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Agenda item 17

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## FORMAL SAFETY ASSESSMENT

### FSA – Crude Oil Tankers

#### Submitted by Denmark

#### SUMMARY

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

#### Introduction

1 The Maritime Safety Committee, at its seventy-fourth session (2001), and the Marine Environment Protection Committee, at its forty-seventh session (2002), approved the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process, as set out in MSC/Circ.1023-MEPC/Circ.392.

2 The Maritime Safety Committee, at its eighty-first session, and the Marine Environment Protection Committee, at its fifty-fifth session, agreed on draft amendments to MSC/Circ.1023-MEPC/Circ.392, and the Secretariat prepared a consolidated version of the FSA Guidelines in MSC 83/INF.2.

3 The Maritime Safety Committee, at its eighty-third session, agreed to convene an FSA Experts Group with the purpose of reviewing the FSA studies submitted to the Organization. The FSA Expert Group is expected to meet during MSC 86 under the provisions of the guidance on the use of human element analysing process (HEAP) and formal safety assessment (FSA) in the rule-making process of IMO (MSC/Circ.1022-MEPC/Circ.391).

For reasons of economy, this document is printed in a limited number. Delegates are kindly asked to bring their copies to meetings and not to request additional copies.

4 As part of the research project SAFEDOR, a high-level FSA study on crude oil tankers has been performed. The main results of the FSA study are provided in the annex and a more comprehensive report is submitted as document MEPC 58/INF.2.

### **Summary of results from the study**

5 The FSA study on crude oil tankers demonstrated that:

- .1 The safety level of modern crude oil tankers lies within the tolerable risk region;
- .2 The risk level is dominated by collision, fire, and explosion scenarios;
- .3 Some identified risk control options were found to be cost-effective according to the cost-effectiveness criteria in MSC 83/INF.2.

6 The following risk control option (RCO) was found to be cost-effective on the basis of GCAF (Gross Cost of Averting a Fatality):

- .1 RCO 8: Hot Works Procedures Training.

7 The following RCOs are recommended to be cost-effective on the basis of NCAF/CATS (Net Cost of Averting a Fatality/gross Cost of Averting a Tonne of Oil Spilt):

- .1 RCO 3: Active Steering Gear Redundancy;
- .2 RCO 4: ECDIS – Electronic Chart Display Information System;
- .3 RCO 6: Navigational Sonar;
- .4 RCO 7.1: Ship Design Modifications – Enhanced Cargo Tank Subdivision;
- .5 RCO 7.2: Ship Design Modifications – Increased Double Bottom Height (not economically viable for VLCC);
- .6 RCO 7.3: Ship Design Modifications – Increased Side Tanks Width.

8 The following RCOs are recommended for further consideration by IMO as costs are not grossly disproportionate:

- .1 RCO 9: Double Sheathed Low Pressure Fuel Pipes;
- .2 RCO 11: Engine Control Room Additional Emergency Exit.

### **Proposal**

9 Based on the FSA study reported in document MEPC 58/INF.2, the following RCOs may be proposed to be made mandatory IMO requirements for crude oil tankers:

- .1 Hot Works Procedures Training;
- .2 Active Steering Gear Redundancy;

- .3 ECDIS – Electronic Chart Display Information System;
- .4 Navigational Sonar;
- .5 Ship Design Modifications – Enhanced Cargo Tank Subdivision;
- .6 Ship Design Modifications – Increased Double Bottom Height (not economically viable for VLCC);
- .7 Ship Design Modifications – Increased Side Tanks Width.

10 From the above list of RCOs, .5, .6 and .7 (Ship Design Modifications) may be recommended for new buildings only.

11 An abridged version of the full FSA report is set out at annex to this document.

**Action requested of the Committee**

12 The Committee is invited to consider the information provided and decide as appropriate, and to refer the FSA study reported to the FSA Expert Group for review.

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## ANNEX

## FORMAL SAFETY ASSESSMENT OF CRUDE OIL TANKERS

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### 1 SUMMARY

A full Formal Safety Assessment (FSA) is performed to estimate the risk level and to identify and evaluate possible risk control options (RCOs) for crude oil tankers with DWT  $\geq$  60,000 tonnes (PANAMAX, AFRAMAX, SUEZMAX, VLCC and ULCC).

The FSA study concluded that both the individual and the societal risk associated with crude oil tankers are within the ALARP area. This means that risks should be made ALARP by implementing cost-effective risk control options. With respect to potential loss of crew life, three areas or generic accident scenarios are identified:

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

With respect to potential loss of oil cargo, four areas or generic accident scenarios are identified:

- Collision of the struck ship;
- Powered grounding;
- Fire due to internal source initiation;
- Explosion.

The basis for the recommendations given in this study is the following:

- With respect to safety an RCO is considered cost-effective if the GCAF (Gross Cost of Averting a Fatality) is less than USD 3 million. This is the value used in all decisions made following the FSA studies submitted under agenda item 5, Bulk Carrier Safety, at MSC 76, December 2002 and suggested in MSC 83/INF.2.
- With respect to safety an RCO is also considered cost-effective if the NCAF (Net Cost of Averting a Fatality) is less than USD 3 million.
- With respect to environmental protection an RCO is also considered cost-effective if the CATS (Cost of Averting a Tonne Spilt) is less than USD 60,000.

The study demonstrates that the following RCOs are providing considerable risk reduction in a cost-effective manner:

- Hot works procedures training;
- Active steering gear redundancy;
- Navigational sonar;
- Some ship design modifications (enhanced cargo tank subdivision, increased double-bottom height, increased side-tanks width).

For several of these RCOs both criteria (CAF and CATS) are satisfied. These four cost-effective RCOs with significant potential to reduce loss of lives and/or reduce the environmental impact are strongly recommended as IMO requirements. Additionally, the following two RCOs should be further considered as cost not grossly disproportionate:

- Double sheathed low pressure fuel pipes;
- Engine control room additional emergency exit.

None of these RCOs are already implemented on crude oil tankers. The cost benefit assessment is based on the introduction of one RCO at a time, but the conclusions are believed to be robust in any case.

## **2 DEFINITION OF THE PROBLEM**

Its role as a prime resource for production of energy and goods renders crude oil an important commodity of worldwide trade. Today, about two thirds of the world's oil trade, including both crude oils and refined products, is transported by tankers; representing 30% of the international trade goods. With respect to deadweight oil tankers and product tankers represent a third of the world merchant fleet.

Recently, the POP&C project presented a study on "The Influence of Regulations on the Safety Record of the AFRAMAX Tankers" in which the impact of some key regulations which prevent accidents taking place was investigated. The study concludes that despite an increase of the tanker fleet on average the number of reported accidents has decreased. Moreover, it can be observed that the number of accidents of a specific type decreased significantly after regulations or industrial restrictions have been introduced that are aimed at addressing these accident types.

It is expected that the volume of oil transported by tanker will increase further in the future and so will the world tanker fleet. Even if the probability of accidents may not increase with the world tanker fleet, the number of accidents may increase. This may yield a higher attention of the society to oil transport by tanker. In order to increase the safety of oil transport several measures were introduced already. Notwithstanding, by application of pro-active risk-based methods new measures may be identified to control the risk of oil transport by tanker.

Despite the positive development observed in recent years it is the aim of IMO to continuously improve the safety and environmental safety of crude oil tankers.

Hence, in an attempt to quantify a baseline risk level for the world fleet of crude oil tankers, and also to identify and evaluate alternative risk control options for improved safety, the full Formal Safety Assessment methodology has been applied on the world fleet of crude oil tankers with a DWT  $\geq$  60,000 tonnes.

The scope of the study is limited to embrace safety issues, loss of life and environmental impact due to oil spill. Thus, security risks and property risks are considered to be out of scope. Similarly, the property risks are taken into consideration in the Cost-Benefit Analysis (CBA) only. Furthermore, the scope is credible accidents of a certain scale; occupational hazards associated with high frequency and low consequence incidents are defined out of scope. The study only covers the operational phase of a crude oil tanker's life cycle. Risks associated with vessels at yards or in dock under construction, repair or maintenance or in the decommissioning and scrapping phase are considered out of scope. Furthermore, only the shipping stage in the

crude oil tanker value chain will be considered, i.e. loading of crude oil at the export terminal, the actual shipping of crude oil in tankers and unloading of crude oil at the receiving terminal or in ship-to-ship transfer. Third party risks to people onshore or on board other vessels are considered out of scope, and only risks to tanker crew are considered.

### 3 BACKGROUND INFORMATION

#### 1. Risk acceptance criteria

In order to assess the risk as estimated by the risk analysis, appropriate risk acceptance criteria for crude oil tankers were established prior to and independent from the actual risk analysis. Acceptance criteria for individual crewmembers and societal risk for crew were established, as outlined in the following.

Criteria for individual risk to crew have been established for previous FSA applications. These are deemed appropriate for crude oil tankers and have been adopted for the purpose of this study. The following risk-acceptance criteria have been employed, corresponding to the risk levels experienced by an exposed crew member:

Boundary between negligible risk and the tolerable risk	$10^{-6}$ per year
Maximum tolerable risk (risks below this limit should be made ALARP)	$10^{-3}$ per year

Individual risk to third parties is intuitively considered negligible.

Societal risk-acceptance criteria for crude oil tankers crew were established according to the approach presented in MSC 83/INF.2, i.e. based on the economic value of crude oil shipping. Based on estimates of daily rates, operational costs and initial investments, the economic value (which is equal to the annual turnover) of a typical crude oil tanker was assessed to be about USD 18 million per year. From these estimates the risk acceptance criteria illustrated in Figure 1 may be derived.

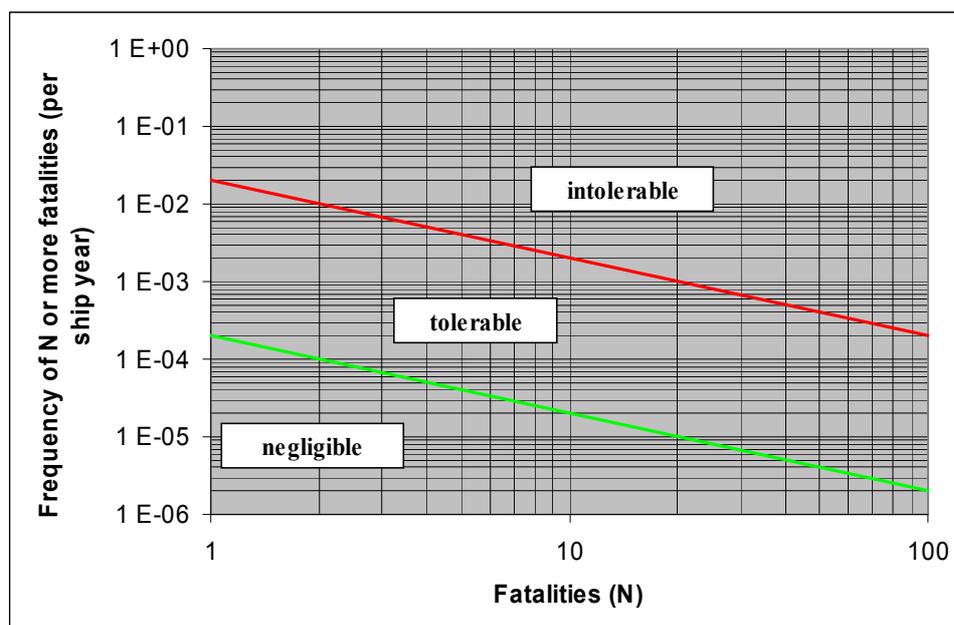


Figure 1: Societal risk-acceptance criteria for crew

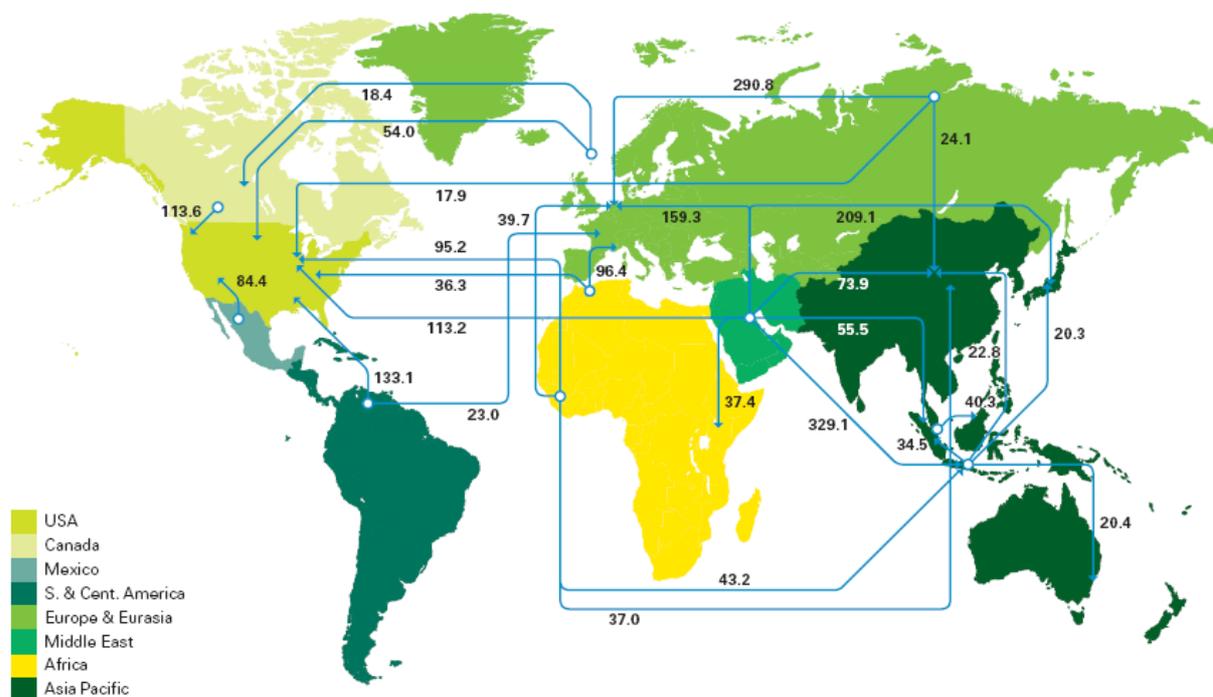
## 2. Crude oil tankers

Crude oil and petroleum products have been carried in ships for more than 100 years. Presently, 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 2 presents the major oil trade movements worldwide.

The practice of carrying the oil directly inside the single hull of a ship has been common since this type of ship was first built 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.

Tanker designs established in the late 1880s remained virtually unchanged until shortly after World War II. Tankers commonly were of 10,000 to 15,000 DWT, with a single skin, the engine room to the stern, and multiple compartmentation with either two or three tanks across.

After the war, the world economy expanded, resulting in a large increase in demand for energy in the form of oil. At the same time, a new shipping pattern evolved: Crude oil often was transported from distant sources, such as the Persian Gulf, to major marketing areas, notably North America, Northern Europe, and Japan, where the crude was refined and redistributed as product. These long voyages set the stage for a dramatic increase in ship size, which started about 1950. Between 1950 and 1975, the largest tanker in the world grew from about 25,000 DWT to over 500,000 DWT. The numbers of tankers in the world fleet also multiplied many times over.



**Figure 2: Major oil trade movements 2006 – Trade flows worldwide (million tonnes)**

This present analysis covers crude oil tankers of the following types:

- PANAMAX (60,000 DWT – 79,999 DWT)
- AFRAMAX (80,000 DWT – 119,999 DWT)
- SUEZMAX (120,000 DWT – 199,999 DWT)
- Very Large Crude Carriers (VLCC; 200,000 DWT – 320,000 DWT)
- Ultra-Large Crude Carriers (ULCC; more than 320,000 DWT).

The development of the world fleet since 1980 with respect to the number of ships and broken down to size categories considered is shown in Figure 3. Since 2002 all fleet sizes increase except the ULCC.

Since MARPOL regulation 13F (International Convention for the Prevention of Pollution: MARPOL) came into force all new tankers are of double hull type. The effect of MARPOL 13F on the distribution of the world tanker fleet is shown in Figure 4 by the DWT-years broken down to size categories. ULCC is not considered in this figure because no ships of DH are known. For all size categories a continuous replacement of single hull (SH) by double hull (DH) is observed and between 2000 and 2004 the majority of the fleet with respect of DWT-years is of DH type.

### **3. Tanker hull configuration**

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. Tanker hull design is mainly influenced by the MARPOL regulations.

The most important regulations were:

- The 1973 Convention with the amended 1954 OILPOL:
  - Replacement and maintenance of the “load on top” system;
  - Segregated ballast tanks (SBT) for new oil tankers (i.e. those whose building contract was placed after 31 December 1975) of 70,000 DWT and above.

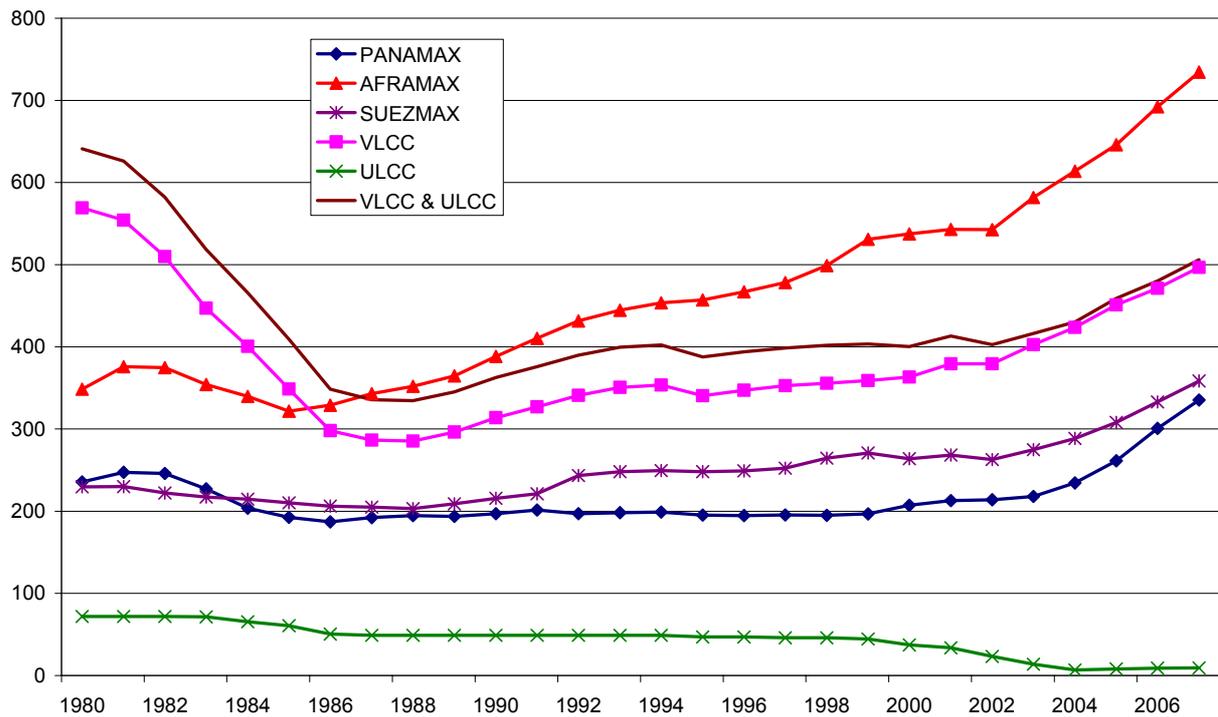


Figure 3: Development of crude oil tanker fleet-at-risk (number of ships) by ship type

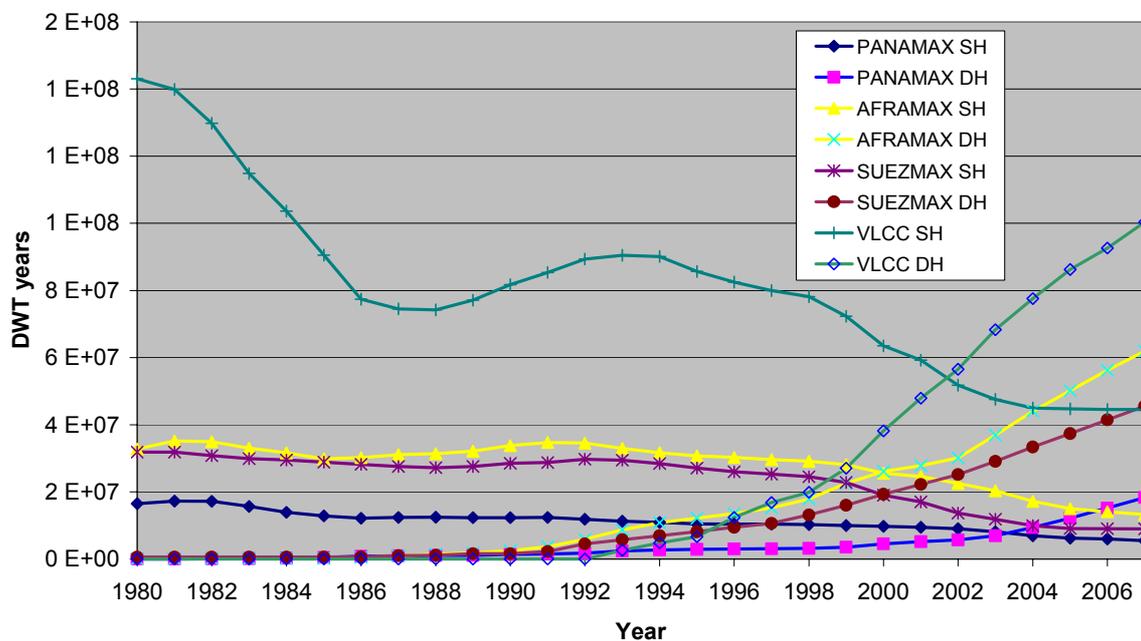
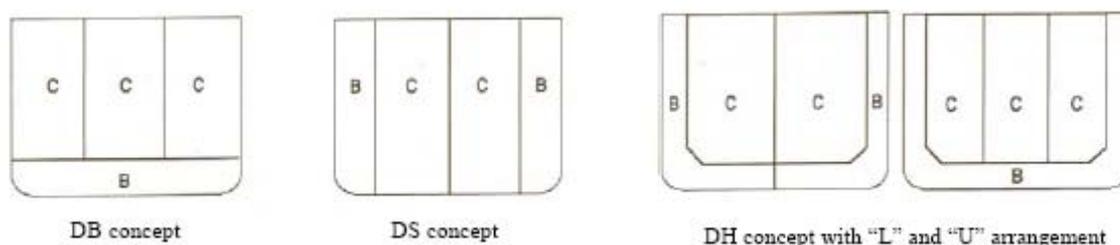


Figure 4: Development of crude oil tanker fleet-at-risk with respect to DWT-years and broken down to hull type (ULCC: no DH registered and thus not considered)

- The Protocol of 1978 (applicable for (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)):
  - SBTs were required on all new tankers of 20,000 DWT and above;
  - SBTs to be Protectively Located (PL).
- The 1992 amendments to Annex I of MARPOL (applicable to new ships – i.e. 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):
  - Regulation 13F: 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 0.76 m);
  - Regulation 13G: 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 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 5 shows some typical configurations forming the present DH tanker “fleet at risk”.

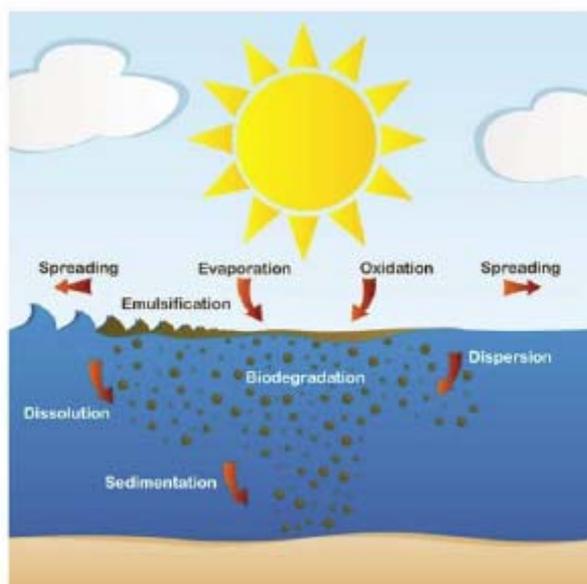


**Figure 5: Typical tanker hull design**

#### **4. Oil transport by tanker and hazards**

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.

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 6.



**Figure 6: Fate of oil spilled at sea showing the main weathering processes**

## **5. Accident statistics**

The accident statistics are determined on basis of LMIU and LRFP data for the period 1980 to 2007. Sub-groups of this database are selected to investigate possible trends in this long period and to determine the input data for the event scenarios which are focused on DH tankers. Table 1 summarizes 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, including also incidents at shipyards and drydocks.

**Table 1: Historical data, Studied Period 1980-2007, Fleet at Risk = 38,211.20 ship years**

**All recorded incidents, independent of the degree of severity.**

Initial event	No. of accidents	No. of accidents with pollution	Tonnes spilt	Frequency		Injured		Fatalities/ Missing	
				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
<b>Total</b>	<b>2,033</b>	<b>166</b>	<b>1,663,111</b>			<b>132</b>		<b>244</b>	<b>60</b>

With respect to the annual number of accidents a downward trend is observed within the investigated period, especially in the post-90 period. The representative frequency of 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. For this period 813 safety-related incidents were reported, namely 148 Non-Accidental Structural Failures (NASF), 39 explosions, 76 fires, 192 groundings, 93 contact and 265 collision events. The derived accident frequencies calculated for 25,780.22 ship years are summarized in Table 2.

**Table 2: Frequency by incident category (covered period 1990 to 2007)**

Collision	<i>1.03E-02</i>
Contact	<i>3.61E-03</i>
Grounding	<i>7.45E-03</i>
Fire	<i>2.95E-03</i>
Explosion	<i>1.51E-03</i>
NASF	<i>DH ships: 1.93E-03</i> <i>All ships: 5.74E-03</i>
Total	<i>3.16E-02</i>

Corresponding data for the environmental impact in terms of oil spilt are summarized in Table 3.

**Table 3: Number of accidents with oil spill and corresponding frequency by incident category (covered period 1990 to 2007)**

<b>Accident category</b>	<b>No. of accidents with pollution</b>	<b>Amount spilt (tonnes)</b>	<b>Frequency of accidents with oil spill</b>
<b>Collision</b>	27	126,532	1.05 E-03
<b>Contact</b>	16	13,162	6.21 E-04
<b>Grounding</b>	17	245,942	6.59 E-04
<b>Fire</b>	1	144,000	3.88 E-05
<b>Explosion</b>	3	278,770	1.16 E-04
<b>NASF</b>	38	170,538	1.47 E-03

#### **4 METHOD OF WORK**

The 5-step FSA methodology outlined in the FSA Guidelines has been used in this study. The FSA application has been carried out as a joint effort between Altair Special Maritime Enterprises (Greece), Det Norske Veritas (Norway), Germanischer Lloyd (Germany), the Ship Stability Research Centre of the Universities of Glasgow and Strathclyde (United Kingdom) and the Ship Design Laboratory of the National Technical University Athens (Greece, coordinator). The project team was comprised of risk analysts, naval architects and other experts from the above partners as well as from Alpha Marine Services Ltd, European Maritime Pilots Association, Euronav Shipping and Kristen Navigation Inc. Technical experts have been extensively consulted throughout the work of the FSA.

The FSA commenced with a HAZID meeting in June 2007, and the final report with cost benefit assessments and recommendations was completed in June 2008.

The HAZID (step 1 of the FSA) was conducted as a two-day technical meeting including brainstorming sessions. The outcome of the HAZID was a risk register containing the hazards and their subjective risk ratings from which a list of the highest ranked hazards could be extracted. Furthermore, the casualty reports for the period 1990 to 2007 are investigated.

The risk analysis (step 2 of the FSA) comprises a thorough investigation of accident statistics for crude oil tankers as well as risk modelling utilizing event tree methodologies for the most important accident scenarios. Based on the survey of accident statistics and the outcome of the HAZID, generic accident scenarios were selected for further risk analysis.

The risk analysis essentially contains two parts, i.e. a frequency assessment and a consequence assessment. For the frequency assessment, estimating the initiating frequency of generic incidents, accident statistics have been utilized for the selected accident scenarios.

The consequence assessment was performed using event tree methodologies. First, conceptual risk models were developed for each accident scenario and event trees were constructed according to these risk models. The event trees were subsequently quantified using different techniques for each branch probability according to what was deemed the best approach in each case. The approaches employed include utilizing accident statistics, damage statistics, fleet statistics, simple calculations and modelling as well as elicitation of expert opinions.

The frequency and consequence assessments provide the risk associated with the different generic accident scenarios. These risks were summarized in order to estimate the individual and societal risks pertaining to crude oil tanker operations.

Risk control options (step 3 of the FSA) were identified and prioritized at technical workshops.

Cost benefit assessments (step 4 of the FSA) were performed on selected risk control options based on the outcome of step 3. The cost-effectiveness for each risk control option was estimated in terms of the Gross Cost of Averting a Fatality (GCAF), the Net Cost of Averting a Fatality (NCAF) and the Cost of Averting a Tonne oil Spilt. That is, the expected costs, economic benefit and risk reduction in terms of averted fatalities were estimated for all risk control options.

All costs and benefits were depreciated to a Net Present Value (NPV) using a depreciation rate of 5% and assuming an expected lifetime of 25 years for crude oil tankers. A typical crew of 30 persons were assumed. Cost estimates were based on information from suppliers, service providers, training centres, yards, technical experts or previous studies as deemed appropriate. The economic benefit and risk reduction ascribed to each risk control option were based on the event trees developed during the risk analysis and on considerations on which accident scenarios would be affected. Estimates on expected downtime and repair costs in case of accidents were based on statistics from shipyards.

Recommendations for decision-making (step 5 of the FSA) were suggested based on the cost benefit assessment of risk control options carried out in step 4 and on the evaluation criteria  $GCAF < USD\ 3\ million$ ,  $NCAF < USD\ 3\ million$  and  $CATS < USD\ 60,000$ . Considerations on the potential for risk reduction that can be provided by each evaluated risk control option were also taken into account in suggesting recommendations.

## **5 DESCRIPTION OF THE RESULTS ACHIEVED IN EACH STEP**

### **6. STEP 1 – Hazard Identification**

The HAZID was conducted as a two-day workshop with participants from various sectors within the tanker industry, i.e. ship owner/operator, ship design office/maritime engineering consultancy, pilots organisations, classification society and research centre/university. The results from the HAZID were recorded in a risk register, which contains a total of 81 hazards. Consequences of hazards were evaluated with respect to human life and environmental damage. According to the outcome of the HAZID the top ranked hazards with respect to human life are in Table 4; the top ranked hazards with respect to environmental damage are presented in Table 5. Each hazard is associated with a risk index based on qualitative judgement by the HAZID participants. Some hazards were assigned different consequences for single hull (SH) and double hull (DH).

Due to a large diversity of causes, crew communications problems were not further addressed at the current state.

**Table 4: Results from hazard identification: Top-ranked hazards w.r.t. human life**

No.	Hazard	Risk index
M1.1	Multiple fatalities as consequence of a tank explosion during weld repairs caused by a high concentration of hydrocarbons due to insufficient tank cleaning and insufficient ventilation.	8
M1.4	Fatalities as a consequence of an explosion during weld repairs of pipes caused by insufficient cleaning of pipes.	7
N1.17 (SH) N1.18 (DH)	Fatalities due to fire/explosion as a consequence of a communications problem leading to a collision.	7

**Table 5: Results from hazard identification:  
Top-ranked hazards w.r.t. environmental damage**

No.	Hazard	Risk index
N1.2 (SH)	Major pollution due to high-energy grounding (single hull only) as a consequence of a communications problem.	7
N1.3 (SH) N1.4 (DH)	Major pollution due to grounding as a consequence of a technical problem.	7
N1.15 (SH)	Major pollution due to an impact as a consequence of a communications problem leading to a collision. (single hull only)	7
N1.17 (SH)	Major pollution due to fire/explosion as a consequence of a communications problem leading to a collision. (single hull only)	7

## 7. STEP 2 – Risk Analysis

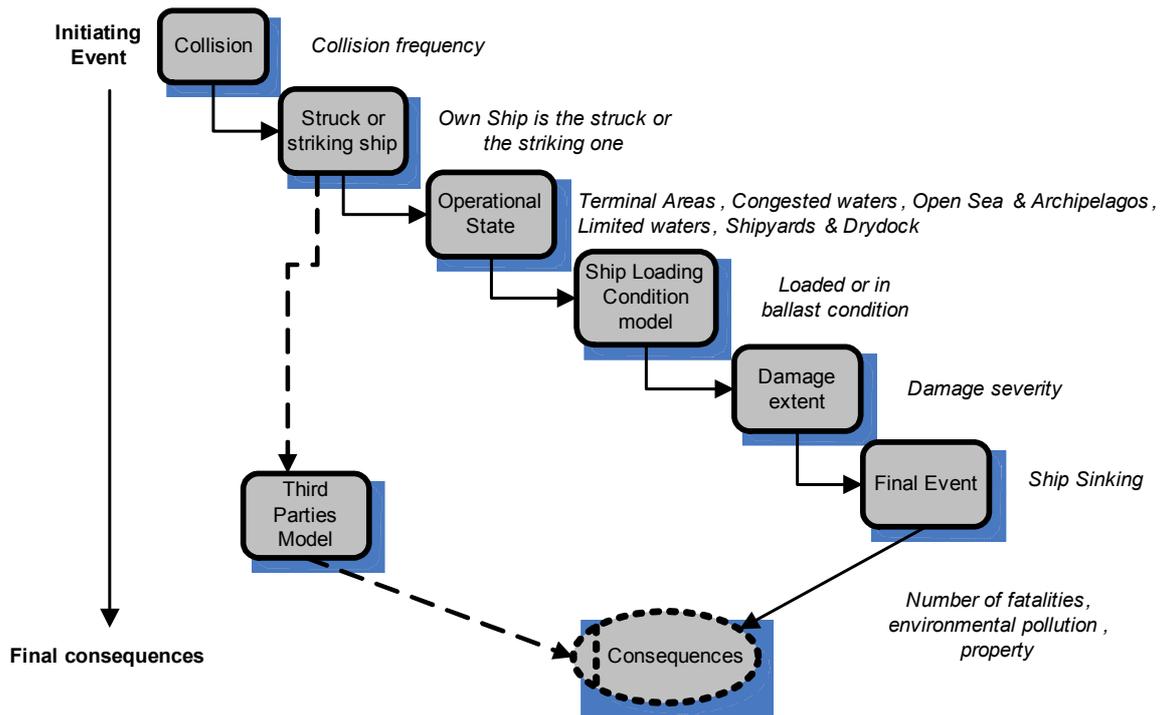
First, a survey of historic accidents of crude oil tankers > 60,000 DWT for the period 1990 (1978) to 2007 was carried out in order to establish the historic risk level associated with these vessels.

Based on available accident statistics and results from the HAZID, seven generic accident scenarios were defined and selected for further analysis. These were:

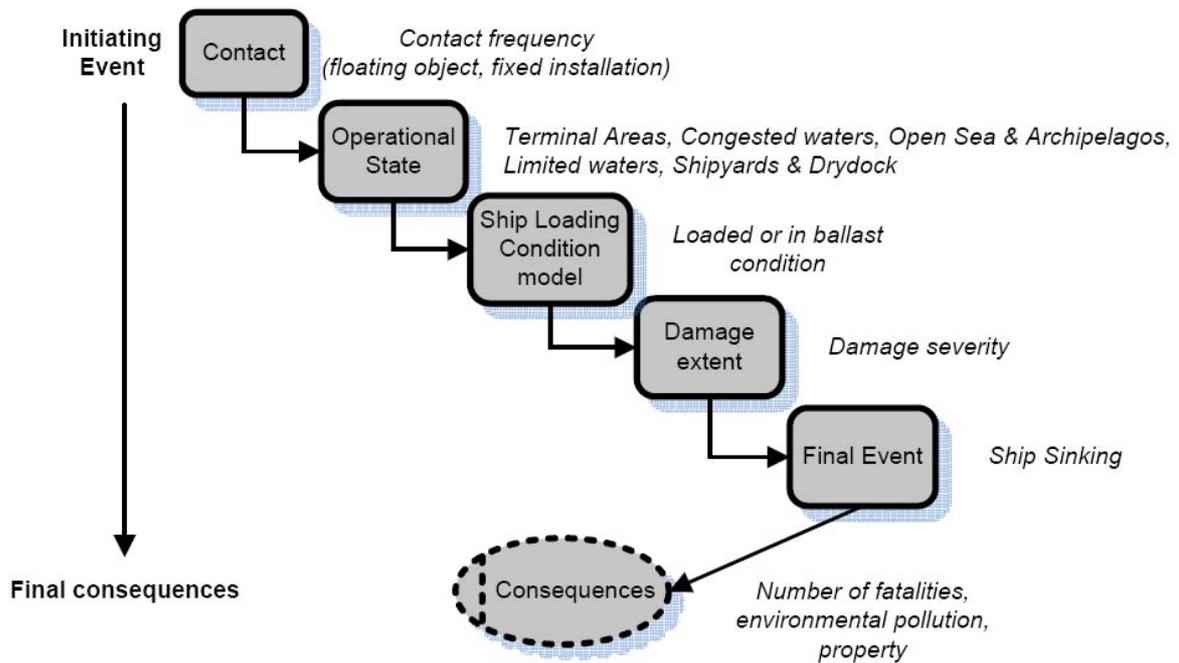
1. Collision;
2. Contact;
3. Grounding;
4. Fire;
5. Explosion;
6. NASF.

Following the selection of accident scenarios to investigate, a frequency assessment was performed in order to estimate the initiating frequencies associated with each of the selected scenarios. It was concluded that previous accident experience would provide a sufficiently accurate estimate of initiating frequencies for the seven selected accident scenarios. Hence, these estimates were adopted for the FSA study, as presented in Table 2.

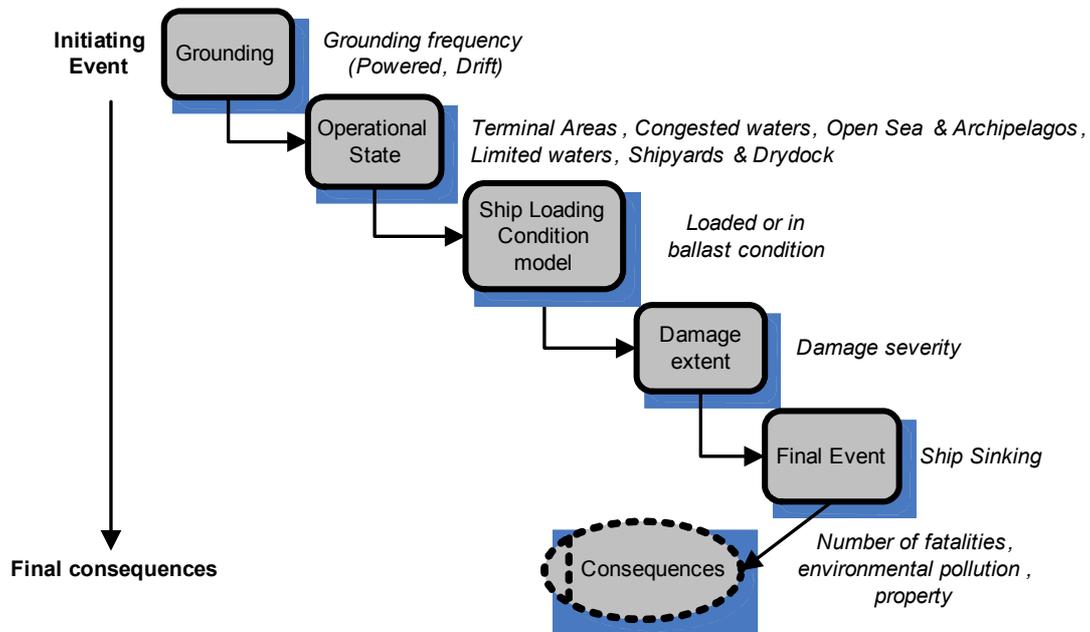
The next step in the risk analysis was to assess the expected consequences for each of the identified scenarios. This was done using event tree techniques, i.e. by constructing and quantifying event trees representing each generic accident scenario. However, first each scenario was described by creating a high level risk model. These models are illustrated in Figure 7 to Figure 12 for collision, contact, grounding, fire, explosion and NASF. The discussion of the scenario of ship-to-ship transfer in the HAZID revealed that the risk contribution from this accident scenario was negligible in comparison with overall risk, and this scenario was hence ignored for the remainder of the study.



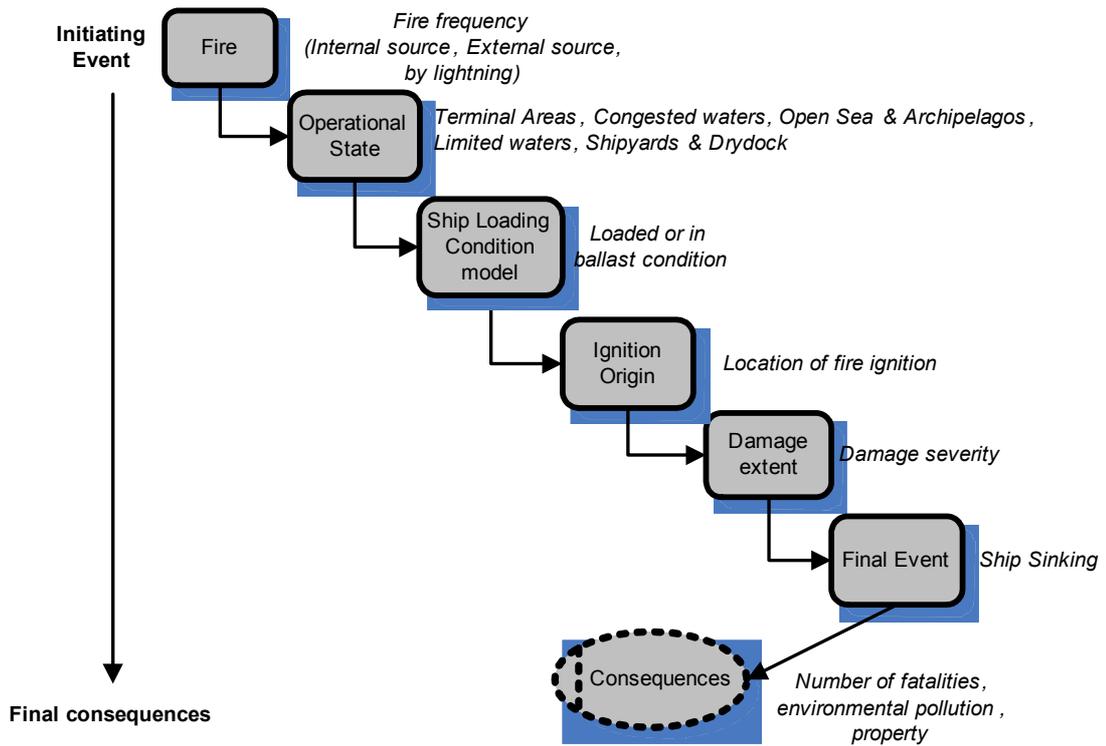
**Figure 7: Event sequence in collision risk model of an Oil Tanker**



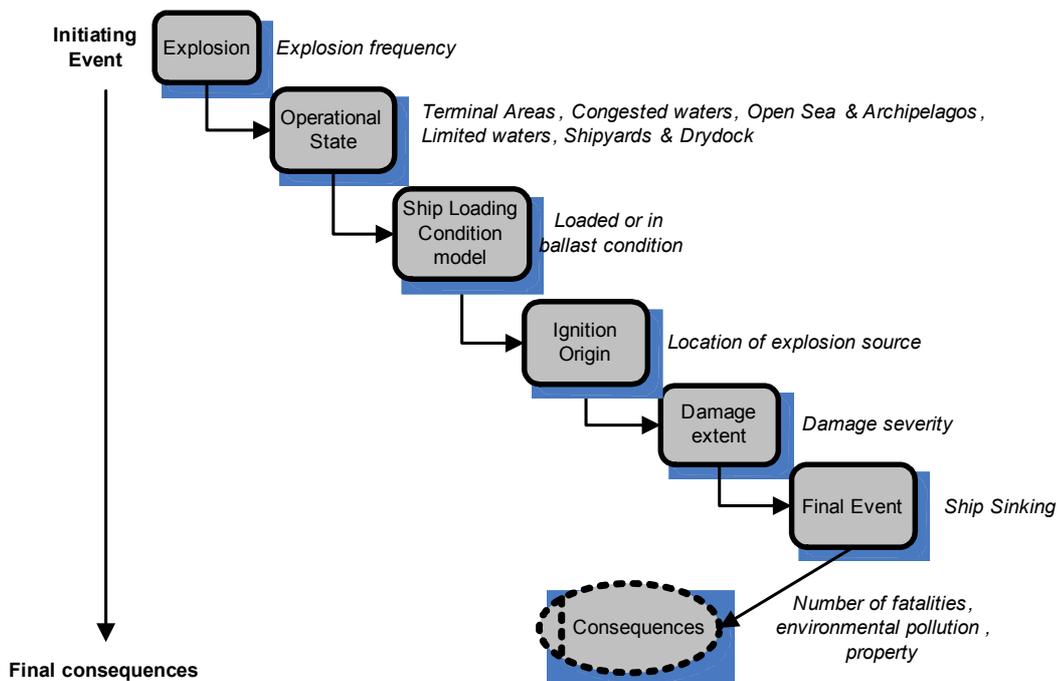
**Figure 8: Event sequence in contact risk model of an Oil Tanker**



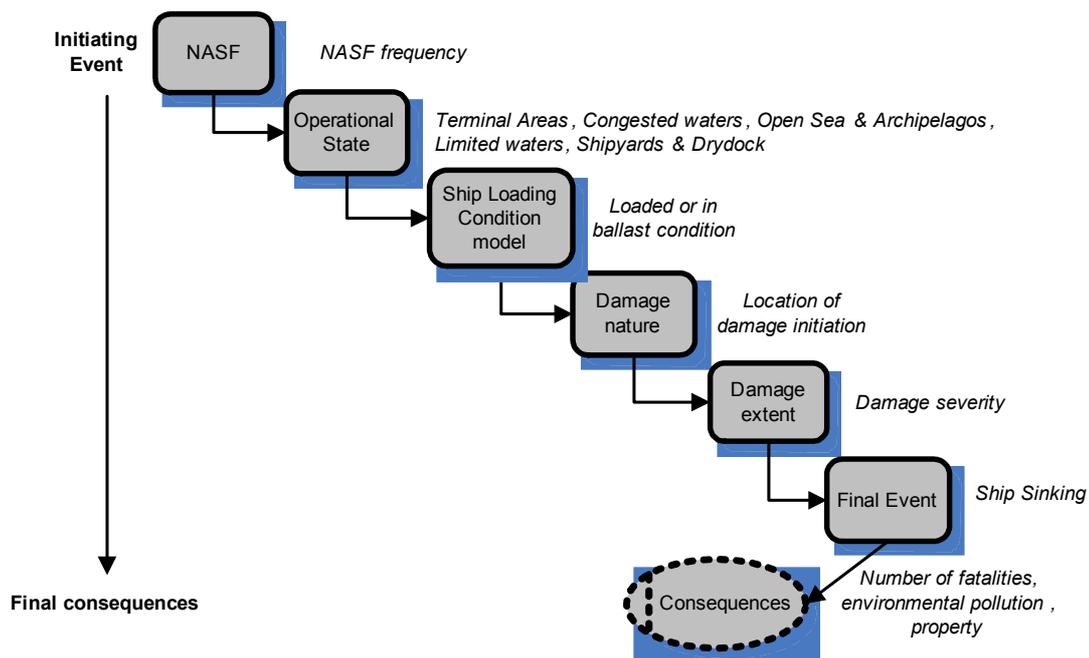
**Figure 9: Event sequence in grounding risk model of an Oil Tanker**



**Figure 10: Event sequence in fire risk model of an Oil Tanker**



**Figure 11: Event sequence in explosion risk model of an Oil Tanker**



**Figure 12: Event sequence in NASF risk model of an Oil Tanker**

In order to assign probabilities for the various escalating events and quantify the event trees accordingly, a set of different approaches and techniques was used. For each sub-model and each branch of the event trees, the method that was found to be most practical and the information sources that were assumed most relevant was utilized. These methods are explained in MEPC 58/INF.2 and in the full SAFEDOR reports together with illustrations of the complete event trees.

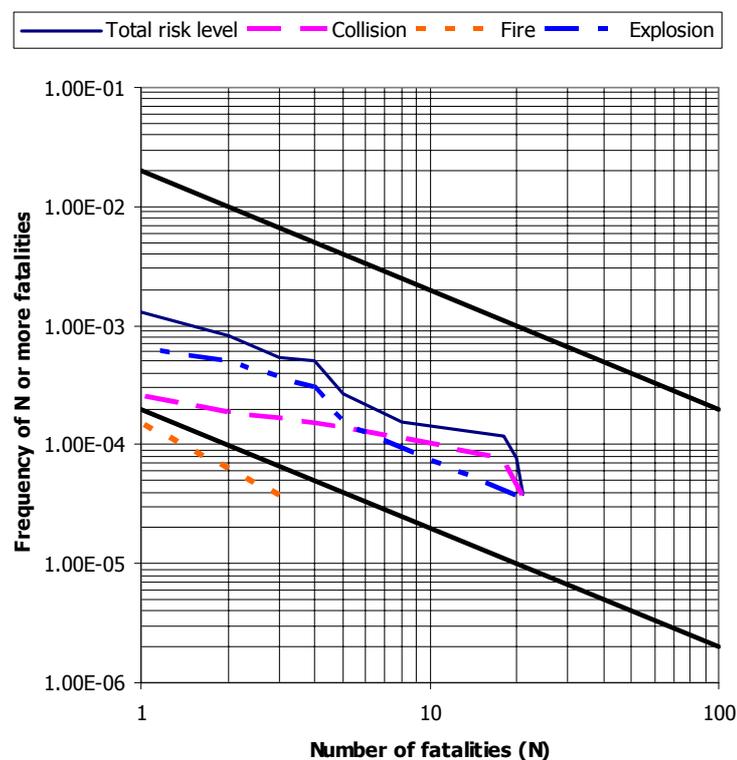
Based on the risk modelling and the event tree construction and quantification, the contributions from the different accident scenarios to the total potential loss of lives (PLL) from crude oil shipping was extracted. This risk summation for PLL and potential loss of cargo (PLC) is presented in Table 6. These results were then used to estimate the individual and societal risk for crude oil tanker crew.

**Table 6: Potential loss of lives and tonnes of oil from crude oil tanker operations (per ship year)**

Accident scenario	PLL (Crew)	PLC (Environment)
Collision	$4.91E-03$	$1.30E+01$
Contact	$\approx 0$	$1.41E+00$
Grounding	$1.32E-04$	$2.48E+01$
Fire	$2.34E-03$	$2.35E+01$
Explosion	$5.07E-03$	$1.23E+01$
NASF	$1.94E-04$	$1.44E+00$
<b>Total</b>	<b><math>1.26E-02</math></b>	<b><math>7.63E+01</math></b>

Intuitively, individual risks for 3rd parties or passengers are not an issue, and only the individual risk for the crude oil tanker crew was 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, and a 50-50 rotation scheme, the individual risk for tanker crew members is estimated to be 2.1E-04 per ship year. According to the individual risk acceptance criteria the individual risk level falls within the ALARP area. It is noted that the risk analysis covered ship accidents and contributions from occupational hazards were excluded from the study.

The societal risk to crew may be expressed through FN diagrams. Such FN diagrams, including risk-acceptance criteria, are presented in Figure 13. It can be seen from these diagrams that also the societal risk associated with cured oil tanker operations falls within the ALARP area.



**Figure 13: FN-diagram for total risk to crew for crude oil tankers DWT > 60,000 and 1990 to 2007**

## 8. STEP 3 – Identification of Risk Control Options

The main risk drivers according to the risk analysis were presented to a group of experts in a workshop. Through a brainstorming session, a list of 79 alternative risk control options (RCOs) was then produced. These RCO are screened with respect to cost efficiency. 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 to a manageable number for a more thorough analysis. Ultimately 11 RCOs were prioritized (Table 7).

Further descriptions of these risk control options can be found in MEPC 58/INF.2.

**Table 7: 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 7.1: Enhanced Cargo Tank Subdivision RCO 7.2: Increased double bottom height RCO 7.3: Increased side tanks width
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

## 9. STEP 4 – Cost Benefit Assessment

The objective for the cost benefit assessment is to evaluate the cost-effectiveness of implementing the alternative risk control options. The aim of performing such an analysis is to establish a list of recommendations on cost-effective risk control options that will reduce the risk of accidents on crude oil tankers. The GCAF, NCAF and CATS values are presented in Table 8.

Cost estimates have been based on information from suppliers, service providers, training centres, yards or technical experts where appropriate. The economic benefit and risk reduction ascribed to each risk control options were based on the event trees developed during the risk analysis and on considerations on which accident scenarios would be affected. Estimates on expected downtime and repair costs due to accidents were based on statistics from shipowners. As a basis for the cost benefit calculations, the following important assumptions were made:

- The size of a typical crude oil tanker crew: 30
- The average lifetime of a crude oil tanker: 25 years
- Depreciation rate: 5%

All numbers are based on introduction of one risk control option only. Introduction of more than one risk control option will lead to higher NCAF/GCAFs for other risk control options addressing the same accident scenarios as the remaining risk will be less. However, the results are believed to be robust in any case. The results from the cost-effectiveness assessments demonstrate that:

- RCO 3, RCO 4, RCO 8, RCO 9 and RCO 12 have a negative NCAF, implying a positive economical effect from implementation. Also the GCAF values of RCO 8 and RCO 9 are below the limit and that one of RCO 11 is close to the limit of USD 3 million per averted fatality. Hence, RCO 8 and RCO 9 could be recommended also based on safety considerations alone.

- All RCOs have a CATS value below the limit of USD 60,000. Even if a significant lower CATS limit is applied, for instance USD 10,000, RCO 3, RCO 4, RCO 6, RCO 8 and RCO 9 are cost-effective and thus could be recommended based on environmental considerations alone.

**Table 8: Results**

	Risk Reduction $\Delta R_S$	Oil Spill Reduction $\Delta R_E$	Cost $\Delta C$	Benefit $\Delta B$	$GCAF = \frac{\Delta C}{\Delta R_S}$	$CATS = \frac{\Delta C}{\Delta R_E}$	$NCAF = \frac{\Delta C - \Delta B}{\Delta R_S}$
	# of saved lives <sup>1)</sup>	Tonnes <sup>1)</sup>	USD <sup>1) 2)</sup>	USD <sup>1) 2) 3)</sup>	USD	USD	USD
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
<sup>1)</sup> Per ship lifetime, assumed to be 25 years. <sup>2)</sup> Includes NPV at 5% per year where relevant. <sup>3)</sup> Reduced PLC and PLP.							

- RCO 8 and RCO 9 could be recommended based on safety (GCAF; NCAF) and on environmental (CATS) considerations.
- For all design modifications described in sub-RCOs 7.1, 7.2 and 7.3 all CATS values are within the USD 60,000 threshold 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 (0.4 m) for AFRAMAX size tankers and RCO 7.3 (0.4 m) for SUEZMAX size tankers thus should be recommended for implementation ahead of the other RCOs which have higher CATS values and are hence less cost-effective.
- RCOs 5 and 12, 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 USD 60,000 limit). 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 to 8% of the total economic benefit, illustrating the disparity between RCOs 5 and 12 and the others.

In general none of the above RCOs are currently implemented on crude oil tankers.

## 10. STEP 5 – Recommendations

As basis for the recommendations it is observed that:

- An RCO is considered cost-effective if the GCAF (Gross Cost of Averting a Fatality) is less than USD 3 million. This is the value used in the FSA Guidelines (MSC 83/INF.2).
- An RCO is also cost-effective if the NCAF is either less than USD 3 million or negative; a negative NCAF indicates that the benefits in monetary units are higher than the costs associated with the RCO. 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  $\Delta R$  (the lower the  $\Delta R$ , the higher the NCAF).
- From a potential loss of cargo (PLC) point of view, an RCO is considered cost-effective if the CATS (Cost of Averting a Tonne of Oil Spilled) is less than USD 60,000.
- Hot works, communications problems, and technical steering gear problems in coastal waters, leading to collision, contact or grounding, emerged as the highest ranked hazard from the HAZID. Due to a large diversity of causes, communications problems were not further addressed at the current state.
- Collision, grounding, non-accidental structural failure, contact and fire were found to be responsible for 94% of the overall risk according to the risk analysis.

- It is commonly acknowledged that one catastrophic collision or grounding accident has the potential to damage the whole crude oil shipping industry.
- Acknowledging the physical properties of crude oil, and the difficulties in assuring that the crude oil tanks will be able to withstand high energy collision and grounding impacts, consequence mitigation is difficult and the consequences of a major spill event may be severe.
- Thus, preventing such accidents to occur seems intuitively to be the best strategy for mitigating the risk. This may be achieved by improved training and technical measures related to safer navigation.

During a brainstorming meeting at the National Technical University of Athens (March 2008) under participation of experts from tanker operators, naval research centres and classification societies, seventy-nine RCOs were identified. These RCOs were screened, and this FSA study demonstrates that the following RCOs are recommended for further consideration at IMO due to GCAF:

- RCO 8: Hot works procedures training.

The following RCOs are recommended for further consideration at IMO due to NCAF/CATS:

- RCO 3: Active steering gear redundancy.
- RCO 4: ECDIS – Electronic chart display information system.
- RCO 6: Navigational sonar.
- RCO 7.1: Ship design modifications – enhanced cargo tank subdivision.
- RCO 7.2: Ship design modifications – increased double bottom height (not economically viable for VLCC).
- RCO 7.3: Ship design modifications – increased side tanks width.

These cost-effective RCOs with significant potential to reduce loss of lives and environmental damage, and are therefore recommended as mandatory IMO requirements pertaining to the crude oil tanker fleet, noting that RCOs 7.1 and 7.2 (Ship Design Modifications) may be recommended for new buildings only.

The following RCOs are recommended for further consideration at IMO as costs are not grossly disproportionate:

- RCO 9: Double sheathed low pressure fuel pipes.
- RCO 11: Engine control room additional emergency exit.

The following RCOs were not found to be cost-effective and are therefore not recommended as mandatory requirements:

- RCO 5: Terminal proximity and speed sensors.
- RCO 12: Hull stress and fatigue monitoring system.

As a final note, it is acknowledged that some of the risk control options that were assessed to be not cost-effective may turn out to be effective in many cases, i.e. for particular ships or particular trades, and the results from this FSA should not be construed to mean that it will not be sensible to consider them on a case-by-case basis.

For example, increased use of simulator training or navigator training can be important and even necessary for specific ports/trades, and this risk control option may emerge as cost-effective in many cases. However, what was evaluated in this high-level FSA was to require increased simulator training as a general requirement through IMO legislation. Indeed, most tanker operators have trained their crew above minimum SOLAS requirements, and it is encouraged that such training should be continued. However, it is believed that the implementation of such training should be the responsibility of the owner or operator, based on commercial considerations, or possibly requirements from certain port States or terminal owners applicable to ships operating particular trades.

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