1	Sinking 0	66	0.00E+00								
						No sinking 1	67	1.38E-05	0.4							
				No 0.97	severe damage 0.1	Sinking 0	68	0.00E+00								
						No sinking 1	69	4.45E-05	1.1							
					no severe damage 0.9	No sinking	70	4.00E-04	10.3							

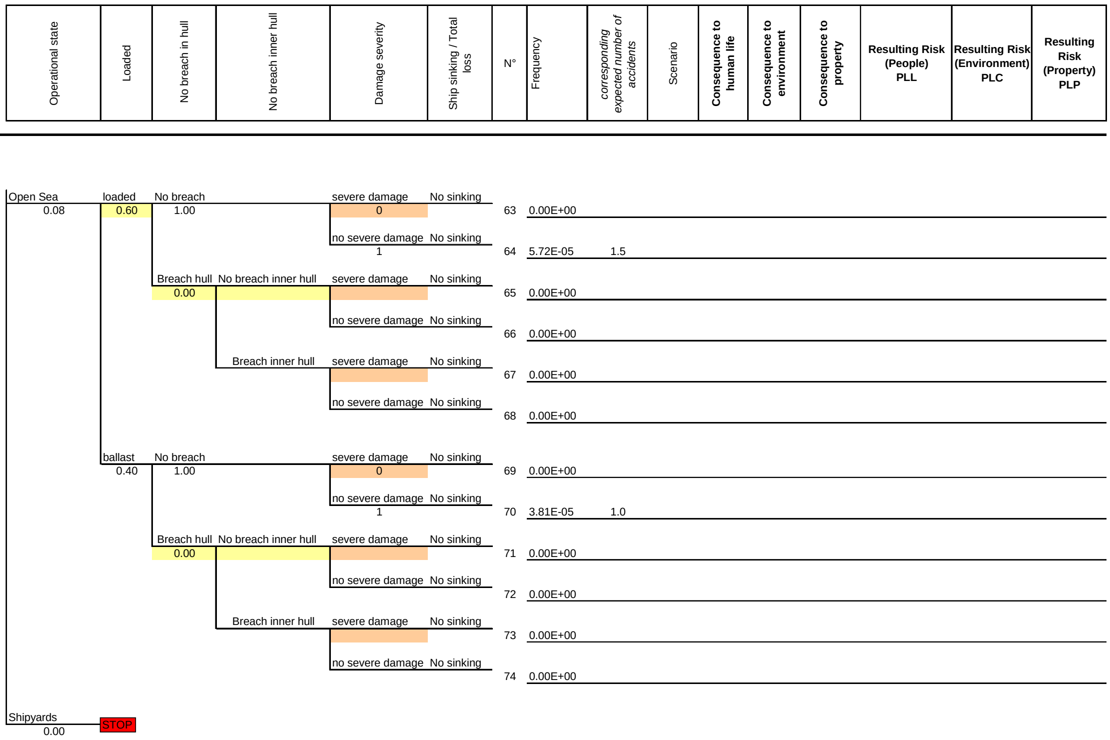
Operational state	Loaded	No breach in hull	No breach inner hull	Fire/Explosion	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
		Breach hull 0.46	No breach inner hull 0.78	Yes 0.23	severe damage 0.83	Sinking 0.2	71	1.16E-05	0.3		13.33		82,500,000	1.55E-04		9.60E+02
						No sinking 0.8	72	4.65E-05	1.2		4.33		4,125,000	2.02E-04		1.92E+02
					no severe damage 0.17	No sinking	73	1.19E-05	0.3							
				No 0.77	severe damage 0.5	Sinking 0	74	0.00E+00								
						No sinking 1	75	1.17E-04	3.0		2.02		4,125,000	2.37E-04		4.84E+02
					no severe damage 0.5	No sinking	76	1.17E-04	3.0							
			Breach inner hull 0.22	Yes 0.23	severe damage 0.83	Sinking 0.2	77	3.28E-06	0.1		13.33		82,500,000	4.38E-05		2.71E+02
						No sinking 0.8	78	1.31E-05	0.3		4.33		4,125,000	5.69E-05		5.41E+01
					no severe damage 0.17	No sinking	79	3.36E-06	0.1							
				No 0.77	severe damage 0.5	Sinking 0	80	0.00E+00								
						No sinking 1	81	3.31E-05	0.9		2.02		4,125,000	6.68E-05		1.37E+02
					no severe damage 0.5	No sinking	82	3.31E-05	0.9							
Limited waters 0.07	loaded 0.60	No breach 0.58		No	severe damage 0.3	No sinking	83	6.29E-05	1.6							
					no severe damage 0.7	No sinking	84	1.47E-04	3.8							
		Breach hull 0.42	No breach inner hull 0.78	No	severe damage 0.5	Sinking 0	85	0.00E+00								
						No sinking 1	86	5.92E-05	1.5		2.02		4,125,000	1.20E-04		2.44E+02
					no severe damage 0.5	No sinking	87	5.92E-05	1.5							
			Breach inner hull 0.22	No	severe damage 0.5	Sinking 0	88	0.00E+00								
						No sinking 1	89	1.67E-05	0.4		2.02	10726	4,125,000	3.37E-05	1.79E-01	6.89E+01
					no severe damage 0.5	No sinking	90	1.67E-05	0.4			184.6			3.08E-03	
	ballast 0.40	No breach 0.58		No	severe damage 0.3	No sinking	91	4.19E-05	1.1							
					no severe damage 0.7	No sinking	92	9.78E-05	2.5							
		Breach hull 0.42	No breach inner hull 0.78	No	severe damage 0.5	Sinking 0	93	0.00E+00								
						No sinking 1	94	3.95E-05	1.0		2.02		4,125,000	7.97E-05		1.63E+02
					no severe damage 0.5	No sinking	95	3.95E-05	1.0							
			Breach inner hull 0.22	No	severe damage 0.5	Sinking 0	96	0.00E+00								
						No sinking 1	97	1.11E-05	0.3		2.02		4,125,000	2.25E-05		4.59E+01
					no severe damage 0.5	No sinking	98	1.11E-05	0.3							
Shipyards 0.00																

Striking 0.20 STOPS

Event Tree: Contact

Contact		Operational state	Loaded	No breach in hull	No breach inner hull	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
Contact 3.72E-03	Fixed installation 0.68	Terminal areas 0.56	loaded 0.60	No breach 0.43		no severe damage 1	No sinking	1	3.66E-04	9.4							
				Breach hull 0.57	No breach inner hull 0.78	severe damage 0.41	No sinking	2	1.55E-04	4.0							
						no severe damage 0.59	No sinking	3	2.23E-04	5.8							
					Breach inner hull 0.22	severe damage 0.41	No sinking	4	4.37E-05	1.1			10726			4.69E-01	
						no severe damage 0.59	No sinking	5	6.29E-05	1.6			912.5			5.74E-02	
			ballast 0.40	No breach 0.43		no severe damage 1	No sinking	6	2.44E-04	6.3							
				Breach hull 0.57	No breach inner hull 0.78	severe damage 0.41	No sinking	7	1.03E-04	2.7							
						no severe damage 0.59	No sinking	8	1.49E-04	3.8							
					Breach inner hull 0.22	severe damage 0.41	No sinking	9	2.92E-05	0.8							
						no severe damage 0.59	No sinking	10	4.20E-05	1.1							
		Limited waters 0.38	loaded 0.60	No breach 0.50		severe damage 0.2	No sinking	11	5.77E-05	1.5							
						no severe damage 0.8	No sinking	12	2.31E-04	6.0							
				Breach hull 0.50	No breach inner hull 0.78	severe damage 0.7	No sinking	13	1.58E-04	4.1							
						no severe damage 0.3	No sinking	14	6.75E-05	1.7							
					Breach inner hull 0.22	severe damage 0.7	No sinking	15	4.45E-05	1.1			10726			4.77E-01	
						no severe damage 0.3	No sinking	16	1.91E-05	0.5			912.5			1.74E-02	
			ballast 0.40	No breach 0.50		severe damage 0.2	No sinking	17	3.85E-05	1.0							
						no severe damage 0.8	No sinking	18	1.54E-04	4.0							
				Breach hull 0.50	No breach inner hull 0.78	severe damage 0.7	No sinking	19	1.05E-04	2.7							
						no severe damage 0.3	No sinking	20	4.50E-05	1.2							
					Breach inner hull 0.22	severe damage 0.7	No sinking	21	2.96E-05	0.8							
						no severe damage 0.3	No sinking	22	1.27E-05	0.3							
		Congested waters 0.02	loaded 0.60	No breach 0.00		severe damage	No sinking	23	0.00E+00								
						no severe damage	No sinking	24	0.00E+00								
				Breach hull 1.00	No breach inner hull 0.78	severe damage 1	No sinking	25	2.37E-05	0.6							
						no severe damage 0	No sinking	26	0.00E+00								
					Breach inner hull 0.22	severe damage 1	No sinking	27	6.68E-06	0.2			10726			7.17E-02	
						no severe damage 0	No sinking	28	0.00E+00								
			ballast 0.40	No breach 0.00		severe damage	No sinking	29	0.00E+00								
						no severe damage	No sinking	30	0.00E+00								
				Breach hull 1.00	No breach inner hull 0.78	severe damage 1	No sinking	31	1.58E-05	0.4							
						no severe damage 0	No sinking	32	0.00E+00								
					Breach inner hull 0.22	severe damage 1	No sinking	33	4.46E-06	0.1							
						no severe damage 0	No sinking	34	0.00E+00								

	Operational state	Loaded	No breach in hull	No breach inner hull	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
	Open Sea 0.00	STOP														
	Shipyards 0.04	STOP														
Floating object 0.32	Terminal areas 0.21	loaded 0.60	No breach 0.60		no severe damage 1	No sinking	35	9.01E-05	2.3							
			Breach hull 0.40	No breach inner hull 0.78	no severe damage 1	No sinking	36	4.68E-05	1.2							
				Breach inner hull 0.22	no severe damage 1	No sinking	37	1.32E-05	0.3							
		ballast 0.40	No breach 0.60		no severe damage 1	No sinking	38	6.01E-05	1.5							
			Breach hull 0.40	No breach inner hull 0.78	no severe damage 1	No sinking	39	3.12E-05	0.8							
				Breach inner hull 0.22	no severe damage 1	No sinking	40	8.81E-06	0.2							
	Congested waters 0.42	loaded 0.60	No breach 0.70		no severe damage 1	No sinking	41	2.10E-04	5.4							
			Breach hull 0.30	No breach inner hull 0.78	severe damage 0.5	No sinking	42	3.51E-05	0.9							
					no severe damage 0.5	No sinking	43	3.51E-05	0.9							
				Breach inner hull 0.22	severe damage 0.5	No sinking	44	9.91E-06	0.3			10726			1.06E-01	
					no severe damage 0.5	No sinking	45	9.91E-06	0.3							
		ballast 0.40	No breach 0.70		no severe damage 1	No sinking	46	1.40E-04	3.6							
			Breach hull 0.30	No breach inner hull 0.78	severe damage 0.5	No sinking	47	2.34E-05	0.6							
					no severe damage 0.5	No sinking	48	2.34E-05	0.6							
				Breach inner hull 0.22	severe damage 0.5	No sinking	49	6.61E-06	0.2							
					no severe damage 0.5	No sinking	50	6.61E-06	0.2							
	Limited waters 0.29	loaded 0.60	No breach 0.57		severe damage 0.5	No sinking	51	5.91E-05	1.5							
					no severe damage 0.5	No sinking	52	5.91E-05	1.5							
			Breach hull 0.43	No breach inner hull 0.78	severe damage 1	No sinking	53	6.95E-05	1.8							
					no severe damage 0	No sinking	54	0.00E+00								
				Breach inner hull 0.22	severe damage 1	No sinking	55	1.96E-05	0.5			10726			2.10E-01	
					no severe damage 0	No sinking	56	0.00E+00								
		ballast 0.40	No breach 0.57		severe damage 0.5	No sinking	57	3.94E-05	1.0							
					no severe damage 0.5	No sinking	58	3.94E-05	1.0							
			Breach hull 0.43	No breach inner hull 0.78	severe damage 1	No sinking	59	4.64E-05	1.2							
					no severe damage 0	No sinking	60	0.00E+00								
				Breach inner hull 0.22	severe damage 1	No sinking	61	1.31E-05	0.3							
					no severe damage 0	No sinking	62	0.00E+00								


Operational state
Loaded
No breach in hull
No breach inner hull
Damage severity
Ship sinking / Total loss
N°
Frequency
corresponding expected number of accidents
Scenario
Consequence to human life
Consequence to environment
Consequence to property
Resulting Risk (People) PLL
Resulting Risk (Environment) PLC
Resulting Risk (Property) PLP
Open Sea
0.08
loaded
0.60
No breach
1.00
severe damage
0
No sinking
63 0.00E+00
no severe damage
1
No sinking
64 5.72E-05 1.5
Breach hull
0.00
No breach inner hull
severe damage
No sinking
65 0.00E+00
no severe damage
No sinking
66 0.00E+00
Breach inner hull
severe damage
No sinking
67 0.00E+00
no severe damage
No sinking
68 0.00E+00
ballast
0.40
No breach
1.00
severe damage
0
No sinking
69 0.00E+00
no severe damage
1
No sinking
70 3.81E-05 1.0
Breach hull
0.00
No breach inner hull
severe damage
No sinking
71 0.00E+00
no severe damage
No sinking
72 0.00E+00
Breach inner hull
severe damage
No sinking
73 0.00E+00
no severe damage
No sinking
74 0.00E+00
Shipyards
0.00
STOP

Event Tree: Grounding

Initiating event		Operational state	Loaded	No breach in hull	No breach double bottom	Damage severity	Ship sinking	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
Grounding 7.49E-03	Powered 0.83	Terminal areas 0.14	loaded 0.80	No breach 0.68		severe damage 0.31	Sinking 0	1	0.00E+00								
							No sinking 1	2	1.47E-04	3.8							
						no severe damage 0.69	No sinking	3	3.27E-04	8.4							
				Breach hull 0.32	No breach db 0.78	severe damage 0.83	Sinking 0	4	0.00E+00								
							No sinking 1	5	1.44E-04	3.7							
						no severe damage 0.17	No sinking	6	2.95E-05	0.8							
					Breach db 0.22	severe damage 0.83	Sinking 0	7	0.00E+00								
							No sinking 1	8	4.07E-05	1.0			10726			4.36E-01	
						no severe damage 0.17	No sinking	9	8.33E-06	0.2							
			ballast 0.20	No breach 0.68		severe damage 0.31	Sinking 0	10	0.00E+00								
							No sinking 1	11	3.67E-05	0.9							
						no severe damage 0.69	No sinking	12	8.17E-05	2.1							
				Breach hull 0.32	No breach db 0.78	severe damage 0.83	Sinking 0	13	0.00E+00								
							No sinking 1	14	3.61E-05	0.9							
						no severe damage 0.17	No sinking	15	7.39E-06	0.2							
					Breach db 0.22	severe damage 0.83	Sinking 0	16	0.00E+00								
							No sinking 1	17	1.02E-05	0.3							
						no severe damage 0.17	No sinking	18	2.08E-06	0.1							
		Congested waters 0.42	loaded 0.80	No breach 0.73		severe damage 0.27	Sinking 0.08	19	3.29E-05	0.8		1	152191	82,500,000	3.29E-05	5.01E+00	2.72E+03
							No sinking 0.92	20	3.79E-04	9.8							
						no severe damage 0.73	No sinking	21	1.11E-03	28.7							
				Breach hull 0.27	No breach db 0.78	severe damage 0.87	Sinking 0.07	22	2.68E-05	0.7		1	152191	82,500,000	2.68E-05	4.08E+00	2.21E+03
							No sinking 0.93	23	3.56E-04	9.2							
						no severe damage 0.13	No sinking	24	5.72E-05	1.5							
					Breach db 0.22	severe damage 0.87	Sinking 0.07	25	7.56E-06	0.2		1	152191	82,500,000	7.56E-06	1.15E+00	6.23E+02
							No sinking 0.93	26	1.00E-04	2.6			10726			1.08E+00	
						no severe damage 0.13	No sinking	27	1.61E-05	0.4							
			ballast 0.20	No breach 0.73		severe damage 0.27	Sinking 0.08	28	8.23E-06	0.2		1		82,500,000	8.23E-06		6.79E+02
							No sinking 0.92	29	9.47E-05	2.4							
						no severe damage 0.73	No sinking	30	2.78E-04	7.2							
				Breach hull 0.27	No breach db 0.78	severe damage 0.87	Sinking 0.07	31	6.70E-06	0.2		1		82,500,000	6.70E-06		5.53E+02
							No sinking 0.93	32	8.90E-05	2.3							
						no severe damage 0.13	No sinking	33	1.43E-05	0.4							
					Breach db 0.22	severe damage 0.87	Sinking 0.07	34	1.89E-06	0.0		1		82,500,000	1.89E-06		1.56E+02
							No sinking 0.93	35	2.51E-05	0.6							
						no severe damage 0.13	No sinking	36	4.03E-06	0.1							

Operational state	Loaded	No breach in hull	No breach double bottom	Damage severity	Ship sinking	N°	Frequency	corresponding expected number of accidents	Scenario	Consequence to human life	Consequence to environment	Consequence to property	Resulting Risk (People) PLL	Resulting Risk (Environment) PLC	Resulting Risk (Property) PLP
Limited waters 0.35	loaded 0.80	No breach 0.85		severe damage 0.15	Sinking 0	37	0.00E+00								
					No sinking 1	38	2.22E-04	5.7							
				no severe damage 0.85	No sinking	39	1.26E-03	32.4							
		Breach hull 0.15	No breach db 0.78	severe damage 1	Sinking 0	40	0.00E+00								
					No sinking 1	41	2.04E-04	5.3							
				no severe damage 0	No sinking	42	0.00E+00								
			Breach db 0.22	severe damage 1	Sinking 0	43	0.00E+00								
					No sinking 1	44	5.74E-05	1.5			10726			6.16E-01	
				no severe damage 0	No sinking	45	0.00E+00								
	ballast 0.20	No breach 0.85		severe damage 0.15	Sinking 0	46	0.00E+00								
					No sinking 1	47	5.55E-05	1.4							
				no severe damage 0.85	No sinking	48	3.14E-04	8.1							
		Breach hull 0.15	No breach db 0.78	severe damage 1	Sinking 0	49	0.00E+00								
					No sinking 1	50	5.09E-05	1.3							
				no severe damage 0	No sinking	51	0.00E+00								
			Breach db 0.22	severe damage 1	Sinking 0	52	0.00E+00								
					No sinking 1	53	1.44E-05	0.4							
				no severe damage 0	No sinking	54	0.00E+00								
Open Sea 0.09	loaded 0.80	No breach 0.50		severe damage 0.2	Sinking 0	55	0.00E+00								
					No sinking 1	56	4.48E-05	1.2							
				no severe damage 0.8	No sinking	57	1.79E-04	4.6							
		Breach hull 0.50	No breach db 0.78	severe damage 1	Sinking 0.17	58	2.97E-05	0.8		1	152191	82,500,000	2.97E-05	4.52E+00	2.45E+03
					No sinking 0.83	59	1.45E-04	3.7							
				no severe damage 0	No sinking	60	0.00E+00								
			Breach db 0.22	severe damage 1	Sinking 0.17	61	8.37E-06	0.2		1	152191	82,500,000	8.37E-06	1.27E+00	6.91E+02
					No sinking 0.83	62	4.09E-05	1.1			10726			4.38E-01	
				no severe damage 0	No sinking	63	0.00E+00								
	ballast 0.20	No breach 0.50		severe damage 0.2	Sinking 0	64	0.00E+00								
					No sinking 1	65	1.12E-05	0.3							
				no severe damage 0.8	No sinking	66	4.48E-05	1.2							
		Breach hull 0.50	No breach db 0.78	severe damage 1	Sinking 0.17	67	7.42E-06	0.2		1		82,500,000	7.42E-06		6.12E+02
					No sinking 0.83	68	3.62E-05	0.9							
				no severe damage 0	No sinking	69	0.00E+00								
			Breach db 0.22	severe damage 1	Sinking 0.17	70	2.09E-06	0.1		1		82,500,000	2.09E-06		1.73E+02
					No sinking 0.83	71	1.02E-05	0.3							
				no severe damage 0	No sinking	72	0.00E+00								

	Operational state	Loaded	No breach in hull	No breach double bottom	Damage severity	Ship sinking	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
Drift 0.17	Terminal areas 0.28	loaded 0.80	No breach 0.75		severe damage 0.33	Sinking 0	73	0.00E+00								
						No sinking 1	74	7.06E-05	1.8							
					no severe damage 0.67	No sinking	75	1.43E-04	3.7							
			Breach hull 0.25	No breach db 0.78	severe damage 0.5	Sinking 0	76	0.00E+00								
						No sinking 1	77	2.78E-05	0.7							
					no severe damage 0.5	No sinking	78	2.78E-05	0.7							
				Breach db 0.22	severe damage 0.5	Sinking 0	79	0.00E+00								
						No sinking 1	80	7.84E-06	0.2			10726			8.41E-02	
					no severe damage 0.5	No sinking	81	7.84E-06	0.2							
		ballast 0.20	No breach 0.75		severe damage 0.33	Sinking 0	82	0.00E+00								
						No sinking 1	83	1.76E-05	0.5							
					no severe damage 0.67	No sinking	84	3.58E-05	0.9							
			Breach hull 0.25	No breach db 0.78	severe damage 0.5	Sinking 0	85	0.00E+00								
						No sinking 1	86	6.95E-06	0.2							
					no severe damage 0.5	No sinking	87	6.95E-06	0.2							
				Breach db 0.22	severe damage 0.5	Sinking 0	88	0.00E+00								
						No sinking 1	89	1.96E-06	0.1							
					no severe damage 0.5	No sinking	90	1.96E-06	0.1							
	Congested waters 0.28	loaded 0.80	No breach 0.50		severe damage 0.25	Sinking 0	91	0.00E+00								
						No sinking 1	92	3.57E-05	0.9							
					no severe damage 0.75	No sinking	93	1.07E-04	2.8							
			Breach hull 0.50	No breach db 0.78	severe damage 1	Sinking 0.25	94	2.78E-05	0.7			152191			4.23E+00	
						No sinking 0.75	95	8.34E-05	2.2							
					no severe damage 0	No sinking	96	0.00E+00								
				Breach db 0.22	severe damage 1	Sinking 0.25	97	7.84E-06	0.2			152191			1.19E+00	
						No sinking 0.75	98	2.35E-05	0.6			10726			2.52E-01	
					no severe damage 0	No sinking	99	0.00E+00								
		ballast 0.20	No breach 0.50		severe damage 0.25	Sinking 0	100	0.00E+00								
						No sinking 1	101	8.91E-06	0.2							
					no severe damage 0.75	No sinking	102	2.67E-05	0.7							
			Breach hull 0.50	No breach db 0.78	severe damage 1	Sinking 0.25	103	6.95E-06	0.2							
						No sinking 0.75	104	2.09E-05	0.5							
					no severe damage 0	No sinking	105	0.00E+00								
				Breach db 0.22	severe damage 1	Sinking 0.25	106	1.96E-06	0.1							
						No sinking 0.75	107	5.88E-06	0.2							
					no severe damage 0	No sinking	108	0.00E+00								

Operational state	Loaded	No breach in hull	No breach double bottom	Damage severity	Ship sinking	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
Limited waters 0.41	loaded 0.80	No breach 0.67		severe damage 0.75	Sinking 0	109	0.00E+00								
					No sinking 1	110	2.10E-04	5.4							
				no severe damage 0.25	No sinking	111	7.00E-05	1.8							
		Breach hull 0.33	No breach db 0.78	severe damage 1	Sinking 0	112	0.00E+00								
					No sinking 1	113	1.08E-04	2.8							
				no severe damage 0	No sinking	114	0.00E+00								
			Breach db 0.22	severe damage 1	Sinking 0	115	0.00E+00								
					No sinking 1	116	3.03E-05	0.8			10726			3.25E-01	
				no severe damage 0	No sinking	117	0.00E+00								
	ballast 0.20	No breach 0.67		severe damage 0.75	Sinking 0	118	0.00E+00								
					No sinking 1	119	5.25E-05	1.4							
				no severe damage 0.25	No sinking	120	1.75E-05	0.5							
		Breach hull 0.33	No breach db 0.78	severe damage 1	Sinking 0	121	0.00E+00								
					No sinking 1	122	2.69E-05	0.7							
				no severe damage 0	No sinking	123	0.00E+00								
			Breach db 0.22	severe damage 1	Sinking 0	124	0.00E+00								
					No sinking 1	125	7.58E-06	0.2							
				no severe damage 0	No sinking	126	0.00E+00								
Open Sea 0.03	loaded 0.80	Breach hull 1.00	No breach db 0.78	severe damage 1	Sinking 0	127	0.00E+00								
					No sinking 1	128	2.38E-05	0.6							
				no severe damage 0	No sinking	129	0.00E+00								
			Breach db 0.22	severe damage 1	Sinking 0	130	0.00E+00								
					No sinking 1	131	6.72E-06	0.2			10726			7.21E-02	
				no severe damage 0	No sinking	132	0.00E+00								
	ballast 0.20	Breach hull 1.00	No breach db 0.78	severe damage 1	Sinking 0	133	0.00E+00								
					No sinking 1	134	5.96E-06	0.2							
				no severe damage 0	No sinking	135	0.00E+00								
			Breach db 0.22	severe damage 1	Sinking 0	136	0.00E+00								
					No sinking 1	137	1.68E-06	0.0							
				no severe damage 0	No sinking	138	0.00E+00								

Event Tree: Fire

Fire	Ignition source	Terminal areas	Operational state / Loaded	Ignition origin	Explosion after fire	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
Fire **3.65E-03**	Ignition source 0.97	Terminal areas 0.35	loaded 0.50	Aft Area 0.84	yes 0	severe damage	Sinking	1	0.00E+00								
							No sinking	2	0.00E+00								
						no severe damage	No sinking	3	0.00E+00								
					no 1	severe damage 0.18	Sinking 0.25	4	2.34E-05	0.6		0.9	152191	82,500,000	2.11E-05	3.56E+00	1.93E+03
							No sinking 0.75	5	7.02E-05	1.8		0.9	10726	8,250,000	6.32E-05	7.53E-01	5.79E+02
						no severe damage 0.82	No sinking	6	4.26E-04	11.0		0.56		2,062,500	2.37E-04		8.79E+02
				Cargo/Slop 0.08	yes 0.5	severe damage 1	Sinking 0	7	0.00E+00								
							No sinking 1	8	2.48E-05	0.6		2	10726	8,250,000	4.95E-05	2.66E-01	2.04E+02
						no severe damage 0	No sinking	9	0.00E+00								
					no 0.5	severe damage 0	Sinking	10	0.00E+00								
							No sinking	11	0.00E+00								
						no severe damage 1	No sinking	12	2.48E-05	0.6		0.56		2,062,500	1.37E-05		5.11E+01
				Ballast/Void 0.08	yes 0	severe damage	Sinking	13	0.00E+00								
							No sinking 1	14	0.00E+00								
						no severe damage	No sinking	15	0.00E+00								
					no 1	severe damage 0	Sinking	16	0.00E+00								
							No sinking	17	0.00E+00								
						no severe damage 1	No sinking	18	4.95E-05	1.3		0.56		2,062,500	2.75E-05		1.02E+02
			ballast 0.50	Aft Area 0.84	yes 0	severe damage	Sinking	19	0.00E+00								
							No sinking	20	0.00E+00								
						no severe damage	No sinking	21	0.00E+00								
					no 1	severe damage 0.18	Sinking 0.25	22	2.34E-05	0.6		0.9		82,500,000	2.11E-05		1.93E+03
							No sinking 0.75	23	7.02E-05	1.8		0.9		8,250,000	6.32E-05		5.79E+02
						no severe damage 0.82	No sinking	24	4.26E-04	11.0		0.56		2,062,500	2.37E-04		8.79E+02
				Cargo/Slop 0.08	yes 0.5	severe damage 1	Sinking 0	25	0.00E+00								
							No sinking 1	26	2.48E-05	0.6		2		8,250,000	4.95E-05		2.04E+02
						no severe damage 0	No sinking	27	0.00E+00								
					no 0.5	severe damage 0	Sinking	28	0.00E+00								
							No sinking	29	0.00E+00								
						no severe damage 1	No sinking	30	2.48E-05	0.6		0.56		2,062,500	1.37E-05		5.11E+01

Operational state	Loaded	Ignition origin	Explosion after fire	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
		Ballast/Void 0.08	yes 0	severe damage	Sinking	31	0.00E+00								
					No sinking	32	0.00E+00								
				no severe damage	No sinking	33	0.00E+00								
			no 1	severe damage 0	Sinking	34	0.00E+00								
					No sinking	35	0.00E+00								
				no severe damage 1	No sinking	36	4.95E-05	1.3		0.56		2,062,500	2.75E-05		1.02E+02
Congested waters 0.17	loaded 0.50	Aft Area 0.91	yes 0.1	severe damage 0.5	Sinking 0.5	37	6.84E-06	0.2		2	152191	82,500,000	1.37E-05	1.04E+00	5.64E+02
					No sinking 0.5	38	6.84E-06	0.2		2	10726	8,250,000	1.37E-05	7.34E-02	5.64E+01
				no severe damage 0.5	No sinking	39	1.37E-05	0.4		0.56		2,062,500	7.59E-06		2.82E+01
			no 0.9	severe damage 0.57	Sinking 0	40	0.00E+00								
					No sinking 1	41	1.40E-04	3.6		0.9	10726	8,250,000	1.26E-04	1.51E+00	1.16E+03
				no severe damage 0.43	No sinking	42	1.06E-04	2.7		0.56		2,062,500	5.88E-05		2.18E+02
		Cargo/Slop 0.09	yes 0	severe damage	Sinking	43	0.00E+00								
					No sinking	44	0.00E+00								
				no severe damage	No sinking	45	0.00E+00								
			no 1	severe damage 1	Sinking 0	46	0.00E+00								
					No sinking 1	47	2.71E-05	0.7		0.9	10726	8,250,000	2.44E-05	2.90E-01	2.23E+02
				no severe damage 0	No sinking	48	0.00E+00								
	ballast 0.50	Aft Area 0.91	yes 0.1	severe damage 0.5	Sinking 0.5	49	6.84E-06	0.2		2		82,500,000	1.37E-05		5.64E+02
					No sinking 0.5	50	6.84E-06	0.2		2		8,250,000	1.37E-05		5.64E+01
				no severe damage 0.5	No sinking	51	1.37E-05	0.4		0.56		2,062,500	7.59E-06		2.82E+01
			no 0.9	severe damage 0.57	Sinking 0	52	0.00E+00								
					No sinking 1	53	1.40E-04	3.6		0.9		8,250,000	1.26E-04		1.16E+03
				no severe damage 0.43	No sinking	54	1.06E-04	2.7		0.56		2,062,500	5.88E-05		2.18E+02
		Cargo/Slop 0.09	yes 0	severe damage	Sinking	55	0.00E+00								
					No sinking	56	0.00E+00								
				no severe damage	No sinking	57	0.00E+00								
			no 1	severe damage 1	Sinking 0	58	0.00E+00								
					No sinking 1	59	2.71E-05	0.7		0.9		8,250,000	2.44E-05		2.23E+02
				no severe damage 0	No sinking	60	0.00E+00								

Operational state	Loaded	Ignition origin	Explosion after fire	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
Open Sea 0.25	loaded 0.50	Aft Area 0.94	yes 0.06	severe damage 1	Sinking 0	61	0.00E+00								
					No sinking 1	62	2.49E-05	0.6		2	10726	8,250,000	4.99E-05	2.67E-01	2.06E+02
				no severe damage 0	No sinking	63	0.00E+00								
			no 0.94	severe damage 0.44	Sinking 0.57	64	9.80E-05	2.5		2	152191	82,500,000	1.96E-04	1.49E+01	8.08E+03
					No sinking 0.43	65	7.39E-05	1.9		2	10726	8,250,000	1.48E-04	7.93E-01	6.10E+02
				no severe damage 0.56	No sinking	66	2.19E-04	5.6		0.56		2,062,500	1.21E-04		4.51E+02
		On deck 0.06		severe damage 0	Sinking	67	0.00E+00								
					No sinking	68	0.00E+00								
				no severe damage 1	No sinking	69	2.65E-05	0.7							
	ballast 0.50	Aft Area 0.94	yes 0.06	severe damage 1	Sinking 0	70	0.00E+00								
					No sinking 1	71	2.49E-05	0.6		2		8,250,000	4.99E-05		2.06E+02
				no severe damage 0	No sinking	72	0.00E+00								
			no 0.94	severe damage 0.44	Sinking 0.57	73	9.80E-05	2.5		2		82,500,000	1.96E-04		8.08E+03
					No sinking 0.43	74	7.39E-05	1.9		2		8,250,000	1.48E-04		6.10E+02
				no severe damage 0.56	No sinking	75	2.19E-04	5.6		0.56		2,062,500	1.21E-04		4.51E+02
		On deck 0.06		severe damage 0	Sinking	76	0.00E+00								
					No sinking	77	0.00E+00								
				no severe damage 1	No sinking	78	2.65E-05	0.7							
Limited waters 0.04	loaded 0.50	Aft Area 1.00	yes 0	severe damage	Sinking	79	0.00E+00								
					No sinking	80	0.00E+00								
				no severe damage	No sinking	81	0.00E+00								
			no 1	severe damage 0	Sinking	82	0.00E+00								
					No sinking	83	0.00E+00								
				no severe damage 1	No sinking	84	7.07E-05	1.8							
	ballast 0.50	Aft Area 1.00	yes 0	severe damage	Sinking	85	0.00E+00								
					No sinking	86	0.00E+00								
				no severe damage	No sinking	87	0.00E+00								
			no 1	severe damage 0	Sinking	88	0.00E+00								
					No sinking	89	0.00E+00								
				no severe damage 1	No sinking	90	7.07E-05	1.8							
Shipyards 0.19	STOP														
External 0.01	STO														
By lightning 0.02	STO														

Event Tree: Explosion

Explosion	Operational state	Loaded	Ignition origin	Fire after Explosion	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
Explosion **1.90E-03**	Terminal areas 0.34	loaded 0.20	Aft Area 0.36	yes 0.6	severe damage 0.67	Sinking 0.5	1	9.35E-06	0.2	3.7	152191	82,500,000	3.43E-05	1.42E+00	7.72E+02
						No sinking 0.5	2	9.35E-06	0.2	3.7	10726	8,250,000	3.43E-05	1.00E-01	7.72E+01
					no severe damage 0.33	No sinking	3	9.21E-06	0.2	2.0		2,062,500	1.85E-05		1.90E+01
				no 0.4	severe damage 1	Sinking 0	4	0.00E+00							
						No sinking 1	5	1.86E-05	0.5	3.0	10726	8,250,000	5.58E-05	2.00E-01	1.54E+02
					no severe damage 0	No sinking	6	0.00E+00							
			Cargo/ Slop 0.64	yes 0.56	severe damage 1	Sinking 0.25	7	1.16E-05	0.3	3.7	152191	82,500,000	4.25E-05	1.76E+00	9.55E+02
						No sinking 0.75	8	3.47E-05	0.9	3.7	10726	8,250,000	1.27E-04	3.73E-01	2.87E+02
					no severe damage 0	No sinking	9	0.00E+00							
				no 0.44	severe damage 0.5	Sinking 0	10	0.00E+00							
						No sinking 1	11	1.82E-05	0.5	3.0	10726	8,250,000	5.46E-05	1.95E-01	1.50E+02
					no severe damage 0.5	No sinking	12	1.82E-05	0.5	2.0		2,062,500	3.65E-05		3.75E+01
		ballast 0.80	Aft Area 0.36	yes 0.6	severe damage 0.67	Sinking 0.5	13	3.74E-05	1.0	3.7		82,500,000	1.37E-04		3.09E+03
						No sinking 0.5	14	3.74E-05	1.0	3.7		8,250,000	1.37E-04		3.09E+02
					no severe damage 0.33	No sinking	15	3.69E-05	1.0	2.0		2,062,500	7.39E-05		7.60E+01
				no 0.4	severe damage 1	Sinking 0	16	0.00E+00							
						No sinking 1	17	7.44E-05	1.9	3.0		8,250,000	2.23E-04		6.14E+02
					no severe damage 0	No sinking	18	0.00E+00							
			Cargo/ Slop 0.64	yes 0.56	severe damage 1	Sinking 0.25	19	4.63E-05	1.2	3.7		82,500,000	1.70E-04		3.82E+03
						No sinking 0.75	20	1.39E-04	3.6	3.7		8,250,000	5.10E-04		1.15E+03
					no severe damage 0	No sinking	21	0.00E+00							
				no 0.44	severe damage 0.5	Sinking 0	22	0.00E+00							
						No sinking 1	23	7.28E-05	1.9	3.0		8,250,000	2.18E-04		6.01E+02
					no severe damage 0.5	No sinking	24	7.28E-05	1.9	2.0		2,062,500	1.46E-04		1.50E+02
	Open Sea 0.33	loaded 0.20	Aft Area 0.59	yes 0.29	severe damage 1	Sinking 0.5	25	1.07E-05	0.3	12.5	152191	82,500,000	1.34E-04	1.63E+00	8.85E+02
						No sinking 0.5	26	1.07E-05	0.3	3.5	10726	8,250,000	3.76E-05	1.15E-01	8.85E+01
					no severe damage 0	No sinking	27	0.00E+00							

Operational state	Loaded	Ignition origin	Fire after Explosion	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
			no 0.71	severe damage 0	Sinking	28	0.00E+00							
					No sinking	29	0.00E+00							
				no severe damage 1	No sinking	30	5.25E-05	1.4	1.0		2,062,500	5.25E-05		1.08E+02
		Cargo /Slop 0.33	yes 0.5	severe damage 1	Sinking 0.5	31	1.03E-05	0.3	12.5	152191	82,500,000	1.29E-04	1.58E+00	8.54E+02
					No sinking 0.5	32	1.03E-05	0.3	3.5	10726	8,250,000	3.62E-05	1.11E-01	8.54E+01
				no severe damage 0	No sinking	33	0.00E+00							
			no 0.5	severe damage 1	Sinking 0.5	34	1.03E-05	0.3	2.0	152191	82,500,000	2.07E-05	1.58E+00	8.54E+02
					No sinking 0.5	35	1.03E-05	0.3	2.0	10726	8,250,000	2.07E-05	1.11E-01	8.54E+01
				no severe damage 0	No sinking	36	0.00E+00							
		On deck 0.08	yes 1	severe damage 1	Sinking 1	37	1.00E-05	0.3	12.5	152191	82,500,000	1.25E-04	1.53E+00	8.28E+02
					No sinking 0	38	0.00E+00							
				no severe damage 0	No sinking	39	0.00E+00							
			no 0	severe damage	Sinking	40	0.00E+00							
					No sinking	41	0.00E+00							
				no severe damage	No sinking	42	0.00E+00							
	ballast 0.80	Aft Area 0.59	yes 0.29	severe damage 1	Sinking 0.5	43	4.29E-05	1.1	12.5		82,500,000	5.37E-04		3.54E+03
					No sinking 0.5	44	4.29E-05	1.1	3.5		8,250,000	1.50E-04		3.54E+02
				no severe damage 0	No sinking	45	0.00E+00							
			no 0.71	severe damage 0	Sinking	46	0.00E+00							
					No sinking	47	0.00E+00							
				no severe damage 1	No sinking	48	2.10E-04	5.4	1.0		2,062,500	2.10E-04		4.34E+02
		Cargo /Slop 0.33	yes 0.5	severe damage 1	Sinking 0.5	49	4.14E-05	1.1	12.5		82,500,000	5.17E-04		3.42E+03
					No sinking 0.5	50	4.14E-05	1.1	3.5		8,250,000	1.45E-04		3.42E+02
				no severe damage 0	No sinking	51	0.00E+00							
			no 0.5	severe damage 1	Sinking 0.5	52	4.14E-05	1.1	2.0		82,500,000	8.28E-05		3.42E+03
					No sinking 0.5	53	4.14E-05	1.1	2.0		8,250,000	8.28E-05		3.42E+02
				no severe damage 0	No sinking	54	0.00E+00							
		On deck 0.08	yes 1	severe damage 1	Sinking 1	55	4.01E-05	1.0	12.5		82,500,000	5.02E-04		3.31E+03
					No sinking 0	56	0.00E+00							
				no severe damage 0	No sinking	57	0.00E+00							

Operational state	Loaded	Ignition origin	Fire after Explosion	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
			no 0	severe damage	Sinking	58	0.00E+00							
					No sinking	59	0.00E+00							
				no severe damage	No sinking	60	0.00E+00							
Congested waters 0.09	loaded 0.20	Aft Area 0.25	yes 0	severe damage	Sinking	61	0.00E+00							
					No sinking	62	0.00E+00							
				no severe damage	No sinking	63	0.00E+00							
			no 1	severe damage 1	Sinking 0	64	0.00E+00							
					No sinking 1	65	8.55E-06	0.2	2.1	10726	8,250,000	1.78E-05	9.17E-02	7.06E+01
				no severe damage 0	No sinking	66	0.00E+00							
		Cargo /Slop 0.50	yes 0	severe damage	Sinking	67	0.00E+00							
					No sinking	68	0.00E+00							
				no severe damage	No sinking	69	0.00E+00							
			no 1	severe damage 0.5	Sinking 0	70	0.00E+00							
					No sinking 1	71	8.55E-06	0.2	2.1	10726	8,250,000	1.78E-05	9.17E-02	7.06E+01
				no severe damage 0.5	No sinking	72	8.55E-06	0.2						
		On deck 0.25	yes 1	severe damage 1	Sinking 1	73	8.55E-06	0.2	2.1	152191	82,500,000	1.78E-05	1.30E+00	7.06E+02
					No sinking 0	74	0.00E+00							
				no severe damage 0	No sinking	75	0.00E+00							
			no 0	severe damage 0.5	Sinking 0	76	0.00E+00							
					No sinking 1	77	0.00E+00							
				no severe damage 0.5	No sinking	78	0.00E+00							
	ballast 0.80	Aft Area 0.25	yes 0	severe damage	Sinking	79	0.00E+00							
					No sinking	80	0.00E+00							
				no severe damage	No sinking	81	0.00E+00							
			no 1	severe damage 1	Sinking 0	82	0.00E+00							
					No sinking 1	83	3.42E-05	0.9	2.1		8,250,000	7.10E-05		2.82E+02
				no severe damage 0	No sinking	84	0.00E+00							

Operational state	Loaded	Ignition origin	Fire after Explosion	Damage severity	Ship sinking / Total loss	N°	Frequency	*corresponding expected number of accidents*	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
		Cargo /Slop 0.50	yes 0	severe damage	Sinking	85	0.00E+00							
					No sinking	86	0.00E+00							
				no severe damage	No sinking	87	0.00E+00							
			no 1	severe damage 0.5	Sinking 0	88	0.00E+00							
					No sinking 1	89	3.42E-05	0.9	2.1		8,250,000	7.10E-05		2.82E+02
				no severe damage 0.5	No sinking	90	3.42E-05	0.9						
		On deck 0.25	yes 1	severe damage 1	Sinking 1	91	3.42E-05	0.9	2.1		82,500,000	7.10E-05		2.82E+03
					No sinking 0	92	0.00E+00							
				no severe damage 0	No sinking	93	0.00E+00							
			no 0	severe damage	Sinking	94	0.00E+00							
					No sinking	95	0.00E+00							
				no severe damage	No sinking	96	0.00E+00							
Limited waters 0.02	loaded 0.20	Aft Area 1.00	yes 0	severe damage	Sinking	97	0.00E+00							
					No sinking	98	0.00E+00							
				no severe damage	No sinking	99	0.00E+00							
			no 1	severe damage 1	Sinking 0	100	0.00E+00							
					No sinking 1	101	7.60E-06	0.2		10726			8.15E-02	
				no severe damage 0	No sinking	102	0.00E+00							
	ballast 0.80	Aft Area 1.00	yes 0	severe damage	Sinking	103	0.00E+00							
					No sinking	104	0.00E+00							
				no severe damage	No sinking	105	0.00E+00							
			no 1	severe damage 1	Sinking 0	106	0.00E+00							
					No sinking 1	107	3.04E-05	0.8						
				no severe damage 0	No sinking	108	0.00E+00							
Shipyards 0.22	STOPS													

Event Tree: NASF

	Weather conditions	Operational state	Loaded	Damage nature	Damage extent	Ship sinking	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
NASF **1.93E-03**	Weather related 0.30	Open Sea 0.67	loaded 0.70	hull damage 0.25	severe 1	Sinking 0	1	0.00E+00								
						No Sinking 1	2	6.78E-05	0.7			10726			7.27E-01	
					no severe 0	No Sinking	3	0.00E+00								
				rudder damage 0.25	severe	No Sinking	4	6.78E-05	0.7							
				deck 0.25	severe 0	Sinking	5	0.00E+00								
						No Sinking	6	0.00E+00								
					no severe 1	No Sinking	7	6.78E-05	0.7		2		825,000	1.36E-04		5.59E+01
				other 0.25	no severe	No Sinking	8	6.78E-05	0.7							
			ballast 0.3	hull damage 0.25	severe 1	Sinking 0	9	0.00E+00								
						No Sinking 1	10	2.91E-05	0.3							
					no severe 0	No Sinking	11	0.00E+00								
				rudder damage 0.25	severe	No Sinking	12	2.91E-05	0.3							
				deck 0.25	severe 0	Sinking	13	0.00E+00								
						No Sinking	14	0.00E+00								
					no severe 1	No Sinking	15	2.91E-05	0.3		2		825,000	5.81E-05		2.40E+01
				other 0.25	no severe	No Sinking	16	2.91E-05	0.3							
		Congested waters 0.33	loaded 0.70	deck 0.50	no severe	No Sinking	17	6.68E-05	0.7							
				other 0.50	no severe	No Sinking	18	6.68E-05	0.7							
			ballast 0.30	deck 0.50	no severe	No Sinking	19	2.86E-05	0.3							
				other 0.50	no severe	No Sinking	20	2.86E-05	0.3							
	No weather related 0.70	Terminal areas 0.29	loaded 0.70	internal 0.75	severe	No Sinking	21	2.05E-04	2.1							
				deck 0.25	severe	No Sinking	22	6.85E-05	0.7							
			ballast 0.30	internal 0.75	severe	No Sinking	23	8.80E-05	0.9							
				deck 0.25	severe	No Sinking	24	2.93E-05	0.3							
		Congested waters 0.14	loaded 0.70	Internal 1.00	no severe	No Sinking	25	1.32E-04	1.4							
			ballast 0.30	Internal 1.00	no severe	No Sinking	26	5.67E-05	0.6							

Weather conditions	Operational state	Loaded	Damage nature	Damage extent	Ship sinking	N°	Frequency	*corresponding expected number of accidents*	Scenario	**Consequence to human life**	**Consequence to environment**	**Consequence to property**	**Resulting Risk (People) PLL**	**Resulting Risk (Environment) PLC**	**Resulting Risk (Property) PLP**
	Open Sea 0.50	loaded 0.70	hull damage 0.14	severe	No Sinking	27	6.61E-05	0.7			10726			7.09E-01	
			Internal 0.43	severe 0.33	Sinking 0	28	0.00E+00								
					No Sinking 1	29	6.70E-05	0.7							
				no severe 0.67	No Sinking	30	1.36E-04	1.4							
			rudder 0.29	severe 0.5	No Sinking	31	6.85E-05	0.7							
				no severe 0.5	No Sinking	32	6.85E-05	0.7							
			deck 0.14	severe	No Sinking	33	6.61E-05	0.7							
		ballast 0.30	hull damage 0.14	severe	No Sinking	34	2.83E-05	0.3							
			Internal 0.43	severe 0.33	Sinking 0	35	0.00E+00								
					No Sinking 1	36	2.87E-05	0.3							
				no severe 0.67	No Sinking	37	5.83E-05	0.6							
			rudder 0.29	severe 0.5	No Sinking	38	2.93E-05	0.3							
				no severe 0.5	No Sinking	39	2.93E-05	0.3							
			deck 0.14	severe	No Sinking	40	2.83E-05	0.3							
	limited waters 0.07	loaded 0.70	rudder 1.00	severe	No Sinking	41	6.61E-05	0.7							
		ballast 0.30	rudder 1.00	severe	No Sinking	42	2.83E-05	0.3							

A.3: Statistical Report

Field Data Model

The information on the accidents/ hazardous events was taken from LRFP and LMIU databases. These records were imported into the NTUA-SDL database in order to register the text information in a proper manner and extract specific information for the risk assessment process, Figure 27. Given this extracted information along with information derived from experts or other sources, probabilities of scenario occurrence and potential consequences are calculated. Frequency assessment is based on probabilities extracted from the setup database and relevant Fleet at Risk as provided by LRFP database [1].

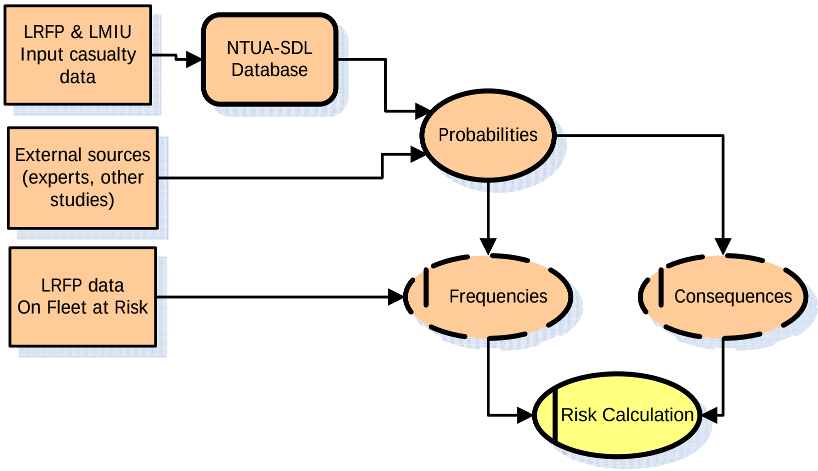


Figure 27

Sample of historical data

Sampling plan of studied tanker subtypes

The study contains tankers of DWT≥ 60,000. The included tanker subtypes are detailed described in [1]. The distribution of these subtypes of tankers involved in the accidents is given in Figure 28 for two different time periods.

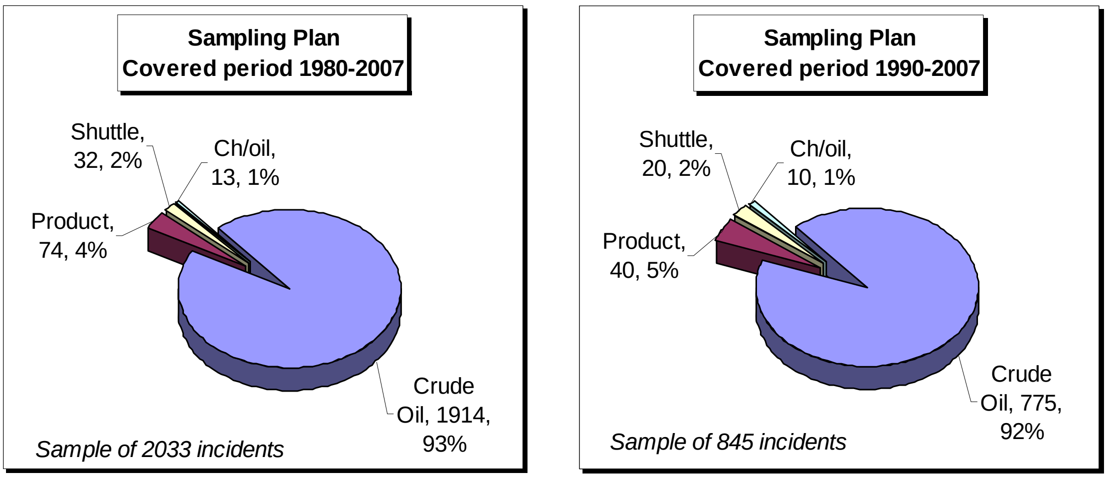


Figure 28

Figure 29 presents the event location of ship at the time of accident. Events in Shipyards and Drydocks reflect to 3-4% of all accidents happened in each time period respectively.

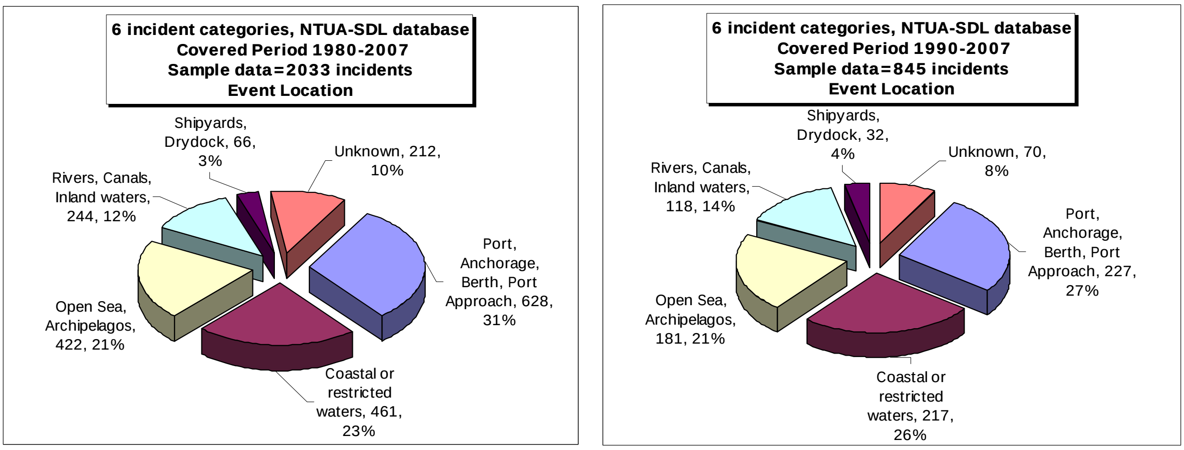


Figure 29

Period 1980-2007

In total, 2033 incidents of serious and non-serious degree of severity were registered in the period 1980-2007. The distribution of incident categories as well as the frequency of each event is given in Figure 30.

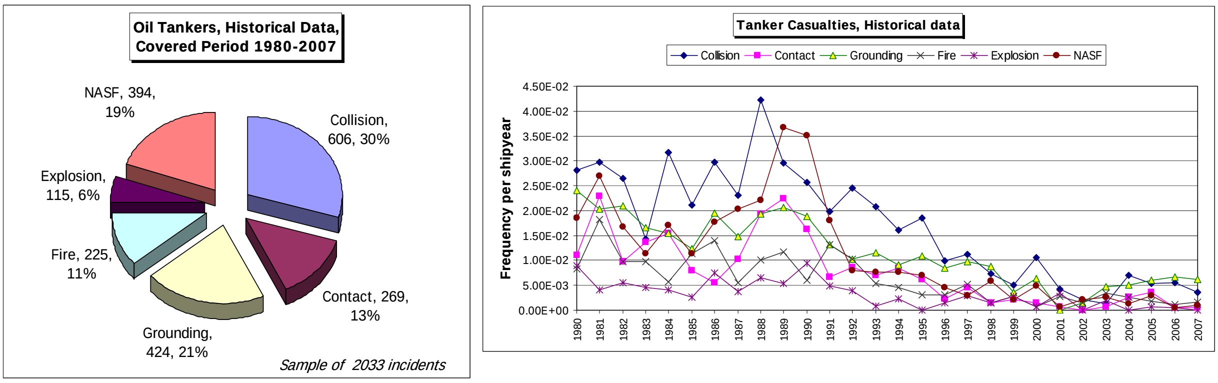


Figure 30

With respect to accidents happened in ship's operational phase, the followings are observed regarding the distribution of incident categories and degree of incidents' severity, Figure 31.

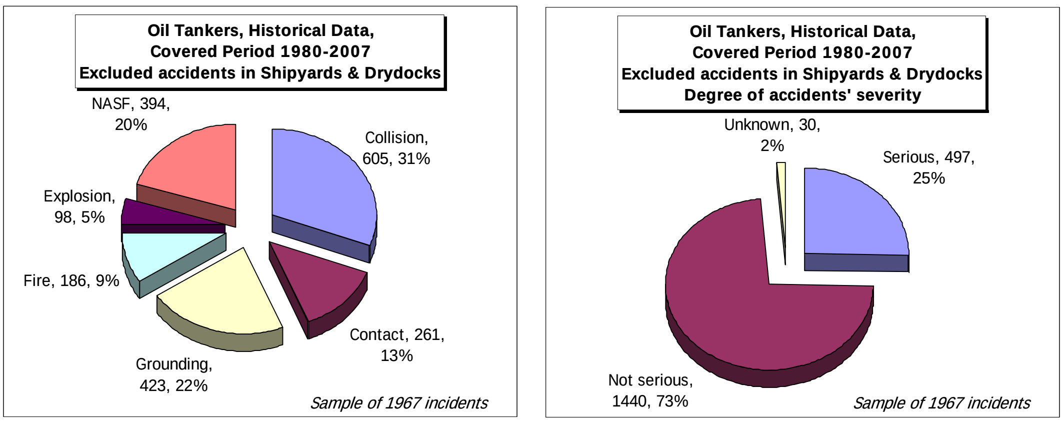


Figure 31

Period 1990-2007

In total, 845 incidents of serious and non-serious degree of severity were registered in the period 1990-2007. The distribution of incident categories and as well as the frequency of each event is given in Figure 32.

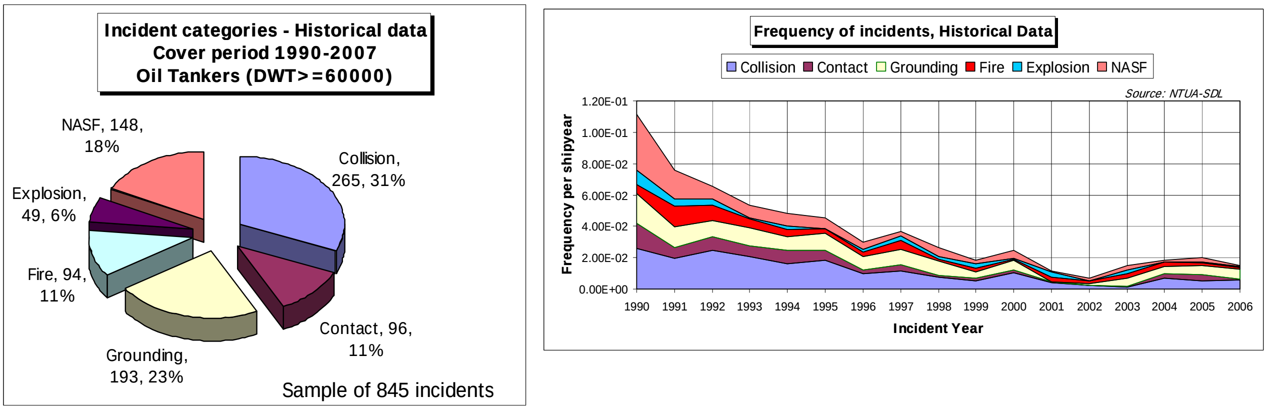


Figure 32

With respect to accidents happened in ship's operational phase, the followings are observed regarding the distribution of incident categories and degree of incidents' severity, Figure 33.

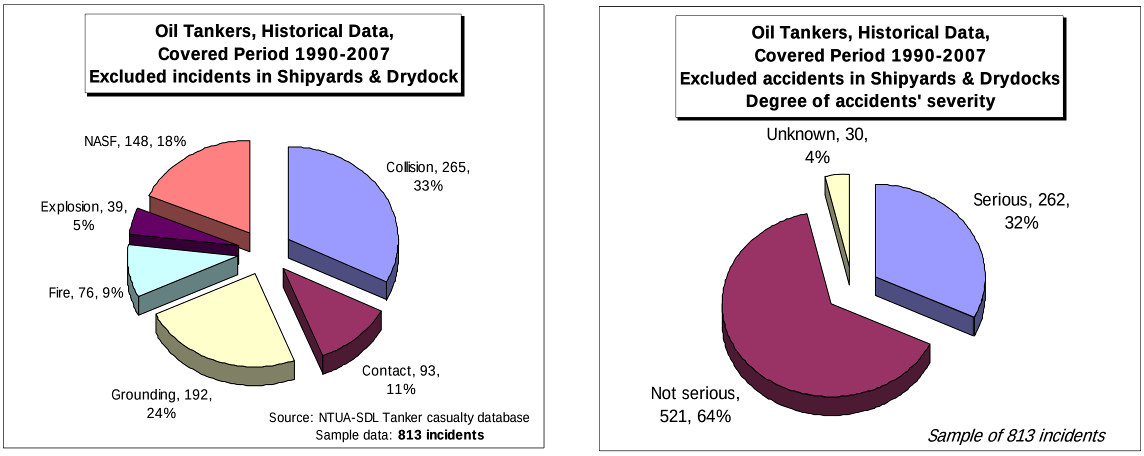
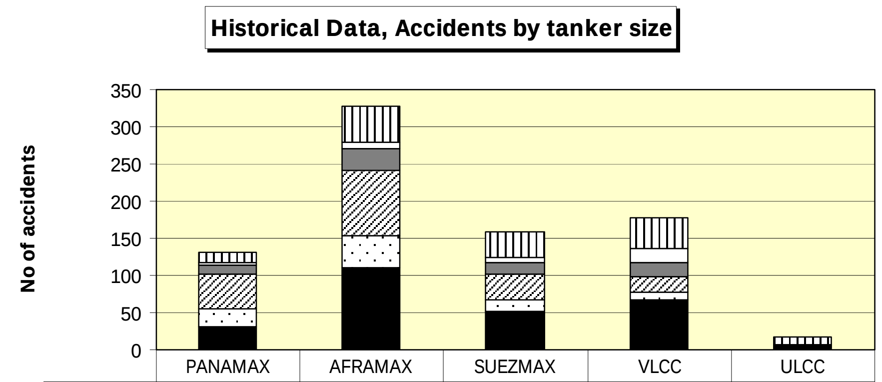


Figure 33

Table 41 presents the average of age of ships involved in the accidents.

Table 41: Average ship age, 813 Incidents	
	Average of ship age
Collision	12.4
Contact	11.8
Grounding	11.4
Fire	15.7
Explosion	15.4
NASF	14.3

Focusing per tanker size, the casualty recording in terms of each incident category is given in Figure 34.



	PANAMAX	AFRAMAX	SUEZMAX	VLCC	ULCC
NASF	13	48	34	42	11
Explosion	5	9	6	19	0
Fire	12	29	16	18	1
Grounding	46	88	35	22	1
Contact	24	43	15	9	2
Collision	31	111	52	68	3

Figure 34

Fleet at Risk

The corresponding Fleet at risk of the studied Oil Tankers subtypes of DWT ≥ 60,000 [1] and the annual proportion of Double Hull and Non-Double Hull ships are presented in Table 42 and Figure 35.

Table 42:Fleet at Risk

Year	PANAMAX	AFRAMAX	SUEZMAX	V&ULCC		4 sizes
1980	237.67	349.41	229.75	641.00		1457.83
1981	249.76	376.92	230.01	626.11		1482.80
1982	250.77	375.77	222.22	582.01		1430.77
1983	232.25	355.25	217.10	518.39		1323.00
1984	208.56	340.64	214.59	465.89		1229.68
1985	197.51	322.84	210.09	409.30		1139.73
1986	191.85	330.08	206.09	348.33		1076.35
1987	197.25	344.04	204.84	335.64		1081.78
1988	199.60	353.05	203.18	334.41		1090.24
1989	198.75	365.70	209.03	345.32		1118.81
1990	202.01	389.49	215.77	362.76		1170.03
1991	206.49	411.28	221.27	375.93		1214.97
1992	201.82	432.45	243.58	389.88		1267.73
1993	203.27	445.62	249.18	399.58		1297.65
1994	203.89	454.62	250.29	402.30		1311.11
1995	200.22	458.05	249.04	387.59		1294.90
1996	200.59	468.14	250.09	393.99		1312.81
1997	201.33	478.21	253.35	398.63		1331.52
1998	200.92	498.86	265.49	401.79		1367.05
1999	202.58	531.04	271.92	403.38		1408.90
2000	213.17	537.41	265.65	400.34		1416.57
2001	218.87	542.82	270.22	413.18		1445.08
2002	219.80	542.59	264.93	402.60		1429.93

2003	223.83	581.76	276.92	416.34		1498.85
2004	240.34	613.79	290.48	430.43		1575.05
2005	267.22	646.08	309.94	459.10		1682.35
2006	306.90	692.29	335.06	480.24		1814.49
2007	340.59	734.28	360.35	506.00		1941.22
	6217.81	*12972.49*	*6990.44*	*12030.47*		*38211.20*

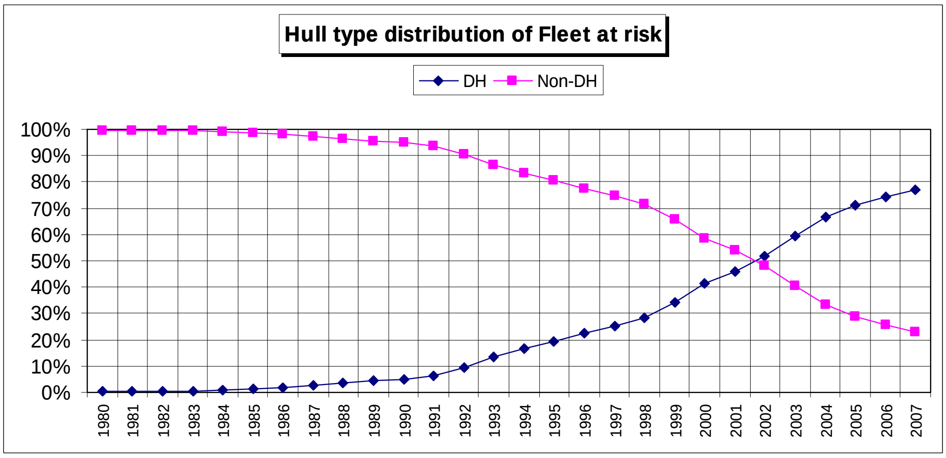


Figure 35

Figure 36 presents the Fleet at Risk by DWT tonne years distributed by tanker size and hull type [2].

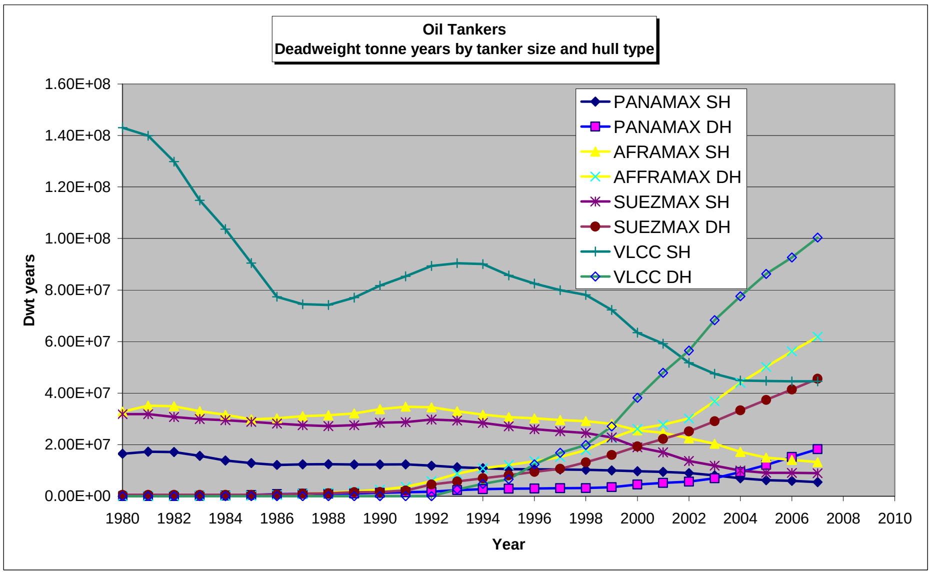


Figure 36

Ship Loading Condition model

Information extracted from LRFP database

Taken into account all accident categories as coded in LRFP database, a ratio of Loaded/Unloaded could be 70/30, Figure 37.

Focusing per LRFP accident category, noting that the recording on this subject is very limited, the results are presented in Table 43.

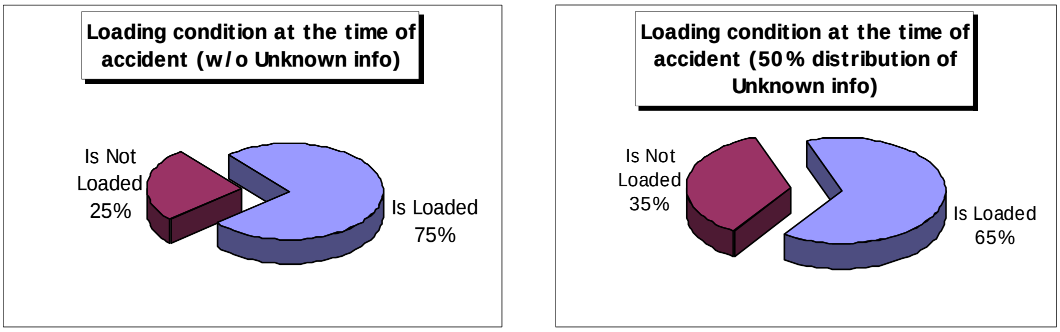


Figure 37

Table 43

	Collision		Contact		Hull/Machinery		Fire/Explosion		Wrecked/Stranded	
w/o taken into consideration the Unknown information										
	#		#		#	%	#	%	#	%
Is Loaded	35	69%	6	67%	51	75%	5	45%	48	86%
Is Not Loaded	16	31%	3	33%	17	25%	6	55%	8	14%
Taken into consideration 50% of Unknown info as loaded and 50% as not loaded										
Is Loaded	55	60%	13	57%	76	64%	10	48%	58	76%
Is Not Loaded	36	40%	10	43%	42	36%	11	52%	18	24%

Experts opinion (ASME provision)

Pollution & grounding accidents are most likely to occur in loaded conditions for obvious reasons. Also more likely to occur are damages on deck due to heavy seas when in loaded condition. Furthermore, the vessel's manoeuvrability is increased when in ballast condition, which suggests that collision accidents are more likely to occur when in loaded condition.

Fire accidents we assume a 50-50 chance for ballast / loaded conditions.

On the other hand, explosion accidents are certainly more likely to occur during ballast condition, when tank washing, purging, entry to cargo spaces, hot works are taking place.

Selection for the risk analysis

The final ratios used in the risk assessment process are given in Table 44.

Table 44

Accident Category	Selected ratio for Loaded/Not Loaded
Collision	60:40
Contact	60:40
Grounding	80:20
Fire	50:50
Explosion	20:80 (experts & setup database)
Non-Accidental Structural Failure	70:30

LOWI occurrence

Based on the setup database, the following was observed with respect to the probability of hull breaching in navigational incidents, Figure 38.

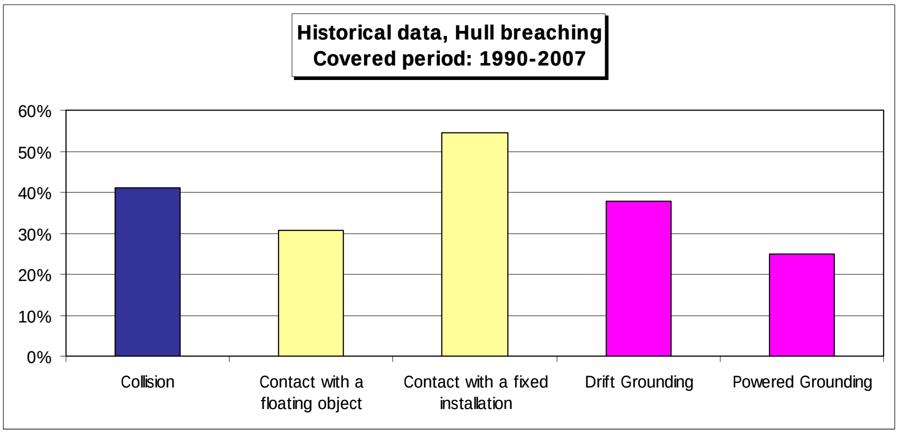
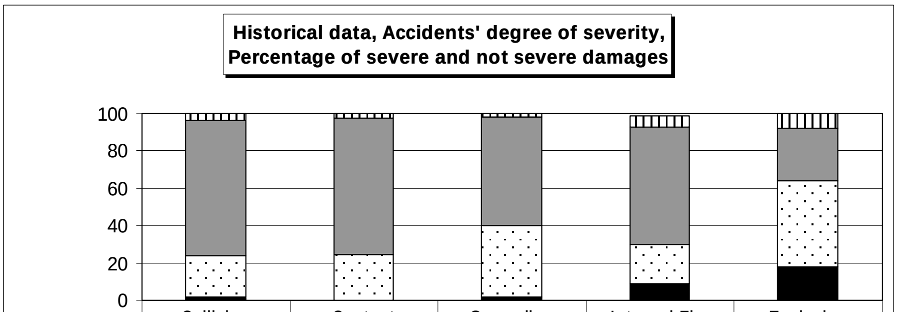


Figure 38

Degree of accident's severity

Based on the sample illustrated in Figure 33, the percentage of registered degree of accidents' severity is presented in Figure 39.



	Collision	Contact	Grounding	Internal Fire	Explosion
Unknown	4	2	2	6	8
Not Serious	72	73	58	63	28
Serious	22	25	38	21	46
Total Loss	2	0	2	9	18

Figure 39

Non-Accidental structural failures

In this paragraph, the statistical results of NASFs are presented independent the ship's hull type occurred within the period 1990-2007.

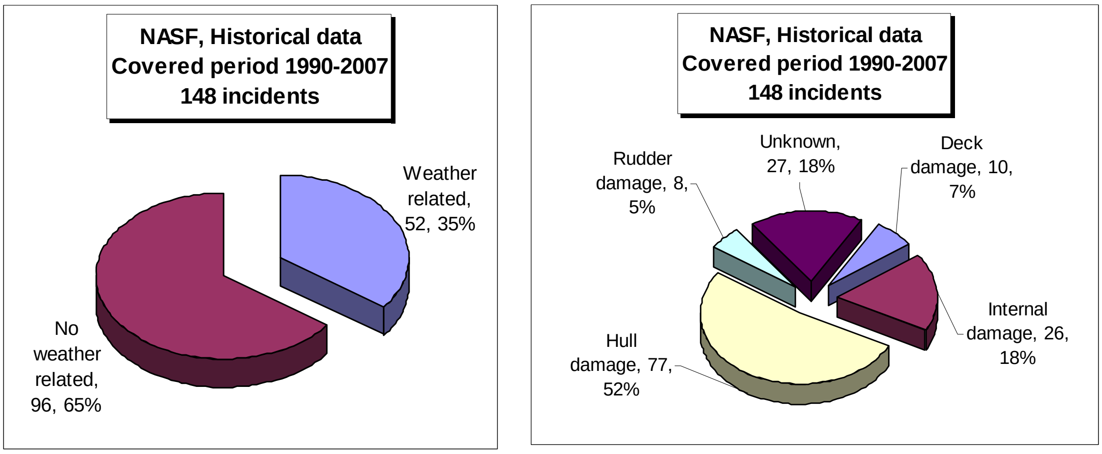


Figure 40

In total, 148 non-accidental structural failures are registered in the setup database. In 52 cases, the environmental condition was a contributor factor to the accident. External hull damage and internal structural damage present the majority of the NASFs events. Figure 40 presents the number of accidents and the distribution of weather relation to the accidents and damage initiation.

Figure 41 presents the operational state and the ship operating condition at the time of accident.

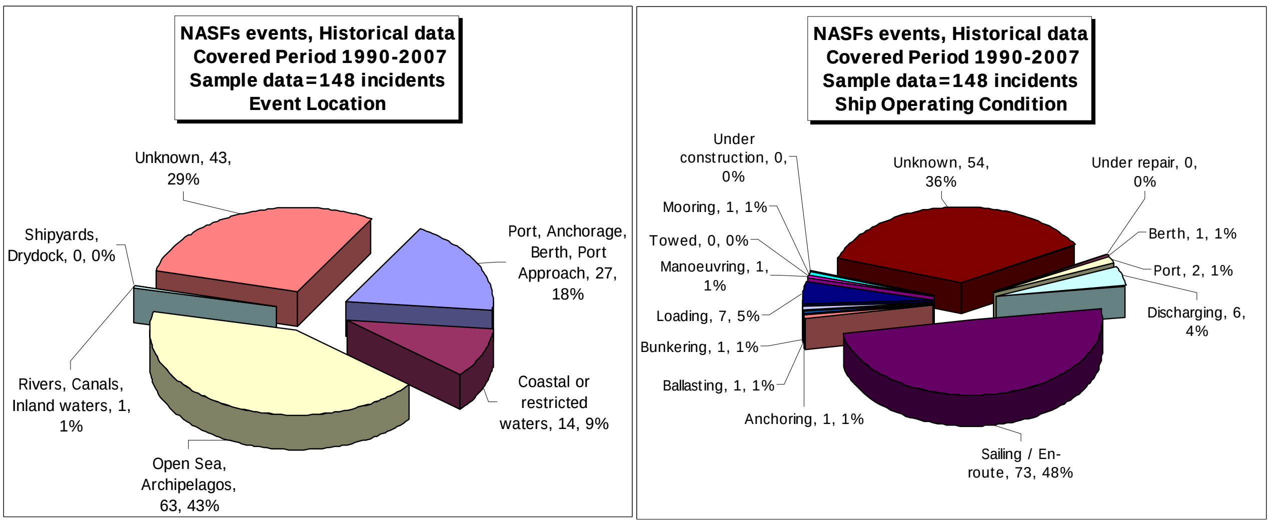


Figure 41

Figure 42 presents the degree of accidents' severity according to the LRFP/LMIU coding. Note that in the 6 cases of ship's total loss, the vessels were of Non-DH construction.

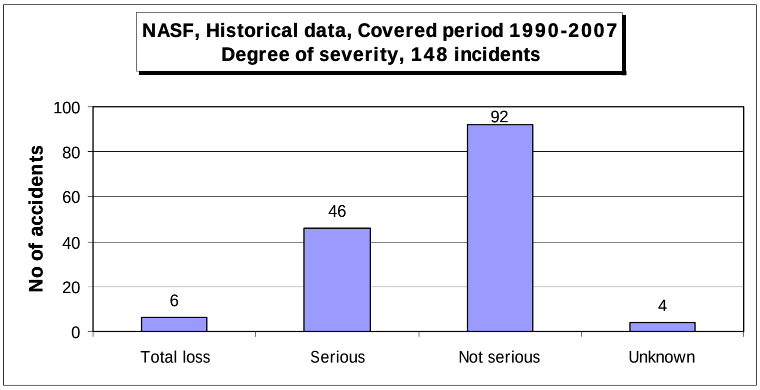


Figure 42

Environmental Pollution

Within the studied period 1990-2007, largest environmental pollution is coming from explosion events. Explosion events with pollution occurrence are not frequent but when they happen, the consequences are the most severe, Table 45.

Table 45			
Covered period 1990-2007 Excluded accidents in Shipyards & Drydocks			
	No of accidents	No of Accidents with pollution occurance	Amount quantity (in tones)
Collision	265	27	126,532
Contact	93	16	13,162
Grounding	192	17	245,942
Fire	76	1	144,000
Explosion	39	3	278,770
NASF	148	38	170,538
	813	102	978,944

Figure 43 presents the number of accidents with oil spill recording, according to Marsden Grid coding.

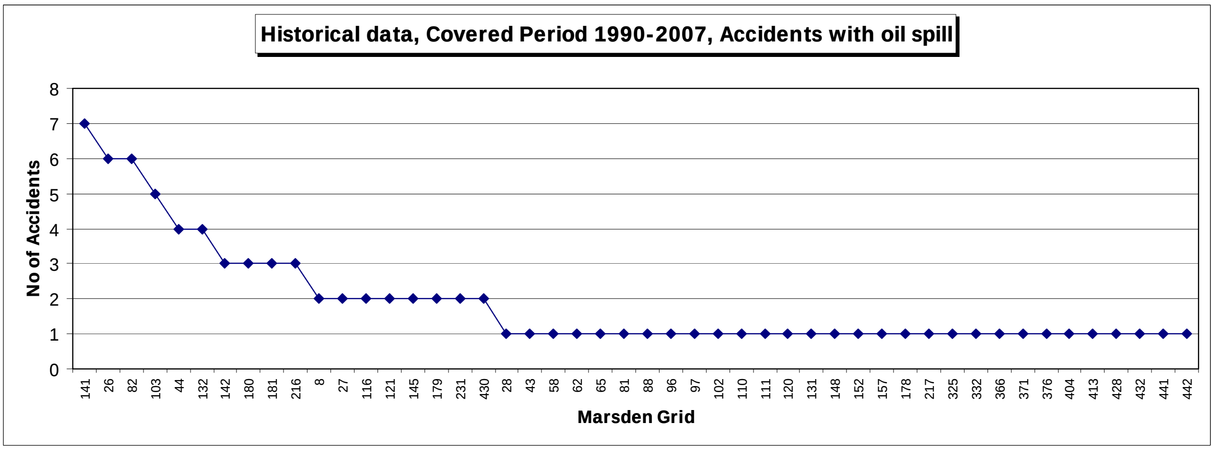


Figure 43

Table 46 presents the Marsden Grid, number of accidents with oil spill occurrence and the related geographic area.

Table 46		
Marsden Grid	No of accidents	Geographic Area
141	7	Suez (Bitter Lake, Port Said)
26	6	Strait of Malacca, Singapore Strait, Indian Ocean
82	6	Gulf of Mexico, Corpus Christi / Aransas Bay
103	5	Gulf of Oman (Al Fujairah)
44	4	Maracaimbo, Venezuela
132	4	Korea Strait (Ulsan, Bussan) - Sea of Japan
142	3	Mediterranean Sea (Alexandria & Libya)
180	3	English Channel
181	3	Scapa Flow Bay, UK
216	3	Hamburg Area
8	2	Panama Canal
27	2	Strait of Malacca, Indian Ocean
116	2	Delaware Bay, USA
121	2	N. America, Pacific Coast
145	2	Bay of Biscay (La Coruna / Brest)
179	2	Mediterranean Sea (Gulf of Venice)
231	2	British Columbia, Canada
430	2	South of Australia

Side vs. Bottom damage

According to [3], the outflow parameters should be calculated independently for collisions and grounding and then combined as follows:

- 0.4 of the combined value for collisions
- 0.6 of the combined value for strandings.

Based on the statistics, the above distribution is not confirmed, Figure 44. It should be noted that the current study investigates scenarios related to navigational incidents for the large tankers. Enhancement with accidents of smaller tankers is needed in order to drawn consistent conclusions.

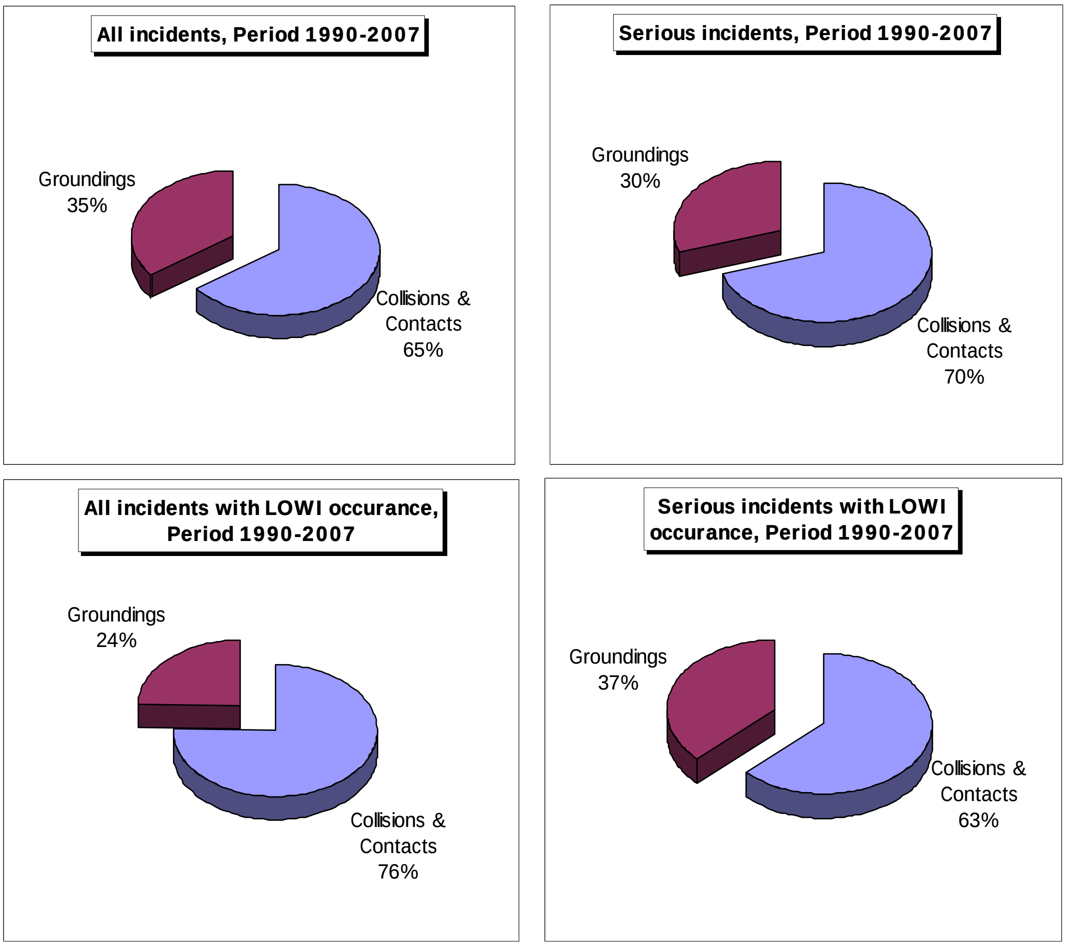


Figure 44

Consequence data model

Environmental impact based on numerical average

The consequences to the environment for each identified scenario are presented as the expected cargo oil tonnes released to the sea.

Table 47 presents the statistical values (mean and standard deviation) for one typical tank size in tonnes that is based on actual data of 1450 ships (Panamax, Aframax, Suezmax, VLCC/ULCC ships), registered in LRFP database [4]. For the purpose of this study, the numerical average size of one tank is taken into consideration for the calculation of expected oil outflow in those scenarios, where *given the accident and the ship is assumed loaded, the inner hull is breached and there is a severe damage without ship sinking.*

Table 47: Average of tank size for SH and DH ships

	SH ships		DH ships	
	Mean (t)	Stdw(t)	Mean(t)	Stdw(t)
PANAMAX	6450.9	1813.5	5285.8	1372.3
AFRAMAX	9298.5	2424.5	8145.8	1654.4
SUEZMAX	10947.9	2622.3	11365.7	2255.4
VLCC&ULCC	19828.4	2443.2	18106.5	2924.2
Average of typical tank sizes, in tonnes			10726	

Based on the capacity of the reference vessels, the total cargo volume is presented in Table 48 for each reference vessel along with the total oil cargo carried based on the assumption of 98% fully loaded and oil specific weight 0.85 t/m^3. For the purpose of this study, the numerical average value of total oil cargo weight is used in the consequences assessment, in those scenarios where *given the accident, the ship is loaded and the accident results to ship's total loss.*

Table 48: Reference ships, Oil cargo carried

Reference Vessel	100%Volume (m^3)	Oil cargo (in tonnes) *(98% full, 0.85 t/ m^3)*
PANAMAX	80,659	67,189
AFRAMAX	125,203	104,294
SUEZMAX	174,846	145,647
VLCC	350,100	291,633
	182,702	*152,191*

Environmental impact based on weighted average

Another approach, instead of using the numerical average values of a generic ship's cargo tank, could be to evaluate the expected oil cargo release by using a generic ship's cargo tank resulting from a weighted value considering the Fleet at Risk of tanker size distribution.

Figure 45 presents the distribution of accidents and Fleet at Risk by tanker size. The share of each tanker category in the distribution of accidents and of the Fleet at Risk is very similar.

Taking into account the share of each tanker category in the Fleet at Risk, the weighted average of a generic ship's tank size and oil cargo carried is given in Tables 49 & 50; it is concluded that there is no significant difference between the two approaches.

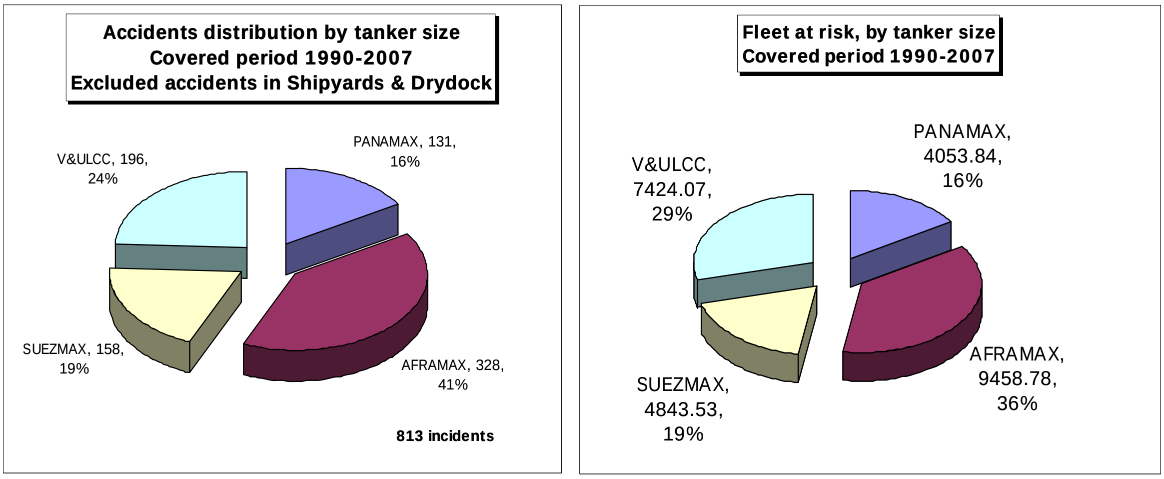


Figure 45

Table 49: Weighted Average of tank size for DH ships

	DH ships		
	wti	Mean tank size (t)	
PANAMAX	0.16	5285.8	845.7
AFRAMAX	0.36	8145.8	2932.5
SUEZMAX	0.19	11365.7	2159.5
VLCC&ULCC	0.29	18106.5	5250.9

Weighted Average of typical tank sizes, in tonnes	11,189

Table 50: Reference ships, Oil cargo carried			
Reference Vessel	wti	Oil cargo (in tonnes) *(98% full, 0.85 t/ m³)*	
PANAMAX	0.16	67,189	10750.2
AFRAMAX	0.36	104,294	37545.9
SUEZMAX	0.19	145,647	27672.9
VLCC	0.29	291,633	84573.7
Weighted average value of oil cargo carried			*160,543*

Potential Loss of Oil Cargo

The present high level risk analysis gives an overview of risk issues of large size oil tankers (over 60.000 tonnes DWT). Due to time limitations, the present study focused on an average size of these large tanker ship categories.

In the risk assessment of oil tankers, the Potential Loss of oil Cargo (PLC) is an essential parameter of risk evaluation. This parameter as well as the ship's damage cost varies significantly among the reference, generic tanker ships.

For the purpose of a more realistic overall risk assessment approach, two additional considerations have been taken into account and are presented in the following subsections.

Keeping the same frequencies

Keeping the same frequencies for all four studied tanker categories, the consequence model was changed in terms of environmental and economic impact for each reference vessel, by using its corresponding values. This resulted to the generation of four event trees (one per tanker size) for each studied event.

Based on this procedure, the Potential Loss of Cargo (PLC) was estimated for each reference category vessel and is presented in Figure 46 (bars) along with PLC derived from the unified calculations for representative ship for all tankers of DWT≥ 60,000 tonnes (line).

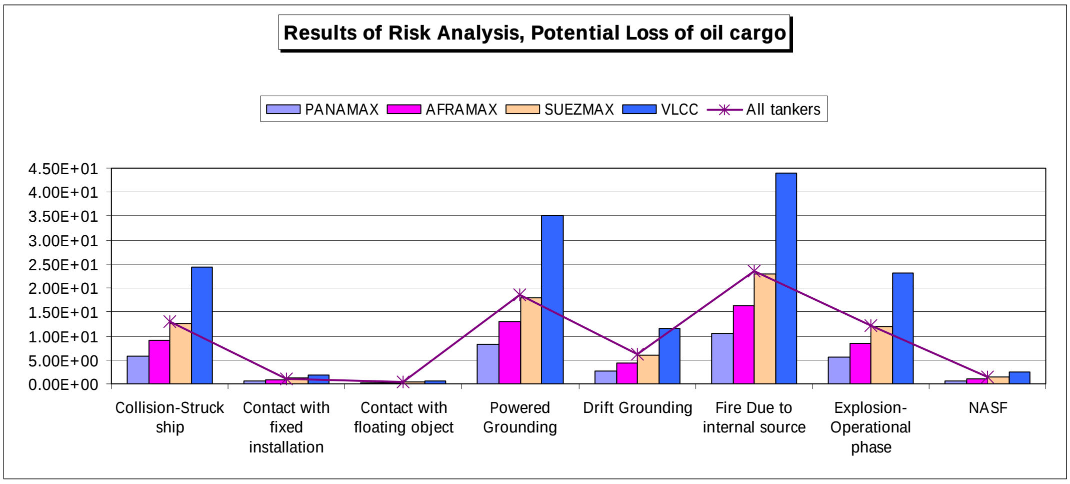


Figure 46

Changing the frequencies

Accounting for the different frequencies (per tanker category)

Figure 47, but keeping else the same probabilities in the Event Tree analysis, and accounting as well for the individual consequence model for each tanker category, the results change as indicated in the Figure 48 (modified results marked with -1 – shaded bars).
Compared to the former procedure, the PLC of V&ULCC for grounding and fire events appear significantly reduced.

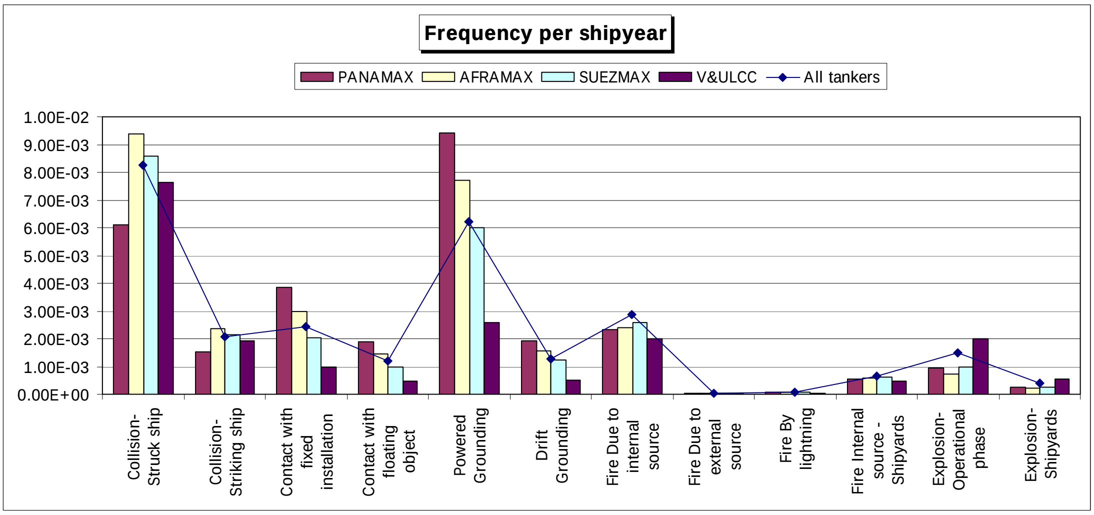


Figure 47

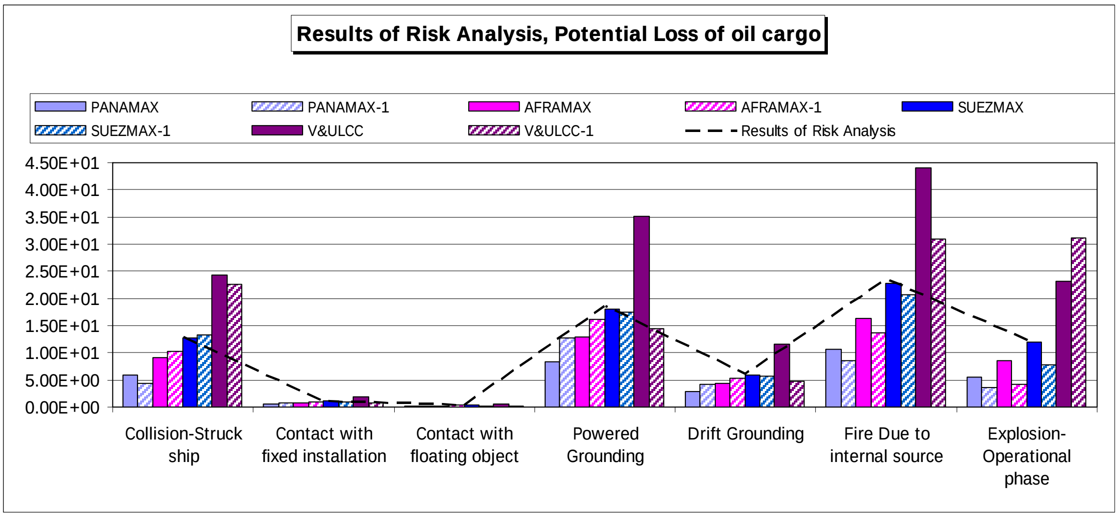


Figure 48

References of A.3

[1] Loer K. and Hamann R., 2007, "HazId of Tanker Operation", SAFEDOR Deliverable D4.7.1.

[2] Hamann R., 2008, "Statistical values of tank size", GL provision, March 2008.

[3] MARPOL 73/78, "Appendix 7: Interim guidelines for the approval of alternative methods of design and construction of oil tankers under regulation 13f(5) of Annex I.

[4] Hamann R., 2008, "Statistical values of tank size", GL provision, March 2008.

Annex II: Risk Control Options and Cost Benefit Analysis

12 Introduction

This annex presents steps three and four, namely the risk control options and cost benefit analysis, of a high-level Formal Safety Assessment (FSA) pertaining to large oil tanker ships according to the FSA guidelines issued by IMO [1]. In this third stage different risk control options (RCOs) are identified to control the major risks identified in the previous tasks of this sub-project. The RCOs are then assessed through cost benefit analysis using the standard IMO procedures and criteria for cost effectiveness. The assessment consists of three parts:

- Identification of relevant risk control options
- Estimation of risk reducing effect of identified RCOs
- Evaluation of cost benefit of RCOs

The risk is reduced either through reduction of frequency or consequence, or both. Only cost effective RCOs – i.e. when delta cost divided by delta risk is below the International Maritime Organisation (IMO) value (cost effectiveness criteria) [41] – are recommended.

The results from the previous tasks *D4.7.1 Hazard Identification* [60] and *D4.7.2 Risk Analysis* [61], presented in Annex I, are used in this task *Risk Control Options and Cost Benefit Analysis* covering the final steps of the FSA process. The list of prioritised hazards has been used as input for building risk-models and to the identification of appropriate risk control options. In parallel there is an ongoing harmonization effort between this project and other FSA projects (SP4.1, SP4.2, SP4.3 and SP4.4), each of them performing an FSA for specific ship types (Cruise, RoRo-Passenger, LNG and Container ships). It is intended to establish common procedures, ranking criteria, and presentation structures.

13 FSA Methodology

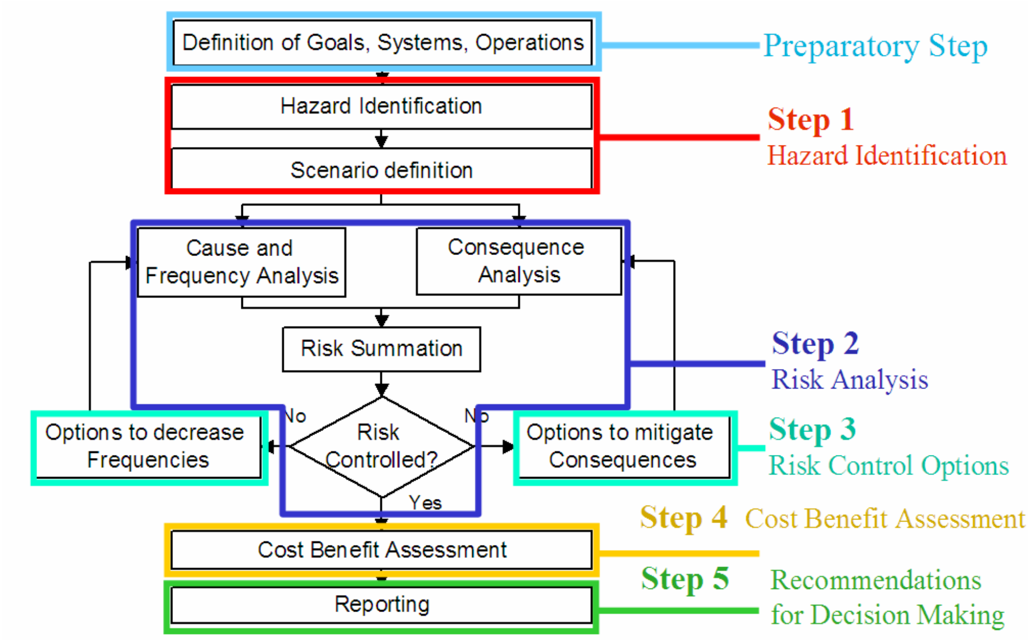


Figure 49: The five steps of Formal Safety Assessment

Figure 49 shows the five main steps of the Formal Safety Assessment (FSA) approach, detailing what each step is comprised of and how the various steps are interrelated. This report is mainly related to the FSA steps 3, 4 and 5 but it is an iterative process to assess the risk reduction effect of identified risk control options. The total risk, defined as the combination of frequency and severity summed up over all identified accident scenarios may be controlled by a number of well-known or newly identified risk control options. Finally, the objective of the cost benefit assessment step is to identify and rank the risk control options in order to determine the most cost efficient ones, i.e. those that provide most risk reduction in relation to cost. The risk models developed in D4.7.2 (in accordance with step 2 of the FSA method) are used for re-evaluation of the total risk after implementation of risk control measures.

The following subsections are based on the IMO FSA Guidelines [40].

13.1 Risk Control Options

The purpose of Step 3 in Figure 49 is to propose effective and practical RCOs comprising the following stages:

1. Focusing on risk areas needing control;
2. Identifying potential RCOs;
3. Evaluating the effectiveness of the RCOs in reducing risk by re-evaluating Step 2 (Figure 49); and
4. Grouping RCOs into practical regulatory options.

The objective of this study is to address points 1-3 only. The purpose of focusing on risk areas is to screen the output of Step 2 (Figure 49) so that the effort is focused on the areas most needing risk control. The main aspects to making this assessment are to review the risk levels, by considering the frequency of occurrence together with the severity of the outcomes. Accidents with an unacceptable risk level become the primary focus.

Structured review techniques are typically used to identify new RCOs for risks that are not sufficiently controlled by existing measures. These techniques may encourage the development of appropriate measures and include risk attributes and causal chains. Risk attributes relate to how a measure might control a risk, and causal chains relate to where, in the "initiating event to casualty" sequence, risk control can be introduced. RCOs should in general be aimed at one or more of the following:

1. Reducing the frequency of failures through better design, procedures, organizational polices, training, etc;
2. Mitigating the effect of failures, in order to prevent accidents;
3. Alleviating the circumstances in which failures may occur; and
4. Mitigating the consequences of accidents.

The output from this step comprises:

1. A range of RCOs which are to be assessed for their effectiveness in reducing risk.; and
2. A list of interested entities affected by the identified RCOs.

This study addresses point 1 only.

13.2 Cost Benefit Assessment

The purpose of Step 4 (Figure 49) as described in [40] is to identify and compare the achieved risk reduction and benefits with the costs associated with the implementation of each RCO identified and defined in Step 3 (Figure 49). A cost efficiency assessment following the IMO procedure may consist of the following stages:

1. Consider the risks assessed in Step 2 (Figure 49), both in terms of frequency and consequence, in order to define the base case in terms of risk levels of the situation under consideration;
2. Arrange the RCOs, defined in Step 3 (Figure 49), in a way to facilitate understanding of the costs and benefits resulting from the adoption of an RCO;
3. Estimate the pertinent costs and benefits for all RCOs by reassessing the risk assuming the option under consideration is in place and comparing this risk level to the established base case;
4. Estimate and compare the cost effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option; and
5. Rank the RCOs from a cost-efficiency perspective in order to facilitate the decision-making recommendations in Step 5 (Figure 49) (e.g. to screen those that are not cost effective or impractical). Costs should be expressed in terms of life cycle costs and may include initial setup, operating, training, inspection, certification, decommission etc. Benefits may include reductions in fatalities, injuries, casualties, environmental damage and clean-up, indemnity of third party liabilities, etc. and an increase in the expected operating life of ships. There are several indices used by IMO that express cost effectiveness in relation to safety of life and the environment; for the purposes of this study the Gross Cost of Averting a Fatality (GCAF) (Equation 1), Gross Cost of Averting one Tonne of Oil Spilled (CATS) [43] (Equation 2) and Net Cost of Averting a Fatality (NCAF) (Equation 3) are used.

The definitions of GCAF, CATS and NCAF are:

$$GCAF = \frac{\Delta C}{\Delta R_S} \qquad \textbf{Equation 1}$$

$$CATS = \frac{\Delta C}{\Delta R_E} \qquad \textbf{Equation 2}$$

$$NCAF = \frac{\Delta C - \Delta B}{\Delta R_S} \qquad \textbf{Equation 3}$$

Where:

ΔC is the cost per ship of the risk control option during the lifetime of the vessel.
ΔB is the economic benefit per ship resulting from the implementation of the risk control option during the lifetime of the vessel (includes environmental and property benefits).
ΔR is the risk reduction per ship, either in terms of the number of fatalities averted (ΔR_S) or tonnes of oil spilled prevented (ΔR_E), implied by the risk control option during the lifetime of the vessel.

The output from this step comprises:

1. Costs and benefits for each RCO identified in Step 3 (Figure 49) from an overview perspective;
2. Costs and benefits for those interested entities which are the most influenced by the problem in question: and
3. Cost effectiveness expressed in terms of suitable indices.

For the purposes of this study only points 1 and 3 described above are addressed.

13.3 Recommendation for Decision Making

The purpose of Step 5 (Figure 49) is to develop recommendations that can be presented to the relevant decision makers in an auditable and traceable manner. Those recommendations are based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of those risk control options which keep risks as low as reasonably practicable. There are several standards for risk acceptance criteria [42][50], however none are presently universally accepted. IMO has published criteria to be used in rule making for GCAF and NCAF [56] and to comply with IMO's requirements these values have been used to assist judgements about the effectiveness of RCO's in this work. The output from Step 5 (Figure 49) comprises:

1. An objective comparison of alternative options, based on the potential reduction of risks and cost effectiveness, in areas where legislation or rules should be reviewed or developed; and
2. Feedback information to review the results generated in the previous steps.

14 Risk Control Options

14.1 Identification of RCOs

Potential risk control options (RCOs) were identified during brainstorming sessions carried out at the National Technical University of Athens in Greece in March 2008. The identification of new RCOs was driven by the review of SAFEDOR D4.7.2 and by the project member brainstorming sessions which involved consultation of experts representing class, industry and academia. (See A.5 for names and positions).

Measures reducing accident consequence and measures reducing accident frequency were sought. From the identification process an extensive list containing all identified RCOs [A.2] was generated. From this list, a selection of nine RCOs was eventually chosen to carry forward for further analysis as identified below.

14.2 Screening of RCOs

To obtain a practicable number of RCOs to analyse in detail a screening process was undertaken on all RCOs identified during the brainstorming meeting at the National Technical University of Athens (March 2008), of which there were seventy-nine (90 RCOs appear in [A.2] but some RCOs appear more than once for different aspects). The screening process eliminated those RCOs which are least likely to be cost effective according to the IMO procedures and criteria. This reduced the number of RCOs down to a manageable number for a more thorough analysis within the time frame allocated for this task. Ultimately 12 RCOs were prioritised [A.3], when were then reduced to nine by the project team (Table 51). The screening process was performed by experts from academia, class, flag state administrations and industry during the meeting conducted at NTUA described above.

The first step of the screening was to order the RCOs into a prioritised list using the following criteria:

1. Preventive options should have priority before mitigating options;
2. Design options should have priority before operative measures; and
3. Passive systems should have higher priority than active systems.

The rating of the RCOs "estimated effect" was discussed. The effect was evaluated through separating the different effects of the RCO and mapping them up against the relevant areas in the Event Trees of Annex I. All RCOs were subjected to a crude estimation of the risk reducing potential, closely linked to the risks described in Annex I. Then, crude cost estimates were used to screen high effect RCOs.

Most of the RCOs considered and discarded will not be discussed further. For the full list of suggested RCOs see [A.2].

14.3 Selected RCOs

The above considerations result in a list of nine RCOs which are studied in detail, and evaluated for cost effectiveness in the following chapter. The nine RCOs to be evaluated are listed in Table 51 below:

Table 51: RCOs Selected for Cost Benefit Analysis	
No	**RCO**
RCO 3	Active Steering Gear Redundancy
RCO 4	Electronic Chart Display and Information System (ECDIS)
RCO 5	Terminal Proximity and Speed Sensors (Docking Aid)
RCO 6	Navigational Sonar
RCO 7	Design modifications to reduce collision, contact, grounding and oil pollution risks
RCO 8	Better implementation of Hot Work Procedures
RCO 9	Double Sheathed Fuel oil pipes within the engine room
RCO 11	Engine control room additional emergency exit
RCO 12	Hull stress and fatigue monitoring system

15 Cost Efficiency Analysis

The RCOs listed in Table 51 are analysed in this chapter using the methods and criteria set out by the IMO [40] & [56] are used in the following subsections to evaluate risk reduction, costs and benefits.

Net Present Value (NPV)
The cost and benefit of the RCOs is spread over the lifetime of the vessel, which is considered to be 25 years for the purposes of this study. Some RCOs may involve costs annually while others only involve costs at given intervals. In order to be able to compare the costs and benefits and calculate the NCAF and GCAF, Net Present Value (NPV) calculations have been performed on applicable RCOs using Equation 4 as given below:

$$NPV = A + \frac{X}{(1+r)} + \frac{X}{(1+r)^2} + \frac{X}{(1+r)^3} + \ldots + \frac{X}{(1+r)^T} = A + \sum_{t=1}^{T} \frac{X}{(1+r)^t}$$

Equation 4

Where:

X = Cost or benefit of RCO for any given year
A= Amount spent initially for implementation of RCO
r = Discount rate
T = 25 (years)

A uniform discount rate of 5% has been used. (This is based on the 'real' above inflation risk free rate of return i.e. 3% inflation and 8% depreciation).

Delphi Method
The Delphi Method was used to gather opinion from DNV experts with extensive practical and theoretical experience of shipping operations with regards to the risk reduction that could be expected with the implementation of the chosen RCOs. To this end the selected experts [A.5] answered questionnaires in two rounds; after each round, a facilitator provided an anonymous summary of the experts' forecasts from the previous round. This process encouraged the revision of earlier answers in light of the replies of other members of the group. During this process the variation in the answers decreased and the group converged towards what is believed to be the "correct" answer. The Delphi Method was employed as it recognizes the value of expert opinion, experience and intuition and allows using the limited information available in these forms, when full scientific knowledge is lacking. In addition, comment with regards to the risk reduction benefit of the various RCOs was also sought from internal and external expert sources [A.6] in order to validate expert opinion gathered during the Delphi meeting.

The experts detailed in [A.5] were involved in a Delphi Method workshop on 14 May 2008 at the headquarters of DNV in Høvik, Norway.

15.1 Risk Reduction of Selected RCOs

All RCOs are assessed independently of each other and associated costs and benefits are calculated at new build stage.

15.1.1 Active Steering Gear Redundancy

This RCO relates to the automatic changeover of the steering gear pump/motor within the steering gear system in the event of failure to reduce the risk of collision/grounding. Upon discussion with experts in the field of ship control systems within DNV [A.5], it has been identified that there would normally be one steering gear pump/motor in use at open waters. In narrow waters and when docking two (both) steering gear pumps/motors are in operation. In event of a pump/motor or electrical failure in narrow waters and in terminal areas, the second pump would already be operating and would be sufficient to control the ship steering gear.

In the event of failure of the running pump or electrical supply in open waters, the navigator is alerted by an audio and visual alarm and will start the second pump manually if not already running. This would suggest that the benefit gained through introduction of this RCO is the reduction in reaction time and the reduced possibility of human error. From the above statement it is clear that any introduction of an automatic changeover facility will only provide risk reduction benefit at open sea.

Through a workshop by means of the Delphi technique using DNV experts [A.5], it was agreed that a risk reduction of 10% with regards to fatalities from powered groundings can be expected from this active steering gear redundancy in open waters, taking into account that not all powered groundings are caused by loss of steering (although the majority are). Using the Collision Event Tree of Annex I it is clear that there is no perceived risk of fatality when striking, as such no risk reduction could be applied. Using the Grounding Event Tree of Annex I, calculations indicate that 4.8E-06 lives per ship year or 1.2E-04 over the 25 year lifetime of a tanker will be saved. Therefore, this RCO is expected to save one life every 208,000 ship years. In terms of potential loss of cargo, calculations suggest that 6.3E-01 tonnes of oil per ship year and 1.6E+01 over the 25 year ship lifetime could be prevented from being spilled.

15.1.2 Electronic Chart Display and Information System (ECDIS)

Electronic Chart Display Information System (ECDIS) means a navigation information system which, with adequate back up arrangements, can be accepted as complying with the up-to-date chart required by Chapter V of the SOLAS Convention [44].

Many detailed studies have previously been carried out considering the implementation of ECDIS across all ship types. DNV have previously identified that a risk reduction of 36% for powered grounding can be expected from the implementation of ECDIS [58] and this was further established through MSC 81/24/5 [57].

Using the grounding Event Tree of Annex I, calculations indicate that 4.7E-05 lives per ship year or 1.2E-03 over the 25 year lifetime of a tanker will be saved. Therefore, this RCO is expected to save one life every 21,000 ship years. In terms of potential loss of cargo, calculations suggest that 6.7E+00 tonnes of oil per ship year and 1.7E+02 over the 25 year ship lifetime may be prevented from being spilled.

15.1.3 Terminal Proximity and Speed Sensors (Docking Aid)

When considering docking aid systems there are three main categories which includes Doppler, ship/land based GPS, and shore based laser/radar. For this study the Doppler system will only be contemplated as consideration for land based systems is outside the scope of this project.

- Doppler systems are common and have been in use for many years. This system displays the bow and stern movement information in the way of direction and speed. This system is considered accurate and well suited to current ship practice.
- Ship + Land based GPS systems use a GPS beacon located on the buoy/ dock and a GPS system on the ship that displays data from the buoy indication relative position between the ship and buoy.
- Shore based Laser/ radar uses laser or radar to measure the distance from the dock to the ship and displays it on a digital board on the dock.

Using the contact Event Trees of Annex I, it is clear that there is no perceived risk of fatality in relation to the ship in terminal areas. As such, there is no perceived reduction in the risk of fatality due to the implementation of a Doppler type docking system. In terms of potential loss of cargo, calculations suggest that 1.4E-01 tonnes of oil per ship year and 4E+00 over the 25 year ship lifetime may be prevented from being spilled.

15.1.4 Navigational Sonar

Navigational Sonar systems have been in use for some time, largely for cruise and smaller ships. The extra consideration with larger ships, such as a VLCC, is the reaction capability after identification of a grounding hazard. It is noted that the stopping distance of a 300 metre VLCC travelling at 15 knots is over 2.4 Nautical Miles as can be seen in reference [59]. Although the ship would only have to turn and not have to come to a complete stop to avoid a grounding hazard, this demonstrates the lack of manoeuvrability that large ships possess. Typical commercial forward looking navigational sonar systems have a range of about 0.25 to 0.5 nautical miles (NM), although to date this is largely due to industry demand rather than the limitations of the technology.

Through a workshop by means of the Delphi technique using DNV experts [A.5], it was agreed that a risk reduction of 15% with regards to fatalities from powered grounding accidents can be expected from the introduction of navigational sonar. Using the grounding Event Tree of Annex I, calculations indicate that 2.0E-05 lives per ship year or 4.9E-04 over the 25 year lifetime of a tanker will be saved. Therefore, this RCO is expected to save one life every 51,000 ship years. In terms of potential loss of cargo, calculations suggest that 2.8E+00 tonnes of oil per ship year and 7.0E+01 over the 25 year ship lifetime may be prevented from being spilled.

15.1.5 Ship Design Modifications

This RCO investigates the effectiveness of three potential hull design modifications, namely:

- **<u>RCO 7.1</u>: Enhanced Cargo Tank Subdivision**
- **<u>RCO 7.2</u>: Increased Double Bottom Height**
- **<u>RCO 7.3</u>: Increased Side Tanks Width**

The potential offered by these RCOs on reducing oil pollution risks due to collision, contact and grounding incidents, and their corresponding cost-effectiveness, are investigated. The potential for oil outflow risk reduction is calculated for all cases using the Event Tree models for collision, contact and grounding of Annex I. The potential offered by these RCOs on reducing risks to life is negligible, hence not investigated. Calculations are carried out for the four representative tankers (Panamax, Aframax, Suezmax and VLCC) used as reference vessels in Annex I, for the following alternatives and ranges of variation (see A.7 for supporting background information):

- <u>RCO 7.1</u>: The current cargo tank configurations of the four representative tankers referred to in [A.7] are a 6 × 2 configuration for the Panamax, Aframax and Suezmax (an arrangement with 6 transverse bulkheads and a longitudinal bulkhead on the centreline, resulting in a 12 cargo tank arrangement) and a 5 × 3 configuration for the VLCC (an arrangement with 5 transverse bulkheads and two longitudinal bulkheads, resulting in a 15 cargo tank arrangement). These are the most typical cargo tank configurations in today's oil tanker fleet. On the alternatives considered, an additional longitudinal bulkhead was considered for the Panamax, Aframax and Suezmax and an additional transverse bulkhead was considered for the VLCC, resulting in all cases in a 6 × 3 cargo tank arrangement. Potential risk reduction is calculated for collision, contact and grounding incidents.

- <u>RCO 7.2</u>: The four representative tankers feature double bottoms of heights 2.04 m, 2.30 m, 2.80 m and 3.00 m (Panamax, Aframax, Suezmax and VLCC, respectively) in way of the cargo area. Parameter studies are performed considering double bottom height increases of 0.50 m and 1.00 m for the 6 × 2 cargo tank configuration for the Panamax, Aframax and Suezmax and the 5 × 3 cargo tank configuration for the VLCC, by considering a corresponding increase in the ships' depth. Potential risk reduction is calculated for grounding incidents.

- <u>RCO 7.3</u>: The four representative tankers feature side tanks of widths 2.075 m, 2.18 m, 2.50 m and 3.38 m (Panamax, Aframax, Suezmax and VLCC, respectively) in way of the cargo area. Parameter studies are performed considering side tank width increases of 0.40 m and 0.8 m for the 6 × 2 cargo tank configuration for the Panamax, Aframax and Suezmax and the 5 × 3 cargo tank configuration for the VLCC, by considering a corresponding increase in the ships' breadth. Potential risk reduction is calculated for collision and contact incidents.

<u>RCO 7.1</u>: Enhanced Cargo Tank Subdivision
The Event Trees for collision, contact and grounding of Annex I have been used to calculate the oil outflow risk for the 6 × 3 cargo tank configurations for the Panamax, Aframax, Suezmax and VLCC

representative ships. Compared to the characteristics of the four representative ships [A.7], the only difference is the average size of the cargo tanks, which is now reduced due to the introduction of additional subdivision. Table 52 presents the results obtained.

Table 52: PLC (tonnes per shipyear) – Enhanced Cargo Tank Subdivision

PANAMAX 6 × 3	Volume of liquid cargo	79,214 m^3 (excluding slop tanks)
	Cargo tank configuration	6 × 3
	Average tank size	3,741 tonnes (4,401 m^3)
	PLC Collision	1.37 tonnes per shipyear
	PLC Contact	0.66 tonnes per shipyear
	PLC Grounding	5.25 tonnes per shipyear
	PLC (Total)	**7.28 tonnes per shipyear**

AFRAMAX 6 × 3	Volume of liquid cargo	122,779 m^3 (excluding slop tanks)
	Cargo tank configuration	6 × 3
	Average tank size	5,798 tonnes (6,821 m^3)
	PLC Collision	3.65 tonnes per shipyear
	PLC Contact	1.03 tonnes per shipyear
	PLC Grounding	6.59 tonnes per shipyear
	PLC (Total)	**11.27 tonnes per shipyear**

SUEZMAX 6 × 3	Volume of liquid cargo	171,009 m^3 (excluding slop tanks)
	Cargo tank configuration	6 × 3
	Average tank size	8,075 tonnes (9,501 m^3)
	PLC Collision	4.60 tonnes per shipyear
	PLC Contact	0.96 tonnes per shipyear
	PLC Grounding	6.99 tonnes per shipyear
	PLC (Total)	**12.55 tonnes per shipyear**

VLCC 6 × 3	Volume of liquid cargo	340,015 m^3 (excluding slop tanks)
	Cargo tank configuration	6 × 3
	Average tank size	16,056 tonnes (18,890 m^3)
	PLC Collision	7.73 tonnes per shipyear
	PLC Contact	0.80 tonnes per shipyear
	PLC Grounding	6.21 tonnes per shipyear
	PLC (Total)	**14.74 tonnes per shipyear**

Table 53 below presents the reduction on oil outflow offered by the 6 × 3 configurations when compared to the current cargo tank configurations of the representative ships.

Table 53: RCO 7.1 (Enhanced Cargo Tank Subdivision) – ΔPLC (tonnes per shipyear)

PANAMAX [6 × 2 → 6 × 3]	AFRAMAX [6 × 2 → 6 × 3]	SUEZMAX [6 × 2 → 6 × 3]	VLCC [5 × 3 → 6 × 3]
1.41	**2.32**	**2.49**	**1.17**

Table 53 values indicate a PLC reduction of 16%, 17%, 17% and 7% on oil pollution risk from collisions, contacts and groundings over the PLC of the current configurations for the Panamax, Aframax, Suezmax and VLCC, respectively. The lesser reduction on the PLC value for the VLCC is attributed to the low overall incident frequency when compared with the other ship sizes (second table, Appendix A.7), and also to the lesser reduction of the average cargo tank size for this ship size (17% reduction for the VLCC compared to 33% reduction for the Panamax).

RCO 7.2: Increased Double Bottom Height

The grounding Event Trees of Annex I has been used to calculate the oil outflow risk for the increased double bottom heights of 0.50 m and 1.00 m for the four representative tanker ships, by correspondingly increasing the ships' depth. In all cases, it should be noted that the increase in draught due to the additional steel and outfit weight is of negligible magnitude (order of centimetres) and as such it is considered that can be compensated for in the full load condition. The cargo tank configurations are considered as of the current configurations for the representative tankers (6 × 2 for the Panamax, Aframax and Suezmax and 5 × 3 for the VLCC). Compared to input data for the case of the four representative ships [A.7], different input constitutes on the probability value for non-breaching the double bottom, denoted $P(z < Z)$, calculated on the basis of a formula given in MARPOL Regulation 23 [45] (full details are given in Annex I) . Table 54 presents the results obtained (the different alternatives are denoted as "$z \times D_s$", where z is the double bottom height and D_s is the ship's depth).

Table 54: RCO 7.2 (Increased Double Bottom Height) – PLC and ΔPLC (tonnes per shipyear)

PANAMAX				
$z \times D_s$	z / D_s	P (z < Z)	PLC	ΔPLC
2.04 × 19.8	0.1030	0.783	6.11	
2.54 × 20.3	0.1251	0.808	5.81	**0.30**
3.04 × 20.8	0.1462	0.831	5.56	**0.55**

AFRAMAX				
$z \times D_s$	z / D_s	P (z < Z)	PLC	ΔPLC
2.30 × 21.0	0.1095	0.790	7.65	
2.80 × 21.5	0.1302	0.813	7.30	**0.35**
3.30 × 22.0	0.1500	0.835	6.97	**0.68**

SUEZMAX				
z × D_s	**z / D_s**	**P (z < Z)**	**PLC**	**ΔPLC**
2.80 × 23.1	0.1212	0.803	8.07	
3.30 × 23.6	0.1398	0.824	7.73	**0.34**
3.80 × 24.1	0.1577	0.843	7.41	**0.66**

VLCC				
z × D_s	**z / D_s**	**P (z < Z)**	**PLC**	**ΔPLC**
3.00 × 31.25	0.0960	0.776	6.62	
3.50 × 31.75	0.1102	0.791	6.46	**0.16**
4.00 × 32.25	0.1240	0.806	6.29	**0.33**

Table 54 values indicate the following PLC reductions on oil pollution risk from groundings over the PLC of the basis configurations:

- Panamax: 4.9% for 0.50 m double bottom increase; 9% for 1.00 m double bottom increase.
- Aframax: 4.6% for 0.50 m double bottom increase; 8.9% for 1.00 m double bottom increase.
- Suezmax: 4.2% for 0.50 m double bottom increase; 8.2% for 1.00 m double bottom increase.
- VLCC: 2.4% for 0.50 m double bottom increase; 5% for 1.00 m double bottom increase. This lesser reduction is attributed to the lower grounding frequency [A.7].

RCO 7.3: Increased Side Tanks Width

The Event Trees for collision and contact of Annex I have been used to calculate the oil outflow risk for the increased side tank widths of 0.40 m and 0.8 m for the four representative tanker ships, by correspondingly increasing the ships' breadth. The cargo tank configurations are considered as of the current configurations for the representative tankers (6 × 2 for the Panamax, Aframax and Suezmax and 5 × 3 for the VLCC). Compared to input data for the case of the four representative ships [A.7], different input constitutes on the probability value for non-breaching the inner hull, denoted P(y < Y), calculated on the basis of a formula given in MARPOL Regulation 23 [45] (full details are given in Annex I). Table 55 presents the results obtained (the different alternatives are denoted as "y × B_s", where y is the side tank width and B_s is the ship's breadth).

Table 55: RCO 7.3 (Increased Side Tanks Width) – PLC and ΔPLC (tonnes per shipyear)

PANAMAX						
y × B_s	**y / B_s**	**P(y < Y)**	**PLC (Collision)**	**PLC (Contact)**	**PLC (Total)**	**ΔPLC**
2.075 × 32.2	0.0644	0.812	1.62	0.96	2.58	
2.475 × 33.0	0.0750	0.846	1.49	0.79	2.28	**0.30**
2.875 × 33.8	0.0851	0.870	1.39	0.67	2.06	**0.52**

AFRAMAX						
y × B_s	**y / B_s**	**P(y < Y)**	**PLC (Collision)**	**PLC (Contact)**	**PLC (Total)**	**ΔPLC**
2.18 × 43.0	0.0507	0.753	4.43	1.51	5.94	
2.58 × 43.8	0.0589	0.790	4.06	1.28	5.34	**0.60**

2.98 × 44.6	0.0668	0.821	3.76	1.09	4.85	**1.09**

SUEZMAX						
y × B$_s$	**y / B$_s$**	**P(y < Y)**	**PLC (Collision)**	**PLC (Contact)**	**PLC (Total)**	**ΔPLC**
2.50 × 48.0	0.0521	0.759	5.57	1.40	6.97	
2.90 × 48.8	0.0594	0.792	5.15	1.21	6.36	**0.61**
3.30 × 49.6	0.0665	0.820	4.81	1.05	5.86	**1.11**

VLCC						
y × B$_s$	**y / B$_s$**	**P(y < Y)**	**PLC (Collision)**	**PLC (Contact)**	**PLC (Total)**	**ΔPLC**
3.38 × 58.0	0.0583	0.787	8.34	0.95	9.29	
3.78 × 58.8	0.0643	0.811	7.92	0.84	8.76	**0.53**
4.18 × 59.6	0.0701	0.832	7.56	0.75	8.31	**0.98**

Table 55 values indicate the following PLC reductions on oil pollution risk from collisions and contacts over the PLC of the basis configurations:

- Side tanks width increased by 0.40 m: 11.6%, 10.1%, 8.6% and 5.7% PLC reduction for the Panamax, Aframax, Suezmax and VLCC, respectively.
- Side tanks width increased by 0.80 m: 20.2%, 18.4%, 15.9% and 10.5% PLC reduction for the Panamax, Aframax, Suezmax and VLCC, respectively.

If breadth increase is not an option due to passage limitations, in order the same carrying capacity to be maintained, for Panamax ships for example, the new-build should either be of greater length or higher depth (given current bunker prices, greater length may be more preferable for the ship's life-cycle). This would incur additional building cost, however this is anticipated to be well depreciated over the ship's life-cycle.

15.1.6 Hot Works Procedures Training

To estimate the risk-reduction of hot works procedures training the Ship Inspection Report (SIRE) [52] Programme produced by the Oil Companies International Marine Forum (OCIMF) to vet ships was adopted as the RCO. SIRE, which follows the guidelines of the International Safety Guide for Oil Tankers and Terminals (ISGOTT) [53], is used by oil majors to ensure chartered ships meet their standards. In the experience of ship owner Kristen Navigation Inc. [A.6] SIRE surveyors usually request that hot works procedures training is carried out twice a year with suitably qualified and experienced personnel. Therefore, this is the standard that this RCO is measured against.

It should be noted that there is very little data available with regards to the causes of fires and explosions; in the process of researching this RCO several potential avenues of information were pursued in an attempt to obtain data, including:

- The Central Union of Marine Underwriters (CEFOR)
- The Oil Companies International Marine Forum (OCIMF)
- DNV internal units
    - Fire Safety
    - Maritime Solutions
    - SeaSkill
    - Market Research

Therefore DNV experts were consulted during Delphi sessions [A.5] which suggests that a risk reduction of 43% with regards to fatalities due to fire and explosion accidents caused by hot works only can be expected from hot works procedures training if applied to suitably qualified and experienced personnel.

Using the Fire and Explosion Event Trees of Annex I in combination with estimates gained from DNV experts in Delphi meeting sessions as well as DNV Fire Safety research on origins of fires [55] and NTUA data [Annex I] (to estimate the percentage of fires and explosions caused by hot works), conservative calculations indicate that 7.8E-04 lives per shipyear or 1.9E-02 over the lifetime of a tanker will be saved by implementing this RCO. Ship lifetime is assumed to be 25 years. Therefore, this RCO is expected to save one life per 1,280 shipyears.

Moreover, calculations following the same procedure described in the paragraph above suggest that 7.1E-01 tonnes of oil per shipyear or 1.8E+01 over the lifetime of the ship will be prevented from being spilled.

15.1.7 Double Sheathed Low Pressure Fuel Pipes

Initially both the insulation of hot surfaces and double sheathed low pressure fuel pipes were recommended to be studied together with regards to reducing overall fire risk in the engine room. However, with regards to insulation of hot surfaces it should be noted that since 1st July 2003 SOLAS Fuel Oil Arrangements [48] require that all engine room surfaces with a surface temperature in excess of 220°C be covered with a type approved fire proof material. Thus, as insulation of hot surfaces is a legal requirement it cannot be considered as a risk control option and hence the risk reduction is not calculated. However, comment from DNV experts (Machinery Ships in Operation unit) suggests that although all hot surfaces should be insulated, in reality approximately 75% are adequately covered. This is typically due to maintenance being carried out on equipment and insulated coverings not being properly refitted or being damaged over time.

Taking into account the opinion that every hot surface is typically not insulated double sheathed low pressure fuel pipes in the engine room that travel over hot surfaces was considered to help reduce the fire risk. The risk reduction gained from installing double sheathed low pressure fuel pipes (40 meters of ‘Schedule 40’ type piping is assumed) was calculated by using the Fire Event Tree of Annex I in conjunction with engine room fire origin research undertaken by DNV Fire Safety specialists [55] which maintains that 56% of engine room fires are caused by fuel coming into contact with hot surfaces. Opinion from Delphi meeting sessions involving DNV experts (A.5) suggests that double sheathed low pressure fuel pipes may reduce the residual risk of fire in the engine room due to oil leakage onto hot surfaces by 55%. This translates to an engine room fire risk reduction of 5.7E-04 lives per shipyear, or 1.4E-02 lives per ship lifetime. Ship lifetime is assumed to be 25 years. Thus, this RCO is expected to save one life approximately every 1,700 shipyears.

In terms of potential loss of cargo calculations undertaken following the same methodology employed for PLL suggest that 6.2E+00 tonnes of oil per shipyear and 1.5E+02 over the 25 year ship lifetime will be prevented from being spilled.

15.1.8 Engine Control Rom Additional Emergency Exit

Chapter II-2, Part D, Reg. 13 of the SOLAS Convention [49] requires that at least two means of escape be provided from each machinery space. In the case of the engine control room the two means of escape connect with the engine room only and no other part of the ship. During an emergency situation personnel could become trapped in the engine control room or may need to exit the area as quickly as possible. Thus, the RCO of installing an additional emergency exit linking the engine control room to the superstructure but independent of the engine room itself was considered. Expert judgement gained from Delphi sessions with DNV suggests that a risk reduction of 21% with regards to fatality of personnel in the engine control room during an emergency situation can be expected with respect to this RCO. It is assumed that one crew member will be present in the engine control room for 30% of the time; this is based on average safe manning certificate numbers and normal unmanned machinery spaces working procedures. (During a crisis event several members of the crew may be sent to the engine control room to attempt to take control of the situation; if evacuation is required in these circumstances the additional emergency exit will have a greater effect on Potential Loss of Life (PLL) due to the fact that a greater number of crew will use the exit. However, this scenario is not considered further at this time as sufficient data is unavailable).

Using the Fire Event Tree of Annex I and research conducted by DNV Fire Safety to calculate the percentage of fires starting in the engine room, in combination with the Collision, Explosion, Grounding and Non-accidental Structural Failure (NASF) Event Trees to sum all crisis events (which for the purposes of this study include sinkings only as this would lead to flooding of the engine room), the risk of fatality in emergency situations was calculated taking into account the fact that one person would be present in the control room 30% of the time. The risk reduction of 21% afforded by the additional emergency exit was discounted from the calculated risk of fatality, which translates to 1.7E-04 lives per shipyear or 4.4E-03 lives per ship lifetime. Ship lifetime is assumed to be 25 years. Therefore, this RCO is expected to save one life every 5,700 shipyears.

It should be noted that this RCO merely reduces risk with regards to PLL, not PLC or PLP, as it is only relevant in a crisis situation (i.e. engine room fire/flood) by offering a means of escape to personnel trapped in the engine control room.

15.1.9 Hull Stress and Fatigue Monitoring System

Hull fatigue, caused by the cumulative effects of dynamic stress that can occur as a result of ballast, cargo load and sea-state, has been identified as a common problem in cargo ships of >20,000dwt [56], particularly bulk carriers and tankers. Fatigue build-up in vessels leads to local cracks in the hull, which if left unrepaired, eventually endanger the structural integrity of the ship. In this respect the RCO hull stress and fatigue monitoring system (HMS) was proposed. Expert opinion from DNV Hydrodynamics, Structures and Stability experts affirms that a HMS will have a positive effect on risk in the two following scenarios:

1) Structural damage due to overloading of hull girder due to heavy weather
2) Structural damage due to fatigue (local and global)

With regards to 1) the utilisation of a HMS will reduce the probability of heavy weather damages significantly; however, the damage may not necessarily lead to fatalities or spilled oil. With regards to 2) a HMS is expected to reduce the risk of undetected cracks in both the inner and outer hull girders, and provide useful information of the loading history on the ship which will be valuable when structural inspections are performed. Taking into account both scenarios described above Delphi meeting sessions involving DNV experts estimate that the risk associated with structural failure will be reduced by 11% by using a HMS.

Using the Non-accidental Structural Failure (NASF) Event Tree of Annex I the total risk of fatality in incidents involving double hull (DH) tankers was calculated (no sinkings recorded in the period 1990 – 2007 (which Event Trees are based on), thus risk reduction relates only to PLL, PLC and PLP brought about through non-critical structural failure). The risk reduction of 11% provided by the HMS was discounted from the total risk of fatality, translating to 2.1E-05 lives per shipyear and 5.3E-04 lives over the 25 year lifetime of a tanker. Consequently this RCO is expected to save one life every 47,000 years.

(It should be noted that for NASF associated with DH tankers the number of entries in the Lloyd's Register Fairplay database is low. This provides a limited statistical database for defining the current risk level for the tanker industry with regards to NASF. Therefore, it is important to acknowledge that the historical risk profile is not necessarily representative for the future; zero incidents today does not automatically mean that a certain event cannot happen).

With respect to potential loss of cargo calculations following the same methodology undertaken for PLL indicate that 1.6E-01 tonnes of oil per shipyear and 4.0E+00 tonnes of oil per ship lifetime will be prevented from spillage.

15.2 Cost of Implementing RCOs

15.2.1 Active Steering Gear Redundancy

The cost associated with introducing the active steering gear redundancy will be negligible as this would only be a slight addition to the existing system layout during the design phase. For calculation purposes an initial purchase price of $2,000 and an annual spares/repairs cost of $200 are considered. Over 25 years this provides a Net Present Value of $4,800.

15.2.2 Electronic Chart Display and Information System (ECDIS)

The cost of implementing ECDIS has been taken from a previous study carried out by DNV [58]. The referenced report indicates a net present value (NPV) of $75,000, which consists of an initial purchase and installation cost of $32,000, back-up arrangements at $20,000, annual maintenance of $500, initial training of $6,000 and an annual training cost of $750.

A number of suppliers were contacted during this study to ensure that the costs identified had not grossly increased subsequent to the referenced report [58]. These suppliers are identified in [A.6].

15.2.3 Terminal Proximity and Speed Sensors (Docking Aid)

The cost of implementing a Doppler type docking system is largely associated with the initial purchase price which is considered to be $70,000 based on industry figures provided by docking aid suppliers, [A.6]. Although new technologies are emerging onto the market which would appear to be marginally cheaper than a typical Doppler type system, it was considered that a ship based system should be used for cost-benefit analysis in this case. Other perceived costs include an outlay of $4,000 every five years for maintenance during dry docking periods, and an annual figure of $400 for general spares and repairs. Over 25 years this provides a Net Present Value of $85,840.

15.2.4 Navigational Sonar

It is noted that a military sonar system with a range of 1-2 NMs can cost between $1 – 1.5 million. Through discussion with industry representatives for navigational sonar [A.6], it has been found that a 0.5 NM system would cost approximately $150,000 for the initial purchase. It is also considered that there would be a maintenance cost of $10,000 every five years during dry docking periods, and an annual figure of $1,500 for spares/repairs. Over 25 years this provides a Net Present Value of $196,650.

15.2.5 Ship Design Modifications

The implementation cost of the various RCOs being examined refers to the construction cost (additional steel and outfit work), maintenance and increased fuel consumption (due to the heavier structure). A life time of 25 years and an interest rate of 5% are assumed in the calculations. Costs refer to implementation of the selected RCOs as features for new-built tankers. RCOs 7.2 (increased double bottom height) and 7.3 (increased side tanks width) may be impractical to implement on existing tankers altogether, whilst there are indications that costs of implementing RCO 7.1 (enhanced cargo tank subdivision) on existing tankers are at least six to seven times higher than those indicated in the analysis. The reason for this difference is that additional costs for re-work of existing systems onboard and staging are of a great magnitude.

RCO 7.1: Enhanced Cargo Tank Subdivision
The following considerations are for the additional steel and outfit weight and related costs:

- The increase in steel weight is the result of the introduction of one additional longitudinal bulkhead running the full length of the cargo holds for the Panamax, Aframax and Suezmax ships. For the case of the VLCC the introduction of one additional transverse bulkhead is considered.
- The project partner Alpha Marine Services Ltd. (design office based in Piraeus, subcontractor to Kristen Navigation Inc.) has provided data indicating that the weight for the additional longitudinal bulkhead is 500 tonnes, 600 tonnes and 950 tonnes for the cases of a Panamax, Aframax and Suezmax, respectively and that the weight of the transverse bulkhead for the case of the VLCC is 350 tonnes. The quoted values include stiffeners' weight.
- Current pricing at Chinese shipyards indicates a cost of $2.2 per kilogram of steel, which includes labour cost but excludes staging or coating. On the basis of this price, the additional cost for construction is $1.1 million for the Panamax, $1.3 million for the Aframax, $2.1 million for the Suezmax and $0.77 million for the VLCC.
- As maintenance costs, 1% of construction cost is considered per annum, as indicated in [46].

The increase in operational cost on a yearly basis is estimated by considering:

- As operating profiles for Panamax and Aframax vessels, 40% of the time is considered in full load condition and 20% at partial load, for Suezmax vessels, 48% in full load condition and 12% at partial load and for VLCC vessels, 51% at full load condition and 9% at partial load. These conditions are considered incurring additional fuel costs. The ballast condition should not incur any additional fuel costs.
- It is noted that the additional steel weight would result in an estimated increase in draught, in the full load condition, of 10 cm for the Panamax, 8 cm for the Aframax, 10 cm for the Suezmax and 3 cm for the VLCC. This is a negligible increase in draught which could be compensated in a great variety of ways in the full load condition.
- It is assumed that the ships will be operating approximately 340 days in a year.
- A Panamax ship consumes 45 tonnes per day of heavy fuel at full load and 35 tonnes per day at partial load, an Aframax 60 tonnes and 45 tonnes per day, a Suezmax 75 tonnes and 58 tonnes and a VLCC 85 tonnes and 65 tonnes, respectively.
- Fuel price is taken as $500 per tonne (May 2008; it should be noted that bunker prices are volatile and are subject to fluctuation; www.bunkerworld.com/markets/prices).

Table 56 provides the cost of implementation for this RCO. As differential cost ΔC in this table, the NPV of the additional costs is calculated over a 25 year life cycle at a rate of 5% interest.

Table 56: RCO 7.1 (Enhanced Cargo Tank Subdivision) – ΔC

Item	PANAMAX	AFRAMAX	SUEZMAX	VLCC
Construction ($)	1,100,000	1,300,000	2,100,000	770,000
Maintenance ($ per year)	11,000	13,000	21,000	7,700

Operation ($ per year)	15,437	17,026	23,837	5,557
ΔC ($)	**1,472,602**	**1,723,185**	**2,731,930**	**956,843**

RCO 7.2: Increased Double Bottom Height
The calculation of implementation cost for this RCO is based on the same assumptions as for RCO 7.1. It is assumed that all alternatives considered would carry the same quantity of cargo, regardless the small increases in steel weight, as calculated below.

The additional steel weight is considered corresponding to the additional 0.50 m or 1.00 m of double bottom height introduced to the side shell, inner shell and longitudinal bulkhead. On this basis, for every additional 0.50 m of double bottom height it is estimated that there will be an additional 93 tonnes for the Panamax, 101 tonnes for the Aframax, 125 tonnes for the Suezmax and 165 tonnes for the VLCC (including stiffeners). These represent a negligible increase in draught which could be compensated in a great variety of ways in the full load condition.

Table 57 provides the cost of implementation for this RCO. As differential cost ΔC in this table, the NPV of the additional costs is calculated over a 25 year life cycle at an interest rate of 5%.

Table 57: RCO 7.2 (Increased Double Bottom Height) – ΔC

PANAMAX	Construction ($)	Maintenance ($ per year)	Operation ($ per year)	ΔC ($)
2.54 × 20.3	204,600	2,046	2,873	**273,928**
3.04 × 20.8	409,200	4,092	5,746	**547,856**

AFRAMAX	Construction ($)	Maintenance ($ per year)	Operation ($ per year)	ΔC ($)
2.80 × 21.5	222,200	2,222	2,868	**293,938**
3.30 × 22.0	444,400	4,444	5,735	**587,862**

SUEZMAX	Construction ($)	Maintenance ($ per year)	Operation ($ per year)	ΔC ($)
3.30 × 23.6	275,000	2,750	3,139	**357,999**
3.80 × 24.1	550,000	5,500	6,277	**717,984**

VLCC	Construction ($)	Maintenance ($ per year)	Operation ($ per year)	ΔC ($)
3.50 × 31.75	363,000	3,630	2,620	**451,087**
4.00 × 32.25	726,000	7,260	5,239	**902,160**

RCO 7.3: Increased Side Tanks Width
The calculation of implementation cost for this RCO is based on the same assumptions as for RCOs 7.1 and 7.2. It is assumed that all alternatives considered would carry the same quantity of cargo, regardless the small increases in steel weight, as calculated below.

The additional steel weight is considered corresponding to the additional 0.40 m or 0.80 m of side tanks width introduced to the bulkhead deck, double bottom top and bottom shell. On this basis, for every additional 0.40 m of side tank width it is estimated that there will be an additional 80 tonnes for the Panamax, 86 tonnes for the Aframax, 108 tonnes for the Suezmax and 144 tonnes for the VLCC (including stiffeners). These represent a negligible increase in draught which could be compensated in a great variety of ways in the full load condition.

Table 58 provides the cost of implementation for this RCO. As differential cost ΔC in this table, the NPV of the additional costs is calculated over a 25 year life cycle at an interest rate of 5%.

Table 58: RCO 7.3 (Increased Side Tanks Width) – ΔC

PANAMAX	Construction ($)	Maintenance ($ per year)	Operation ($ per year)	ΔC ($)
2.475 × 33.0	176,000	1,760	2,472	**235,646**
2.875 × 33.8	352,000	3,520	4,943	**471,277**

AFRAMAX	Construction ($)	Maintenance ($ per year)	Operation ($ per year)	ΔC ($)
2.58 × 43.8	189,200	1,892	2,442	**250,283**
2.98 × 44.6	378,400	3,784	4,884	**500,566**

SUEZMAX	Construction ($)	Maintenance ($ per year)	Operation ($ per year)	ΔC ($)
2.90 × 48.8	237,600	2,376	2,712	**309,310**
3.30 × 49.6	475,200	4,752	5,423	**618,606**

VLCC	Construction ($)	Maintenance ($ per year)	Operation ($ per year)	ΔC ($)
3.78 × 58.8	316,800	3,168	2,286	**393,668**
4.18 × 59.6	633,600	6,336	4,572	**787,337**

15.2.6 Hot Works Procedures Training

The cost of undertaking one day hot works procedures training onboard is estimated at $1,000/ship by ship manager Alpha Marine Services [47]; this cost covers training of all personnel involved in hot works activities and is conducted to a level commensurate with ISGOTT [53]. As per oil major vetting requirements hot works training should be conducted twice a year, giving a total yearly cost of $2,000/ship. Travel and subsistence costs are not considered as training takes place on the ship. Therefore, total costs over the lifetime of the tanker taking into account NPV [Equation 4] are approximately $28,000.

15.2.7 Double Sheathed Low Pressure Fuel Pipes

The cost of 'Schedule 40' double sheathed low pressure fuel pipes is estimated at $420/m for 350mm (d) and $350/m for 250mm (d) including materials and labour. These costs are estimated after discussion with shipyards by ship owner Kristen Navigation Inc. [47] which has thirteen new build tankers on order with Daewoo Shipbuilding and Marine Engineering, Samsung, Hyundai, SWS and Hudong at the time of writing. Only those sections of the heavy fuel pipes that traverse areas in the engine room with hot surfaces are considered as these are the places where fuel leakage could potentially lead to fire. With this in mind the total length of heavy fuel pipe to be double sheathed is 40m. For the purposes of this study it is assumed that 30m of the heavy fuel pipe requires 350mm sheathing and 10m requires 250mm; this translates to a total one-off cost of $16,100; in addition advice from Kristen Navigation Inc. suggests that $40,000 maintenance costs will be incurred over the 25 year lifetime of a tanker, which translates to approximately $23,000 when NPV is taken into account. Taken together calculations suggest that the total cost of implementation of this RCO over the lifetime of a ship will be approximately $39,000.

15.2.8 Engine Control Room Additional Emergency Exit

The installation of an additional emergency exit from the engine control room independent of the engine room itself at new build stage includes material costs associated with steel, A60 insulation and miscellaneous items such as the door and ladder, as well as the actual labour. Indicative costs following discussion with Kristen Navigation Inc. [47] suggest the total cost of installing this RCO will be $13,280; advice from Yeong Hwan Mun [A.6] based at Daewoo Shipbuilding and Marine Engineering Co (DSME) estimates the cost to be $14,400. Thus an implementation cost of $13,840 representing the mean between the two figures has been used in NPV calculations. As this RCO is a structural addition to the ship there will be no associated maintenance costs throughout the lifetime of the ship.

15.2.9 Hull Stress and Fatigue Monitoring System

The "SENSFIB Hull Monitoring System" manufactured by "Light Structures" of Norway (www.lightstructures.biz) is used to represent the typical cost of a HMS. This HMS was chosen as it is either fitted or due to be fitted on about 40 DNV classed ships, thus DNV has detailed knowledge of this system. Moreover, "SENSFIB" uses state-of-the-art fibre optic technology, thus allowing the greatest benefit in terms of risk reduction to be gained. According to DNV Hydrodynamics, Structures and Stability experts [A.5,A.6] the total cost of the "SENSFIB" equipment including 12 sensors and installation is approximately $117,000; the cost of maintenance over a typical 25 year tanker lifetime is estimated to be $20,000, which when taking into account NPV is approximately $11,000, giving a grand total of $128,000.

15.3 Economic Benefit of Implementing RCOs

Summary values have been provided within this chapter for the GCAF, NCAF and CATS figures. Calculation figures can be found within the results table (Table 62).

15.3.1 Active Steering Gear Redundancy

The economic benefit of introducing an active steering gear redundancy is the reduction in groundings leading to fatal accidents, oil spills and property damage. Although the cost of introduction at the design phase is low, the risk of fatality is not reduced significantly as can be seen by the GCAF figure of $40,000,000, which is considerably higher than the $3 million per life saved as recommended by IMO [41]. When considering the risk reduction benefits with regards to reduced oil spill per ship year ($37,800) and property damage to the ship ($392) this provides a benefit NPV of $538,000, the resulting NCAF being - $4,377,000,000. This NCAF figure would suggest that this RCO should be introduced on the basis of the economic benefits achieved. The CATS achieved with the implementation of this RCO is $300 which is well within the $60,000 limit and as such would indicate that this RCO may be introduced simply on the risk reduction of oil spills.

15.3.2 Electronic Chart Display and Information System (ECDIS)

The economic benefit of introducing ECDIS is the reduction in groundings leading to fatal accidents, oil spills and property damage. Although the cost of introduction at the design phase is relatively low, the risk of fatality is not reduced significantly as illustrated by the GCAF figure of $62,500,000, which is considerably higher than the $3 million per life saved as recommended by IMO [41]. When considering the risk reduction benefits with regards to reduced oil spill per ship year ($402,000) and property damage to the ship ($391) this provides a benefit NPV of $567,000, these costs are a substantial factor in the NCAF figure of - $4,660,000,000. This NCAF figure would suggest that this RCO should be introduced on the basis of the benefits achieved. The CATS figure attained with the implementation of this RCO is

$450 which is well within the $60,000 limit and as such would indicate that this RCO may be introduced simply on the risk reduction of oil spills.

15.3.3 Terminal Proximity and Speed Sensors (Docking Aid)

The economic benefit of introducing Terminal Proximity/Speed Sensors is the reduction in contacts leading to oil spills. Within the Contact Event Tree there are no fatal accidents or property damage frequencies, suggesting that outcomes in this respect are not reported due to negligible consequences. As such GCAF or NCAF figures cannot be calculated, although CATS can be considered. The CATS achieved with the implementation of this RCO is $21,500 which is well within the $60,000 limit and as such would indicate that this RCO may be introduced simply on the risk reduction of oil spills.

15.3.4 Navigational Sonar

The economic benefit of introducing a Navigational Sonar is the reduction in groundings leading to fatal accidents, oil spills and property damage. Although the cost of introduction at the design phase is low, the risk of fatality is not reduced significantly as illustrated by the GCAF figure of $461,000,000, which is considerably higher than the $3 million per life saved as recommended by IMO [41]. When considering the risk reduction benefits such as reduced oil spill per year ($167,379) and property damage to the ship ($1,630), these costs are a substantial factor in the NCAF figure of - $4,417,000,000. This NCAF figure would suggest that this RCO should be introduced on the basis of the benefits achieved. The CATS achieved with the implementation of this RCO is $2,800 which is well within the $60,000 limit and as such would indicate that this RCO may be introduced simply on the risk reduction of oil spills.

15.3.5 Ship Design Modifications

Cost-effectiveness of the RCOs considered is evaluated on the basis of CATS. Table 59, Table 60 and Table 61 below provide the relevant cost-effectiveness calculations.

Table 59: RCO 7.1 (Enhanced Cargo Tank Subdivision) – CATS ($)

PANAMAX [6 × 2 → 6 × 3]	AFRAMAX [6 × 2 → 6 × 3]	SUEZMAX [6 × 2 → 6 × 3]	VLCC [5 × 3 → 6 × 3]
41,776	**29,710**	**43,886**	**32,713**

Table 60: RCO 7.2 (Increased Double Bottom Height) – CATS ($)

Increase of double bottom height by 0.50 m	
PANAMAX	36,524
AFRAMAX	33,593
SUEZMAX	42,118
VLCC	112,772

Increase of double bottom height by 1.00 m	
PANAMAX	43,828
AFRAMAX	34,580
SUEZMAX	43,514
VLCC	109,353

Table 61: RCO 7.3 (Increased Side Tanks Width) – CATS ($)

Increase of side tanks width by 0.40 m	
PANAMAX	31,419
AFRAMAX	16,686
SUEZMAX	20,283
VLCC	29,711

Increase of side tank width by 0.80 m	
PANAMAX	36,252
AFRAMAX	18,369
SUEZMAX	22,292
VLCC	32,136

Observing Table 59 it is apparent that it is cost-effective to build alternative tank configurations at new build stage for all tanker types. The greatest benefit with regards to cost vs. reduction in risk of oil spill is gained with Aframax and VLCC tankers.

Examining
Table 60 it is clear that it is economically viable to increase the double bottom height by both 0.5m and 1.00m with regards to Panamax, Aframax and Suezmax tankers as the total cost-effectiveness is within the $60,000/tonne of oil spilled threshold prescribed by CATS. Conversely, it is not cost-effective to increase the double bottom height of a VLCC by either 0.5m or 1.00m; this is due to the cost of implementation and the low historical grounding frequency.

Table 61 suggests that it is cost-effective to increase the width of the side tanks on all tankers from a CATS point of view. The greatest benefit is gained with an increase of 0.40m for all tanker types, with Aframax and Suezmax types exhibiting the greatest cost-effectiveness.

15.3.6 Hot Works Procedures Training

The economic benefit of undertaking hot works procedures training to SIRE standards is achieved through a reduction in fires and explosions leading to fatal accidents, oil spill and property damage (i.e. to the ship). The GCAF of undertaking hot works procedures training incorporating NPV at 5% is approximately $1.45 million/per life saved, representing less than 50% of the recommended criterion of $3 million. Moreover, the CATS is $450, which translates to less than 1% of the $60,000 limit. In addition to the above, the NCAF is -$111 million indicating that this RCO is cost-effective. What is more, the annual cost of this RCO is negligible compared to the operational costs of running a tanker.

15.3.7 Double Sheathed Low Pressure Fuel Pipes

Calculations taking into account NPV at 5% suggest that the benefits of implementing this RCO are realised from GCAF, CATS and NCAF perspectives. The GCAF is calculated at $2.7 million, 10% short of the $3 million recommended criterion. CATS is $250, which is less than 1% of the $60,000/tonne of spilled oil threshold proposed by Skjong et al (2005) [42]. NCAF is calculated at -$371 million indicating that this RCO is cost-effective due to the economic benefit gained due to reduced risk associated with PLC and PLP.

15.3.8 Engine Control Room Additional Emergency Exit

The economic benefit of this RCO is realised through a reduction in fatalities due to fires and sinking events from collision, grounding and explosion incidents. The GCAF is estimated at $3.17 million which is 5% above the $3 million/life recommended criterion adopted by the IMO [41]. As this RCO only aids escape from the engine control room during a crisis event there is no PLC or PLP benefit, rendering the NCAF equal to the GCAF. However, as the GCAF is not grossly disproportionate and the initial implementation cost at new build stage is very low (i.e. $14,000) and there is no maintenance, this RCO could still be considered at new build stage.

15.3.9 Hull Stress and Fatigue Monitoring System

The economic benefit of installing a HMS system is achieved through a reduction in hull fatigue cracks leading to spilled oil. This is borne out by the NCAF calculation of -$10.2 million and CATS of $32,000. The GCAF is inordinately high at $240 million; however, this is not unexpected due to the fact a HMS is principally intended to identify structural fatigue to help in the planning of a ship's maintenance, hence reducing PLC and PLP risk, but not necessarily PLL.

16 Results

Table 62: Results

	Risk Reduction ΔR_S	Oil Spill Reduction ΔR_E	Cost ΔC	Benefit ΔB	$GCAF = \frac{\Delta C}{\Delta R_S}$	$CATS = \frac{\Delta C}{\Delta R_E}$	$NCAF = \frac{\Delta C - \Delta B}{\Delta R_S}$
	# of saved lives 1)	Tonnes 1)	$ 1) 2)	$ 1) 2) 3)	$	$	$
RCO 3: Active Steering Gear Redundancy	1.2E-4	16	4,800	530,000	40,000,000	300	-4,377,000,000

RCO 4: ECDIS	1.2E-3	170	75,000	5,667,000	62,500,000	440	-4,660,000,000
RCO 5: Terminal Proximity & Speed Sensors	N/A	4	86,000	119,000	N/A	21,500	N/A
RCO 6: Navigational Sonar	4.9E-4	70	196,500	2,361,000	401,000 ,000	2,800	-4,417,000,000
RCO 8: Hot Works Procedures Training	1.9E-02	45	28,000	2,200,000	1,450,000	450	-111,000,000
RCO 9: Double Sheathed Low Pressure Fuel Pipes	1.4E-02	154	39,000	5,300,000	2,700,000	250	-371,000,000
RCO 11: Engine Control Room Additional Emergency Exit	4.4E-03	N/A	13,840	N/A	3,169,000	N/A	3,169,000
RCO 12: Hull Stress & Fatigue Monitoring System	5.3E-04	4	128,000	134,000	241,000,000	32,000	-10,200,000
1) Per ship lifetime, assumed to be 25 years 2) Includes NPV at 5% per year where relevant 3) Reduced PLC and PLP							

The results in Table 62 above show that *RCO 8 Hot Works Procedures Training*, *RCO 9 Double Sheathed Low Pressure Fuel Pipes* and *RCO 11 Engine Control Room Additional Emergency Exit* have relatively low GCAF values compared to *RCO 3 Active Steering Gear Redundancy*, *RCO 4 ECDIS, RCO 6 Navigational Sonar*, *RCO 12 Hull Stress and Fatigue Monitoring System*. A GCAF value of less than $3 million implies that an RCO should be implemented according to IMO criteria [56]. However, in order to assess the global benefit of each RCO the NCAF values incorporating the economic benefit of reduced PLC and PLP must be considered. With this in mind it is clear that the NCAF values of RCOs 3, 4, 6, 8, 9 and 12 are negative indicating that these RCOs are economically beneficial in themselves i.e. the costs of implementing the RCO is less than the economic benefit of applying it, regardless of how many lives are saved. With regards to RCO 11 NCAF is equal to the GCAF, which is 5% above the upper limit of $3 million; however, this is not grossly disproportionate. With regards to RCO 5, GCAF and NCAF could not be calculated as there is no perceived risk of fatality associated with this RCO within the Collision Event Tree developed in SAFEDOR D4.7.2.

RCO 7: Ship Design Modifications is an in-depth analysis and as such the results are presented in separate tables below. Specifically with regards to Table 63, Table 64, Table 65 and Table 66 the following observations can be made:

- All three RCOs examined, namely 7.1 (enhanced cargo tank subdivision), 7.2 (increased double bottom height) and 7.3 (increased side tank width) are cost-effective for new-built tankers of all sizes considered (Panamax, Aframax, Suezmax and VLCC), with the exception of RCO 7.2 (increased double bottom height) which is found not to be cost-effective for VLCCs.
- For Panamax, Aframax and Suezmax, the greater (twice to three times) potential for oil outflow reduction is offered by RCO 7.1 (enhanced cargo tank subdivision) when compared with the other two RCOs examined. For VLCCs, RCO 7.1 is still more effective in this respect than RCO 7.3 (increased side tank width), however, not at the same magnitude.
- Since current levels of oil outflow are not explicitly documented against acceptance criteria, it is not possible, at the time of writing this report, to make more specific recommendations than the above. It is noted that all possible combinations of the cost-effective RCOs considered are also cost-effective, offering a greater potential for oil outflow risk reduction.
- RCO 7.1 (enhanced cargo tank subdivision) is cost-effective and also offers a substantial potential for oil outflow reduction (16-17% for Panamax, Aframax and Suezmax, on the potential for oil outflow from collisions, contacts and groundings over the current configurations). This implies that if oil outflow from collisions, contacts and groundings should be substantially reduced, RCO 7.1 should be considered first for implementation over RCOs 7.2 (increased double bottom height) and 7.3 (increased side tanks width).
- Between RCO 7.2 (increased double bottom height) and 7.3 (increased side tanks width), RCO 7.3 offers a greater potential for oil outflow reduction.

Table 63: Panamax Results for RCO 7: Ship Design Modifications

	Risk Reduction ΔR_E		Cost ΔC		Benefit ΔB		$CATS=\frac{\Delta C}{\Delta R_E}$	
	# tonnes of oil saved[1)]		\$[2)]		\$[3)]		\$	
RCO 7.1: Enhanced Cargo Tank Subdivision	35.25		1,472,602		2,115,000		41,776	
RCO 7.2: Increased Double Bottom Height	0.5m	7.5	0.5m	273,928	0.5m	450,000	0.5m	36,524
	1.0m	13.75	1.0m	547,856	1.0m	825,000	1.0m	43,828
RCO 7.3: Increased	0.4m	7.5	0.4m	235,646	0.4m	450,000	0.4m	31,419

Side Tanks Width	0.8m	13	0.8m	471,277	0.8m	780,000	0.8m	36,252

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5% per year where relevant
3) Reduced PLC only

Table 64: Aframax Results for RCO 7: Ship Design Modifications

	Risk Reduction ΔR_E		Cost ΔC		Benefit ΔB		$CATS=\frac{\Delta C}{\Delta R_E}$	
	# tonnes of oil saved[1)]		$[2)]		$[3)]		$	
RCO 7.1: Enhanced Cargo Tank Subdivision	58		1,723,185		3,480,000		29,710	
RCO 7.2: Increased Double Bottom Height	0.5m	8.75	0.5m	293,938	0.5m	525,000	0.5m	33,593
	1.0m	17	1.0m	587,862	1.0m	1,020,000	1.0m	34,580
RCO 7.3: Increased Side Tanks Width	0.4m	15	0.4m	250,283	0.4m	900,000	0.4m	16,686
	0.8m	27.25	0.8m	500,566	0.8m	1,635,000	0.8m	18,369

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5% per year where relevant
3) Reduced PLC only

Table 65: Suezmax Results for RCO 7: Ship Design Modifications

	Risk Reduction ΔR_E		Cost ΔC		Benefit ΔB		$CATS=\frac{\Delta C}{\Delta R_E}$	
	# tonnes of oil saved[1)]		$[2)]		$[3)]		$	
RCO 7.1: Enhanced Cargo Tank Subdivision	62.25		2,731,930		3,735,000		43,886	
RCO 7.2: Increased Double Bottom Height	0.5m	8.5	0.5m	357,999	0.5m	510,000	0.5m	42,118
	1.0m	16.5	1.0m	717,984	1.0m	990,000	1.0m	43,514
RCO 7.3: Increased Side Tanks Width	0.4m	15.25	0.4m	309,310	0.4m	915,000	0.4m	20,283
	0.8m	27.75	0.8m	618,606	0.8m	1,665,000	0.8m	22,292

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5% per year where relevant

3) Reduced PLC only

Table 66: VLCC Results for RCO 7: Ship Design Modifications

	Risk Reduction ΔR_E		Cost ΔC		Benefit ΔB		$CATS=\frac{\Delta C}{\Delta R_E}$	
	# tonnes of oil saved[1)]		$[2)]		$[3)]		$	
RCO 7.1: Enhanced Cargo Tank Subdivision	29.25		956,843		1,755,000		32,713	
RCO 7.2: Increased Double Bottom Height	0.5m	4	0.5m	451,087	0.5m	240,000	0.5m	112,772
	1.0m	8.25	1.0m	902,160	1.0m	495,000	1.0m	109,353
RCO 7.3: Increased Side Tanks Width	0.4m	13.25	0.4m	393,668	0.4m	795,000	0.4m	29,711
	0.8m	24.5	0.8m	787,337	0.8m	1,470,000	0.8m	32,136

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5% per year where relevant
3) Reduced PLC only

17 References to Annex II

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18 Appendices to Annex II

A.1: Acronyms

CBA	Cost Benefit Analysis
CEFOR	The Central Union of Marine Underwriters
DB	Double Bottom
DH	Double Hull
DS	Double Side
DSME	Daewoo Shipbuilding and Marine Engineering Co
ECDIS	Electronic Chart Display and Information System
FSA	Formal Safety Assessment
GCAF	Gross Cost of Averting a Fatality
CATS	Gross Cost of Averting One Tonne of Oil Spilled
HMS	Hull Stress Monitoring System
IACS	International Association of Classification Societies
IGS	Inert Gas System
IMO	International Maritime Organisation
MEPC	Marine Environmental Protection Committee
MSC	Maritime Safety Committee
NASF	Non-Accidental Structural Failure
NCAF	Net Cost of Averting a Fatality
NM	Nautical Mile
NPV	Net Present Value
NTUA	National Technical University of Athens
OCIMF	Oil Companies International Marine Forum
PL	Protectively Located (in context with SBTs)
PLC	Potential Loss of Cargo
PLL	Potential Loss of Life
PLP	Potential Loss of Property
RCO	Risk Control Option
SBT	Segregated Ballast Tanks
SIRE	Ship Inspection Report Programme
SH	Single Hull
SSRC	Ship Stability Research Centre
VLCC	Very Large Crude Carrier

A.2: Complete List of RCOs Considered at NTUA – March 2008

#	RCO
	General
1	Imposition of maximum training hours for crew at terminal
2	Avoid night berthing
3	Training in crisis management for masters and officers
	Collision – Preventative Measures
4	Improve communication between pilot/VTS and master
5	Early communication with pilot (1-2 days) – passage planning
6	Timely boarding of the pilot – before ship reaches bay area
7	Redundant propulsion
8	Redundant steering
9	Reduce speed – maximum speed limit in harbours and congested waters
10	Standardisation of navigational instruments
11	Pilot training and competence standards
12	Automatic check of non-active systems e.g. software checks to ensure rudder and steering components work correctly
13	ECDIS
14	Standardised pilot vocabulary in English/simplified communication code
15	Acoustic warning system
16	Automatic collision avoidance system
17	Minimum watch conditions for different operational states (navigation and bridge)
18	Minimum closest point of approach (CPA)
	Collision – Mitigation Measures
19	Increase the double hull width
20	Reduce tank size (increase the number of tanks)

21	Bag in box concept
22	Improve damage resistance of sides
23	Use ballast tanks for oil transfer during breach
24	Reduce load capacity by leaving one tank empty for oil transfer in case of breach
25	Oil spill recovery kit onboard – booms, oil in water emulsion to increase viscosity
26	Emergency response plan – review
27	Increase residual strength of hull
	Contact – Preventative Measures
28	Emergency response plan – review STS procedures
29	Up-to-date electronic maps with fixed/floating objects in port – available from internet daily
30	Fit cameras to flanks to make visible objects below the bridge
31	Proximity sensors
32	Berthing speed – visual communicators/alarms
	Grounding – Powered Grounding Preventative Measures
33	Redundancy and improvement of echo-sounder
34	Sonar
35	Minimum under keel clearance – ship specific
36	ECDIS
37	Increase minimum distance from coast – ship specific
38	Squat effect pre-calculation
39	Redundant steering
40	Improved ship separation schemes
41	Improve communication between pilot/VTS and master
42	Temporary notices on electronic nautical charts e.g. sand banks, recent sinkings
	Grounding – Drift Grounding Preventative Measures
43	Twin screw propellers

44	Mooring failure system at terminal – alarm sounds when predetermined tension reached
45	Redundant propulsion
46	Install additional tug towage capacity
47	Anchor watch radar
	Grounding – Mitigation Measures
48	Forward sloping upwards inner bottom; increase the double bottom height
49	Reduce tank size (increase number of tanks)
50	Bag in box concept
51	Improve damage resistance of bottom
52	Use ballast tanks for oil transfer during breach
53	Reduce load capacity by leaving one tank empty for oil transfer in case of breach
54	Oil spill recovery kit onboard – booms, oil in water emulsion to increase viscosity
55	Emergency response plan – review
56	Increase residual strength of hull
57	US/Canadian reporting requirements to be used as global standard – one united system, reduce burden on the master
58	Establish ports of refuge
	Fire – Engine Room Preventative Measures
59	Better implementation of hot works procedures; ISGOTT standard
60	Double sheath fuel and lube oil pipes over hot surfaces
61	Insulate equipment with hot surfaces
62	Inspect electrical faults at earliest convenience
63	Ignition proof equipment
	Fire – Pump Room Preventative Measures
64	Training for certain scenarios – e.g. excess vapours (CO), pump over heating
	Fire – Accommodation Preventative Measures
65	Increase power outlet number and improve location

66	Establish basic requirements for fire risk assessments
67	Install smoke detectors in cabins
	Fire – Galley Preventative Measures
68	Improved cleaning methods for extractor fans
69	Use only industrial cooking equipment (no domestic equipment) – inspection by HSE
70	Create fire risk assessment – basic requirements; marine standard equipment certification
	Fire – Cargo Area Preventative Measures
71	IGS for ballast tanks – introduce vents, O_2 pressure on IGS lines
72	Redundancy of O2 level analysers – all tanks should maintain the same positive pressure to balance ship and keep out external air; automated tank pressure radar
	Fire – Deck Mitigation Measures
73	Cofferdams between decks in aft
	Fire – Engine Room Mitigation Measures
74	Sprinkler system
75	Second emergency exit from control room independent of engine room
76	Install incinerators in fire proof room; ensure incinerators are manned when in use
	Fire – Steering Gear Room Mitigation Measures
77	Should not be used for storage of flammable materials, which should be kept in a fire proof room
	Fire – Cargo Samples Mitigation Measures
78	Establish designated room for cargo samples, which should not be stored with flammable materials/liquids
79	Introduce metal cargo sample containers
	Explosion – Preventative Measures
80	Better implementation of hot works procedures; ISGOTT standard
81	Place boiler in a segregated area
	Non-Accidental Structural Failure – Preventative Measures
82	Improvement of internal tank coating to reduce corrosion

83	Hull stress and fatigue monitoring system
84	Reduced high tensile steel usage to reduce metal fatigue
85	Design life of 30 years and above; longer guarantee with new ship
86	Improved corrosion monitoring
87	Proper implementation of design; proper plan approval by owner (when ship building market declines owners can push for higher standards)
88	Finite Element Analysis (FEA) covering the whole cargo area including global loads
89	Additional structural members for extra support to increase residual strength
90	Improved maintenance procedures (particularly at beginning of life and after 15 years)

A.3: Description of 12 Prioritised RCOs

#	Area	RCO	Description	Previously analysed
1	Crew fatigue	Maximum of 18 operational hours for loading/ unloading at terminal	Loading/unloading operations in port is a 24hrs a day process; restricting this activity to 18hrs in every 24hrs during is aimed at reducing crew fatigue (in addition to the ILO 'Seafarers' Hours of Work' Convention which requires a minimum of 10 hours rest in a 24 hour period for each crew member).	
2	Collision/Contact	Terminal risk assessments	Risk assessments could be carried out at each port to consider the risks associated with tanker operations.	
3	Collision/ Grounding	Active steering gear redundancy	the automatic changeover of the steering gear pump within the steering gear system in the event of failure to reduce the risk of collision/grounding	
4	Collision/ Grounding	ECDIS	An Electronic Chart Display and Information System (ECDIS) provides a real-time navigation system that integrates information from a variety of sensors to continuously determine a ship's position in relation to land, charted objects, aids-to-navigation, and unseen hazards to reduce the risk of collision or grounding.	Yes, [57]
5	Contact	Terminal proximity and speed sensors	Terminal Proximity and Speed sensors are used in terminal areas as a docking aid to reduce contact incidents.	
6	Grounding	Navigational Sonar	Sonar is a device that uses sound energy to locate objects, measure their distance, direction and speed. As a navigational aid this is used to avoid grounding incidents.	
7	Collision/ Contact/ Grounding	Alternative cargo tank configurations, increase double bottom height,	These ship design modifications are intended to reduce the risk and amount of oil spill in the instance of collision, contact and grounding.	

		increase side tanks width		
8	Fire/Explosion	Hot works procedures training	Hot works procedures training (HWPT) is intended to ensure that all crew involved in hot works follow industry best practice i.e. that advocated by OCIMF. HWPT is designed to reinforce correct processes and emphasise safety checks to reduce injury, loss of life, oil spill and property damage from fire and/or explosion.	
9	Fire	Insulated hot surfaces/Double sheathed low pressure fuel pipes	SOLAS Fuel Oil Arrangements require that all hot surfaces (>220°C) are insulated with type approved materials. Therefore this RCO is not considered further. Double sheathed low pressure fuel pipes may leak where pipes connect with flanges and other joints. Double sheathing with Schedule 40 piping at these points aims to divert any oil leakage away from hot surfaces that may exist below them reducing the possibility of fire.	
10	Fire/Explosion	IGS for ballast tanks	Due to structural cracks in ballast tanks excess O_2 can ingress into cargo holds, raising the level above 8% and increasing the likelihood of explosion. Channelling inert gas from the boiler system into the ballast tanks reduces the O_2 level, lowering the risk of explosion.	
11	Fire/Evacuation	Additional exit from engine control room	SOLAS II-2-D-13 requires that there are at least two means of escape from machinery spaces. In the case of the engine control room the two emergency exits connect only with the engine room; in the case of a crisis event such as sinking or major fire crew may become trapped in the control room or need to exit the area in the minimum time possible. An additional exit from the control room independent of the engine room itself may provide the most expedient means of escape in such a situation.	
12	Structural failure	Hull stress and fatigue monitoring	The ship's hull suffers stresses in operational state which can lead to	

		system	structural damage particularly due to 1) over loading of hull girder due to heavy weather and 2) general fatigue (global and local). The purpose of a HMS is to monitor the stresses of the hull girder and give warning when the degree of stress approaches levels that require corrective action. Further, the information acquired by a HMS can be utilised in planning of the ship's maintenance.	

A.4: Experts Involved in RCO Brainstorming Sessions in Athens

The project team received input from a number of experts undertaking various roles in the maritime industry. These are listed below. The current report however, does not express the views and opinions of the listed experts explicitly, and the content of the report is the responsibility of the project team alone.

Name	Affiliation	Background
Prof. Apostolos D. Papanikolaou	National Technical University of Athens	Naval Architect and Marine Engineer
Dr. Eleftheria Eliopoulou	National Technical University of Athens	Naval Architect and Marine Engineer
Dr. Rainer Hamann	Germanischer Lloyd	Mechanical Engineer and Safety Analyst
Dr. Karsten Loer	Germanischer Lloyd	Safety Engineer
Mr. Jeppe Skovbakke Juhl	Danish Maritime Authority	Naval Architect
Mr. Sokratis Dimakopoulos	Alpha Marine Services Ltd / Kristen Navigation Inc	HSQE Manager
Mr. Philip Tsichlis	Alpha Marine Services Ltd / Kristen Navigation Inc	Naval Architect and Marine Engineer
Captain Anastassios Maroussis	Alpha Marine Services Ltd / Kristen Navigation Inc	Master Mariner
Captain Touliatos	Alpha Marine Services Ltd / Kristen Navigation Inc	Master Mariner
Dr. Rolf Skjong	Det Norske Veritas	Chief Scientist Risk and Reliability
Dr. Dimitris Konovessis	University of Strathclyde	Naval Architect and Marine Engineer

A.5: Delphi Method Workshop – Experts Consulted

DNV Experts Involved in Delphi Method Workshop		
Name	**Affiliation**	**Background**
Arvind Phatak	DNV	Fire Safety expert/Master Mariner
Øyvind Lund-Johansen	DNV	Hydrodynamics expert
Bernt Hofset	DNV	Controls Systems expert
Matthew Seides	DNV	Ships in Operation/Tanker expert

The above named experts were involved in a Delphi Method workshop at DNV headquarters in Høvik, Norway, on 14 May 2008.

A.6: Other Experts Consulted

The experts named below were consulted at different stages throughout the project to provide advice and expert opinion on the cost of implementation and the potential risk reduction benefit that could be realised with regards to introducing various risk control options on tankers.

Name	Affiliation	Background
Svein Erik Jacobsen	DNV	Fire Safety expert
Anders Tosseviken	DNV	Fire Safety expert
Gaute Storhaug	DNV	Hydrodynamics expert
Arthur Iversen	DNV	Ship Machinery expert
Garrone Velloso	DNV	Principal Surveyor
Sam Aase	DNV	Principal Surveyor
Stephen Bligh	DNV	Master Mariner
Yeong Hwan Mun	DNV	Senior Surveyor (DSME site office)
Sew Kait Thong	Neptune Orient Lines	Director, Newbuildings
Olav Denker	Raytheon Anschuetz GmbH	Steering Gear Control System Supplier
Steve Colliss	VT Group PLC	Steering Gear Supplier
David Edmonds	PC Maritime Ltd	ECDIS Supplier
John Davies	Kelvin Hughes Ltd	ECDIS Supplier
Giles Verdon	Ami Marine Ltd	Docking System Supplier
Per Bjerring	Marimatech AS	Docking System Supplier
Ian Bowles	Farsounder Inc	Navigational Sonar Supplier
Susan Phillips	EchoPilot Marine Electronics Ltd	Navigational Sonar Supplier

A.7: Ship Design Modifications – Supporting Information

Table 67 presents summarised particulars of the four representative tankers used in this study, at their original configuration. The Event Trees for collision, contact and grounding, presented in Annex I are used to calculate Potential Loss of Cargo (PLC). Table 68 contains the input frequency values used for the purposes of this study (also deriving from Annex I), whilst the PLC values calculated for the four representative tankers at their current configuration are illustrated in Table 69. These are used as the basis risk in calculating the potential risk reduction (ΔPLC) for the various alternatives considered in this study.

Table 67: Particulars of Representative Tankers

PANAMAX	L_{BP} × B × D	219.0 m × 32.2 m × 19.8 m
	Double skin width	2.075 m
	Double bottom height	2.040 m
	DWT	69,684 tonnes
	Volume of liquid cargo	79,214 m^3 (excluding slop tanks)
	Cargo tank configuration	6 × 2
	Average tank size	5,611 tonnes (6,601 m^3)

AFRAMAX	L_{BP} × B × D	238.0 m × 43.0 m × 21.0 m
	Double skin width	2.18 m
	Double bottom height	2.30 m
	DWT	105,357 tonnes
	Volume of liquid cargo	122,779 m^3 (excluding slop tanks)
	Cargo tank configuration	6 × 2
	Average tank size	8,697 tonnes (10,232 m^3)

SUEZMAX	L_{BP} × B × D	264.0 m × 48.0 m × 23.1 m
	Double skin width	2.50 m
	Double bottom height	2.80 m
	DWT	158,982 tonnes
	Volume of liquid cargo	171,009 m^3 (excluding slop tanks)
	Cargo tank configuration	6 × 2
	Average tank size	12,113 tonnes (14,251 m^3)

VLCC	L_{BP} × B × D	318.0 m × 58.0 m × 31.25 m
	Double skin width	3.38 m
	Double bottom height	3.00 m
	DWT	309,020 tonnes
	Volume of liquid cargo	340,015 m^3 (excluding slop tanks)
	Cargo tank configuration	5 × 3
	Average tank size	19,268 tonnes (22,668 m^3)

Table 68: Incident Frequencies (per shipyear)

Incident Type	PANAMAX	AFRAMAX	SUEZMAX	VLCC

Collision	7.65E-03	1.17E-02	1.07E-02	9.56E-03
Contact	5.75E-03	4.42E-03	3.01E-03	1.44E-03
Grounding	1.14E-02	9.30E-03	7.23E-03	3.10E-03
TOTAL	**2.48E-02**	**2.54E-02**	**2.09E-02**	**1.41E-02**

Table 69: Basis PLC (tonnes per shipyear)

	PLC (Collision)	PLC (Contact)	PLC (Grounding)	TOTAL PLC
PANAMAX	1.62	0.96	6.11	**8.69**
AFRAMAX	4.43	1.51	7.65	**13.59**
SUEZMAX	5.57	1.40	8.07	**15.04**
VLCC	8.34	0.95	6.62	**15.91**

On Table 69 calculations, the proportionally lesser potential oil outflow attributed to VLCC tankers is due to the lesser grounding frequency for this ship size, as calculated in Annex I and presented in Table 68 (VLCC's grounding frequency is 57%, 67% and 73% less than the grounding frequency of Suezmax, Aframax and Panamax, respectively).

A.8: Hot Works as Cause of Fires and Explosions Onboard

Data is sourced from the National Technical University of Athens Ship Design Laboratory database.

Table 70: Fire due to Internal Source

Cause	#	Area
Hot works	4	2 in cargo/slop tanks and 2 in ballast tanks
Electrical faults	6	in Engine Room
Electrostatic charges	2	in Engine Room
Heating equipment	2	Other Areas
Total	14	

(Registered information regarding the ignition source in 14 cases out of 67 fires due to internal source)

Table 71: Explosions in Operational Phase

Cause	#	Area
Hot works	4	in cargo/slop tanks
Electrical faults	4	3 in Engine Room, 1 in Boiler
Electrostatic charges	1	On deck
Heating equipment	1	Boiler
Total	10	

(Registered information regarding the ignition source in 10 cases out of 39 explosions)

Annex III: Recommendations

19 Recommendations

As the basis for recommendations it is observed that:

- An RCO is considered cost effective if the GCAF is less than $3 million. This is the criteria used in 'Amendments to the Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule Making Process' [41] and in previous SAFEDOR reports.
- An RCO is also cost effective if the NCAF is either less than $3 million or negative; a negative NCAF indicates that the benefits in monetary units are higher than the costs associated with the RCO [41]. A negative NCAF shows only that there is a general benefit; it allows no ranking of the RCOs nor does it identify which RCO is the most efficient. It should be noted that a high negative NCAF may result from either of the following:
    - the benefits are much higher than the costs associated with the RCO: or
    - the RCO has a low risk reduction potential ΔR (the lower the ΔR, the higher the NCAF)
- From a PLC point of view an RCO is considered cost effective if the CATS (Cost of Averting a Tonne of Oil Spilled) is less than $60,000. It should be noted that of the RCOs considered all have a CATS of approximately 50% or less of the upper limit of $60,000 except certain outcomes in RCO 7.

This study demonstrates that one RCO detailed in Table 72 below is cost-effective purely from a GCAF point of view according to the IMO criteria and the information available. On the other hand the RCOs listed in Table 73 can be recommended from a NCAF and CATS perspective only, indicating that they are not cost-effective in terms of preventing fatalities but are cost-effective in reducing oil spilled and property damage. Each RCO is discussed further below.

Table 72: RCOs recommended for further consideration at IMO due to GCAF

No.	RCO
8	Hot Works Procedures Training

Table 73: RCOs recommended for further consideration at IMO due to NCAF/CATS

No.	RCO
3	Active Steering Gear Redundancy
4	ECDIS – Electronic Chart Display Information System
6	Navigational Sonar
7	Ship Design Modifications (in certain instances; see discussion below)

Table 74: RCOs recommended for further consideration at IMO as cost not grossly disproportionate

No.	RCO
9	Double Sheathed Low Pressure Fuel Pipes
11	Engine Control Room Additional Emergency Exit

Table 75: RCOs not recommended for further consideration at IMO	
No.	**RCO**
5	Terminal Proximity and Speed Sensors
12	Hull Stress and Fatigue Monitoring System

As Table 73 illustrates four of the selected RCOs recommended for further consideration by the IMO are significant due to their potential for reduced risk with regards to PLC and PLP rather than PLL. Thus, RCOs 3, 4, 6 and 7 should be considered further by the IMO by virtue of their economic benefit. Specifically with regards to RCO 7 Ship Design Modifications the following recommendations can be made.

For all design modifications described in sub-RCOs 7.1, 7.2 and 7.3 all CATS values are within the $60,000 threshold recommended by [42] thus can be considered cost-effective, with the exception of RCO 7.2 for VLCCs, which can be rejected as not economically viable. However, particular CATS outcomes are more cost-effective than others, namely RCO 7.1 and RCO 7.3 (0.4m) for Aframax size tankers (Table 64) and RCO 7.3 (0.4m) for Suezmax size tankers (Table 65), thus should be recommended for implementation ahead of the other RCOs which have higher CATS values and are hence less cost-effective.

Only one RCO offers a significant degree of risk reduction with regards to potential lives lost (Table 72), and can be recommended for implementation by the IMO. With regards to Table 74 it is recommended that further research is conducted into the fire risk reduction potential and associated economic benefit of RCO 9 before implementation is approved. Similarly, RCO 11 (Table 74) is recommended for further consideration by the IMO due to the fact that the installation cost is not grossly disproportionate to the benefit gained in terms of reducing the risk associated with PLL.

Table 75 describes RCOs 5 and 12, which are not recommended for further consideration by the IMO as the economic benefits compared to the costs of implementation are much lower than all the other RCOs studied (despite both having CATS within the $60,000 limit [42]) i.e. The cost of implementation of RCO 5 is 72% of the economic benefit and RCO 12 is 96%. In contrast, the cost of implementation of the remaining RCOs ranges from 1 – 8% of the total economic benefit, illustrating the disparity between RCOs 5 and 12 and the others.

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