Safety Assessment of Crude oil tankers

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Abstract:

Crude oil tankers are transporting between 50 to 60 percent of all crude oil in world production. These huge amounts of black gold represent a source of a global economic development at the same time as they represent a threat for the sea and coastal environment. The transport of goods with ships is a controlled system, systematically managed by ship companies and regulated by international maritime standards. The control of different risks could, therefore, be monitored and managed.

The paper presents the overall risk management state for the crude oil tanker fleet evidenced by EMSA, and other international marine organisations. Based on historical statistical data, related to fleet size, accident reports, amount of oil spilled on the sea and the economic value of the crude oil transport business, the risk acceptance criteria are evaluated. The Formal Safety Assessment is further used for a systematic assessment of risk where potential hazards are analysed with structured methods (HAZID and HAZOP) and represented in events trees. The paper studies three risks: PLL (potential loss of lives), PLC (potential loss of containment) and PLP (potential loss of property). A general approach is presented and discussed with a particular focus on the evolution of risk acceptance in recent decades and evaluations of risk F-N curves for different tanker sizes.

1 Introduction

Maritime safety is governed by maritime safety policy instruments, which aim to maintain the risk level with an acceptable range. For accidents mainly concerning persons the criteria are related with a potential loss of lives and represented by individual and societal risk. Oil tanker transport directly impacts the safety of a crew that is limited, depending on a ship size, from 20 to 30 crew members. EMSA reports that the number of fatalities among crew on cargo ships varies from 30 to 50 (last five years). Oil tankers have the lowest percent compared to other ship types [1]. The direct impact of tanker accidents on civilians is limited and analysed mainly for port areas close to cities and straits passing populated areas [1]. This implies a specific risk assessment that usually considers local ship traffic statistics. Small ports or new terminals do apply here, because the representative data are not available, and so qualitative approaches (like PAWSA) or a comparative method with data from a similar region or terminal is used. A comprehensive approach is proposed by IMO in the Formal Safety Assessment for Crude Oil Tankers [MEPC 58/INF.2] and further developed by [A. Papanikolaou] in the SAFEDOR project and his team publications [2], [3].

Oil tanker transport risk is particularly sensitive from the environmental aspect, related to the loss of containment, particularly in coastal areas. The reason could be mainly expressed from the economical view. First there is the cost of cleaning a polluted coastline; second, much more

comprehensive, is the loss of revenue from other economic sectors (tourism, mariculture, quality of coastal living, value of land and parcels…). Based on past oil spills and consequent shoreline clean up procedures, Etkin [6] and Ugurlu [28] evaluated cleaning costs for different clean-up factors - e.g., geographic location, type of shoreline, labour costs, equipment costs, disposal costs, materials costs (absorbents or chemicals) and logistical costs. The correlation of clean-up costs is nearly linear related to spill size. Etkin [7] model based on total tonnes spilled and shoreline length oiled gives $y = 87.59x + 9.469$ where x length of shoreline oiled (km) and y the overall clean-up cost per tonne. The topic of the potential loss of containment is also the most publicly evident, drawing the most public concern.

The third risk estimation regards the economy of the oil transport itself. This refers to the risk of the loss of property, including the value of the ship and cargo, but also the costs of penalties, compensation and other direct and indirect costs. Different insurances reduce the economic risk for the shipping company (like ship insurance, cargo insurance during carriage, insurance for war risks and risks of environmental damage such as oil spills and pollution). For a single accidental event, the economic value could vary depending on the value of the ship, cargo, location of the accident though mainly on the magnitude of the accident. An MSC Formal safety assessment [8] assumes that for severe collision damage the ship damage cost is 5% of the ship's value. Damage costs are not information in the public domains, which is why an average value was used.

A framework for risk analysis for oil spills from tankers is presented by Goerlandt and Montewka [9], [10] as a semi-qualitative approach. The propagation of uncertainty is based on Bayesian Networks where weighting factors are obtained partially from expert proposals and partially from statistical data of past events. Compared to the HAZID approach and events tree representation of accidents course proposed by Papanikolaou [2], it stands out for the extent of the analysis. The latter is globally posted, while the BN approach is used in a localized navigation area. However, both approaches could be used independently on the scale of the assessment. The FSA [8] process is based on risk analysis procedures and enhanced by a cost benefit evaluation for potential RCOs (Risk Control Options) to mitigate risk. The identification of hazards and the analysis of historical casualty data are of signal importance in evaluating the weighing factor of a singular event course. In this context, the analysis of historical data provides important information about the development of relevant risk over recent years, as well as of the present situation. Furthermore, the prognosis of data regarding world fleet growth and production and consumption of oil could suggest the future evolution of risk, but more important, calculated risk *acceptability* [12]. Even a forecast of a few years regarding risk acceptability change is important for planning ROCs, because in the maritime sector the time period when ROCs could take effect are months and years. Month periods are in line with charter parties, voyages or time; year periods are related to inspection surveys or class renewal (every five years). An important time period is also the delivery time of a new building, usually two to three years. In a good market and economic conditions risk could be reduced by owning a new ship built in accord with the latest construction standards, the latest navigation equipment and reliable machinery.

All tree risks are calculated from the same interrelation of data. The tanker world fleet review is obtained from the German ISL (Institute of Shipping Economics and Logistics) statistical publication [13] from 2007 to 2016. Fleet statistics and causalities up to 2007 are already analysed in the MSC FSA report [8] and used to extend the statistical period to the year 1980 and evaluate a more representative result.

1.1 Tanker fleet review

The oil tanker fleet is in direct relation with global oil demand. Figure 1 shows basic relations between global oil production and consumption and a number of oil tankers of different sizes. We

should note that the number of oil tankers from Handysize to VLCC is just a half of all tankers registered. However, tankers smaller than Handysize are not analysed as potential large polluters. A large percentage of these other tankers are supply ships or barges for oil and products supply. These ships mainly engage in coastal navigation.

The increasing industrialization in a developing world has been the primary influence driving the demand for global crude oil. Overall non-OECD demand has increased at a rate of 3.6% per annum, with the Asia/Pacific region's oil demand growing at roughly 2.7%. Developed nations have diminishing oil demand with a negative -0.4% per annum growth rate. The decline in OECD oil demand is not enough to offset the rising demand from the developing world. The net result is an increasing supply/demand imbalance that is visible on global scale [14], [15].

The graph indicates that global oil production has increased by about 10% over the last ten years, while oil consumption has increased by about 12% in the same period. At the same time the oil tanker fleet of ships of Handysize and larger gained about 220 ships. Assuming the quantity of oil production difference from 2016 and 2008, and assuming that the percent of oil on seaborne trade was 59% in 2008 and 56% in 2016 we obtain the additional ship capacity growth. Taking into account the fraction of this additional cargo space and the number of additional tankers in the fleet and the average number of voyages per ship-year (4.99 in 2016 and 5.51 in 2008) we obtain the average carrying capacity of an additional ship in the last decade. This is about 92,800 tons, the average between Panamax and Aframax tanker size.

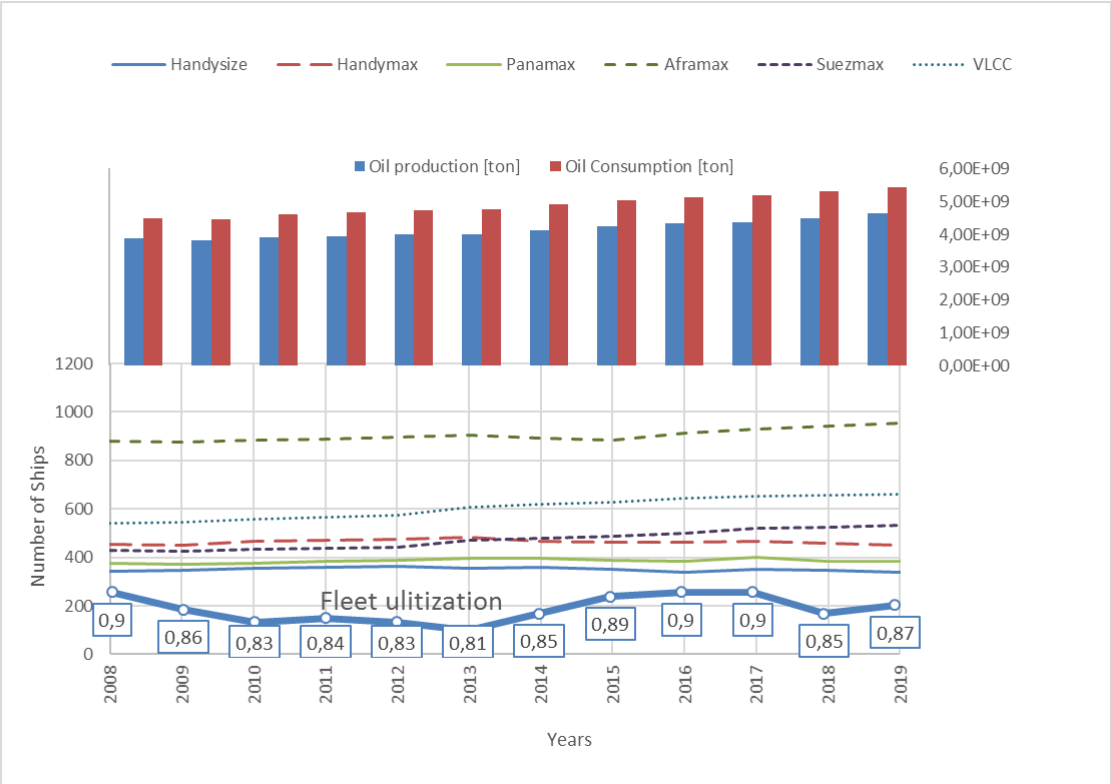


Figure 1: Relation of oil production/consumption and tanker fleet utilization

The statistics of the world tanker fleet only now makes sense. First the reduction of small tanker like Handysize, almost constant rate of Handymax and Panamax ships and the growth of larger tankers especially VLCC.

The forecast of the oil tanker fleet change indicates the growth of the fleet [13]. The difference of oil tankers new-building's and fleet reduction is 166 ships added to the world fleet in 2011, 71 ships in 2015 and at the end of 2017 about 200 new ships will expand the fleet [16]. Based on the fleet growth and oil production prognosis the fleet utilisation factor is calculated. It has mainly been

constant in the last decade, but never exceeded 90%. On a global level, these free capacities mitigate changes in oil production and demand especially because additional transport capacities are delayed by two to three years, requiring the building of new ships. The trend in oil tankers is to is to increase the transport capacity with bigger ships of Aframax class and larger. Despite its critics, the oil tanker shipping industry in general has an excellent safety record; however serious losses can and do occur. A number of accidents, despite their large size, caused little or no 'visible' environmental damage as the oil was spilled offshore and no coastline was affected. For this reason, many accidents are not familiar. More known ships accidents like the Prestige, Exxon Valdez or Hebei Spirit are known because oil seriously polluted the nearby coastline. According to ITOPF [17] the number of spills is reducing on average to 1.8 spills per year for spills over 700 tonnes. Similarly, the number of small spills, less than 700 tonnes, is in decline. The rate of occurrence of large and small spill is on average one-third. On the other hand, the number of accidents is increasing in accord with the growth of the fleet. Small and medium size spills account for 95 per cent of all accidents recorded. A large percentage of these spills occurred during loading (40%) and discharging (30%), which normally takes place in ports/oil terminals. The largest part (60%) is caused by fires, explosions and equipment failure. The majority of these are caused by equipment and hull failure. The other 50% of accidents with oil spill occur when the ship is underway. Collison and grounding are the main cause of spillage. Considering EMSA reports from 2007 until 2016 [4], contact, collision and grounding may be the biggest danger to a tanker ship but fire/explosion and equipment damage may also have serious consequences.

1.2 Focus on risk assessments

Authorities are struggling with the need to adapt to the expanding tanker ship trade, which includes the need to accept larger ships. Safety analyses are necessary to understand the eligibility of specific risk control options (ROCs). This way investments in safety are not only justified but become effective too. While the international shipping community has long been concerned with maritime safety, in recent decades the safety of tanker ships has become more of a concern. Tanker ships must also comply with the safety standards set by the International Maritime Organization (IMO) enforced through the International Convention for the Prevention of Pollution from Ships, or the MARPOL Convention. One of the most important risk control options integrated in 1992 into MARPOL was the amendment making mandatory a double hull construction for tankers of 5000 dwt and more. The accident of the tanker Erika closed the coast off France in December 1999, encouraging IMO members to adopt a revised schedule for the phase-out of single-hull tankers, which came into effect in April 2005.

The Formal Safety Assessment (FSA) for crude oil tankers is a tool for risk evaluation developed by IMO, more precisely the SAFEDOR project consortium [3] to enhance the safety of ships, crews, and the environment. The FSA uses five steps: hazard identification (HAZID), risk assessment, risk control options, cost benefit assessment and decision-making recommendations. Its goal is a systematic approach to safety in all aspects regarding particular vessels. This paper examines the FSA in relation to the latest tanker fleet and accidents statistics with a particular focus on risk acceptance criteria and events that influence mostly a risk level. The use of statistics and expert opinion for hazard operability (HAZOP) is valuable information for the evaluation of probability rather than the evaluation of consequences. The magnitude of these last is more a matter of physics and consequence analysis. The following chapters are going to present the proposed methodology and results are going to be validated and discussed regarding wider application.

2 Risk evaluation criteria

Risk evaluation begins with the conception of appropriate risk acceptance criteria. Terminal operators identify potential hazards strictly related with ship hazards, when the ship is approaching or leaving the port or is moored at a terminal. The term risk acceptance is established in many industries and regulations [8]; however, it is worth noting that the term itself can be misleading. The risk is never completely acceptable, but the activity might imply that the risk to be acceptable because of the benefits. One reason for explicitly mentioning Risk Acceptance is the need to focus management's attention on this issue, which would otherwise be treated superficially. “Risk evaluation” is the official term at IMO [18] and reflects the organization's position that risks are not acceptable; yet decisions involving risks are accepted because their benefits are deemed to outweigh the risks. During the last decade the terminological difference between evaluation and acceptance became more evident, and is clearly distinguished in the recent EMSA report. The risk evaluation process in the EMSA report is used to evaluate risk acceptance criteria. The evaluation is mainly based on accident statistics and risk-based hull integrity, provided by the SAFEDOR project report [3]. The maritime sector has widely accepted ALARP risk criteria, the British risk acceptability framework, widely recognized in Norway and other countries. It uses the following categories: unacceptable, tolerable and broadly acceptable risk. Risks within the ALARP region are tolerable up to the “As Low as Reasonably Practicable”. If tolerable, risks shall be reduced as long as the risk reduction is not disproportionate to the costs or implemented cost beneficial Risk Control Options (RCOs).

Risk Acceptance has been included in the assessment of methods and tools, as it might be a decision criterion of organizations (e.g., in the financial and insurance sector, in critical infrastructure protection, the shipping sector). Again, one reason for explicitly mentioning Risk Acceptance is the need to draw management's attention to this issue. The risk criteria should reflect the organization’s values, policies, and objectives, should be based on its external and internal context, should consider the views of stakeholders, and should derive from standards, laws, policies, and other requirements [19]. Considering the IMO FSA guidelines for Crude oil tankers, regarding ALARP one can understand the reasons for risk acceptance levels based on cost benefit computations. However, depending on the country and company policy on risk acceptance level, risks treatment could and should be a continuous challenge, independently based on results of risk evaluation or cost benefit equilibrium [12]. For crude oil tankers, the risk criteria are based on three primary risks; potential loss of life (PLL), potential loss of containment (PLC) and potential loss of property (PLP). The responsibility to keep each of these primary risks at an acceptable level is shared between the ship company, state legislation, maritime rule regulator and individual seafarer. The calculated tolerable risk is directly related to the product of accidental events and the economic value of the assessed business, that which delivers higher business values allows higher tolerable risks. As the oil industry is a highly profitable business the calculated risk criterion are presented and compared with the actual ones related to accidental events in the last decade, to understand the evolution of risk acceptance and the necessary influence of rules and regulation in the maintenance of social risk acceptability.

In the following, the modelled risk level for oil tanker ships will be evaluated using risk evaluation criteria concerning individual risk and societal risk.

2.1 Individual risk

Individual risk is the frequency for an individual fatality per year, the likelihood that the most exposed crew member will die as a result of an accident or event on board a ship. This report only considers events related to ship operation. Accidents due to intentional activities and occupational risks are not within our scope.

Crew members are very aware of their risks and have been trained to carry out their job responsibilities safely and effectively. Safety regulations on ships are regulated by the SOLAS convention, which requires the duty holder to ensure and demonstrate, through the SMS (Safety Management System) that risk to employees, part time employed persons and the public is acceptable. In 1989 the Health and Safety Executive (HSE) published a document entitled Risk Criteria for Land Use Planning in the Vicinity of Major Industrial Hazards. Those criteria bound the ALARP region and are still in applicable currently.

The authors Trbojevic [21], Cornwell [22], Lohansen [23], and others have emphasized the individual risk criteria based on existing national standards and guidelines. The harmonization of risk acceptance criteria for the transport of dangerous goods is proposed in the final report of the DG-MOVE project [24] finalized by DNV-GL for the EU. The report indicates that a cost of £2M per fatality averted is often used to indicate where risk reduction measures were "reasonably practicable". Though there is logic to the amount and how it was arrived at, the idea essentially is misguided. The risk criteria should always be based on the economic value of the business. The value of 2 million per person (fatality) is equivalent to an average earning of a person in 40 years of work. In my opinion, the valuation of human life on this basis would not be socially accepted, because it is posting a price on people's lives. Basically, this could only be the measure of a low acceptance criteria. The upper should always be based on the economic value of the business. The potential loss of life is calculated as:

$$\boldsymbol{PLL_A = r \cdot EV} \qquad \textbf{eq. 1}$$

where r is the number of fatalities due to the activity divided by the financial contribution of the activity and EV is the economic value of the business, and in this case EV represents a reference vessel and is derived from the revenue of a ship per year. Based on this approach both values change yearly. The change of main values in last decade are presented on Figure 2.

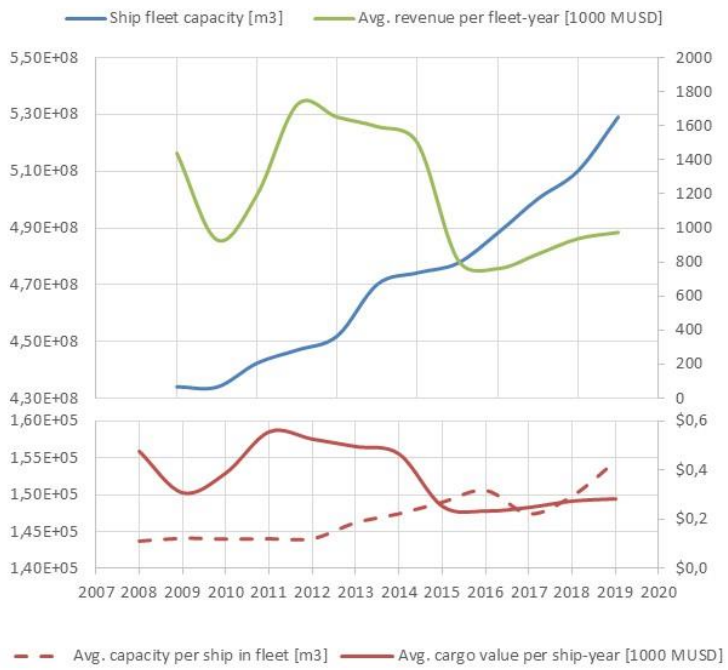


Figure 2: Global and average oil tanker capacity and revenue

Considering the size of the oil tanker business and the number of crew members on a single ship (between 20 to 30) the calculated risk criteria for a crew member is very high compared to other

transport processes. For the year 2016, r is calculated to 0.002623 fat/1000M$. Converting this to risk acceptable cost per fatality yields 381.2 1000M$/fat. Compared to cruise shipping the risk level acceptance criteria for passengers is about 1.5 fat/1000M$ or 666 M$/fat, for road transport 100M$/fat and so on. Observing these values, risk criteria are posted very high, but they are not the only criteria dictating risk policy and risk control actions. The potential loss of life is calculated from eq.1 and gives 0.000617 fat/ship year for 2016.

Oil tanker shipping also has environmental risks due to pollution and economic risks due to potential loss of property in case of accidents.

2.2 Oil pollution risk

Assuming the same approach for calculating risk criteria as that for crew, the oil pollution criteria r is calculated as a fraction of total spill quantity and financial contribution of the activity in a single year. The spill quantity is obtained from ITOPF statistics [17] and varies from 2,000 to 15,000 tons per year. This gives a pollution criteria of 6.55 tons spilled/1000M$ or 152.6 M$/ton spilled. Further, the potential quantity spilled is a product of the pollution risk criteria and the economic value of the oil shipping business.

$$\boldsymbol{PLC_A = r \cdot EV} \qquad \textbf{eq. 2}$$

This gives a potential loss of containment that is 1543 ton/ship year for 2016. This value is obviously a spill quantity for an average ship size in the fleet. The average ship size is calculated considering a number of ships in each category form Handysize to VLCC tankers. The average size is about 70,000 DWT, almost Panamax size. Further the frequency of accidents with a ton or more oil spilled is calculated and for the year 2016 it gives $1.30 \cdot 10^{-1}$ /year.

$$\boldsymbol{F_2 = \frac{PLC_A}{\sum_{N=1}^{N_u} \frac{1}{N}}}, \qquad \textbf{eq. 3}$$

where:

F_2 is the frequency of accidents involving one or more ton spilled,

N_u is the upper limit of spill quantity that may occur in one accident (total loss),

PLC_A annual potential loss of containment

The calculated value F_2 could be considered as the tolerable accident frequency for an oil spill. The boundary area around this value defines the ALARP region. This is defined dividing F_2 with factor 0.1 for the upper border of ALARP and multiplying by 0.1 to bound the lower border.

2.3 Loss of property risk

The risk of losing part or all of the cargo and costs of ship damage or total loss is an economic risk that primarily influences the company policy. The world fleet statistics show that the number of accidents is increasing in recent along with the number of ships. On the other hand, the consequences of accidents are less severe thanks to the continuous maritime standards improvements for ship construction, electronic navigation control, shore vessel traffic services and more.

The risk of property loss is here calculated with the same approach as PLL and PLC. The calculation for PLP in now:

$$\boldsymbol{PLP_A = r_P \cdot EV} \qquad \textbf{eq. 4}$$

Where EV is an average ship revenue per year and r_P is an loss of property per average revenue per ship.

$$\boldsymbol{r_P = (NA \cdot SV_{av} \cdot f_{dmg}) + (Q_{spill} \cdot P_{av_y})/rev_{a\_s}} \textbf{ eq. 5}$$

where,

NA – is the number of accidents for oil tankers with 60,000 DWT and more in the analysed year
SV_{av} – an average new ship value (when analysing sizes from Handysize to VLCC the average value is about 50 M$)
f_{dmg}- is an average factor of damage cost. According to MEPC 58-INF-2 is about 5% of the new ship value for severe collisions, 10% for severe fire and explosion accidents. Non-severe accidents have a damage factor of about 2%. For the purpose of this study f_{dmg} is assumed to be 4%.
Q_{spill}- is the of oil spilled in the analysed year according to ITOPF
P_{av_y}- is the average oil price in the analysed year, and
rev_{a_s}- the average revenue per ship in the fleet during the analysed year

The unit for PLP_A is the ratio of property loss in M$/ship year M$ business economic value. Further the frequency of property loss is calculated with eq. 6, where N_u is the cost of a total loss depending on ship type. An average value of $\sum_{N=1}^{N_u} \frac{1}{N}$ for Panamax size is 4.5.

$$\boldsymbol{F_3 = \frac{PLP_A}{\sum_{N=1}^{N_u} \frac{1}{N}},} \qquad \textbf{eq. 6}$$

For the year 2016, the tolerable damage cost F_3 is $2.96 \cdot 10^{-2}$ property lost M$/ship year. The acceptable area around this value is defined by factor 0.1.

2.4 Societal risk

A societal risk criterion takes the possibilities of catastrophic accidents of major societal concern into account to ensure that the risks imposed on the society from the activity are controlled. Depending on the system under consideration, both individual and societal risk evaluation criteria might apply. Societal risk posed by a tanker ship is measured by the probability of a group of people (crew) and their direct risks of accidents, and more extensively the consequences of pollution. From the social point of view this last is the most important risk because an accident could directly influence the living environment and have indirect negative economic impacts. The societal risk is dependent on both the density of people in the vicinity of an accident and the location of the population in relation to the event. The societal risk is generally presented in the form of an F-N curve, expressing the relationship between the annual probability (F) of exceeding a given number of fatalities and the number (N) **Error! Reference source not found.**.There are exceptions that cannot be generalised like for low population coastal communities with virtually a single economic activity like fishing. An

accident in that case risks destroying an entire culture. This kind of societal risks are not considered here.

In most countries, the risk assessment is performed on the basis of potential fatalities to the exposed population. Different countries use slightly different criteria for risk acceptability. In the UK, the Health and Safety Executive (HSE) guidelines are available for use for individual risk as the principal measure, but also for use as the societal risk criteria for land use planning. Facilities are permitted only when these (published) criteria are met. In the Netherlands, however, both the individual risk criteria and the societal risk criteria must be met when considering those events whose hazardous effects extend to such distances at which the conditional probability for lethality is higher than 1% **Error! Reference source not found.**.

F-N curves are, however, a common way of presenting societal risk and are considered by some parties the best way of illustrating this data. The method of deriving societal risk evaluation criteria in this report is based on IMO MEPC 58-INF-2 [8], decision parameters including risk acceptance criteria [8] and updated by the EMAS report on Risk level acceptance criteria [24]. The risk level is plotted as a cumulative function of consequence and frequency on a log-log graph.

$$\boldsymbol{F_1 = \frac{r \cdot EV}{\sum_{N=1}^{N_u} \frac{1}{N}}} \qquad \textbf{eq. 7}$$

where:

F_1	is the frequency of accidents involving one or more fatalities,
N_u	is the upper limit of the number of fatalities that may occur in one accident,
r	the number of fatalities due to transportation divided by contribution to GNP by transportation. It can be calculated as r = fatalities/$ GNP and
EV	is the economic value of the industry. In this case EV represents a reference vessel and is derived from the revenue of a ship per year.

The value of tolerable risk is calculated for the year 2016 and is $1.6 \cdot 10^{-4}$ fat/year. The upper tolerable limit has been obtained by multiplying the calculated tolerable risk by a factor of 10, obtaining $F_{upper}=1.6 \cdot 10^{-3}$, and the lower limit by dividing the calculated risk by factor 10, obtaining $F_{lower}= 1.6 \cdot 10^{-5}$. The criteria used are presented in Table 1. The boundary limits are therefore computed; however computed limits, as discussed in the introduction, could only be used as the lower boundary limit of the upper risk criteria limit. Additional reduction of the upper risk criteria limit could be based on company policy.

As presented in paragraphs 2.2 and 2.3 the boundary of ALARP are calculated and presented in Table 1.

Table 1: Limits for societal risk for 2016

Parameters for societal risk criteria	Value	Denomination
F_{1_upper} (loss of life)	$1.6 \cdot 10^{-3}$	fatality/year
F_{1_lower}	$1.6 \cdot 10^{-5}$	fatality/year
F_{2_upper} (loss of containment)	1.3	spills/ship year
F_{2_lower}	$1.3 \cdot 10^{-2}$	spills/ship year
F_{3_upper} (loss of property)	$2.96 \cdot 10^{-1}$	property lost MUSD/year
F_{3_lower}	$2.96 \cdot 10^{-3}$	property lost MUSD/year

Based on equation 1 and the yearly statistics, the upper limit of the ALARP region changes its value. Taking into account only the period between 2010 and 2016 that is best documented, we can see the variation of the frequency of accidents involving one or more fatalities, spills and property loss depending on accident type. A simple trend prognosis is also applied for data up to 2019 to see the evolution of risk acceptability. Figure 3 shows the calculated tolerable frequency of fatalities per year (F_1). Similarly, the tolerable spill frequency (F_2) and tolerable property loss (F_3) are presented. First of all, the magnitude of each is distinguished. The higher acceptability likelihood is for spill events that occurs continuously. The continuous large number of these events influence their higher acceptability. The loss of containment itself gives just a first answer to oil spill acceptability; the second is the quantity of the spill directly related with the loss of property. The frequency of both loss of containment and loss of property have an increasing trend related with oil production and seaborne trade. Simply, more oil production and trade, higher acceptability of spill related accidental events. Fortunately, the trend event frequency acceptability is much slower than the seaborne trade of oil. This could indicate that rules adopted by IMO, as mentioned in the introduction, have had positive results on tanker safety. Last is the acceptability for the loss of lives due to accidents. The average frequency value is about 6·10-4. Compared to IMO recommendations [8] the maximum tolerable risk for crew members is 1·10-3/year. It means an average crew member on an oil tanker is sailing safely. For comparison, the maximum tolerable risk for passengers on cruise ships is 1·10-4/year.

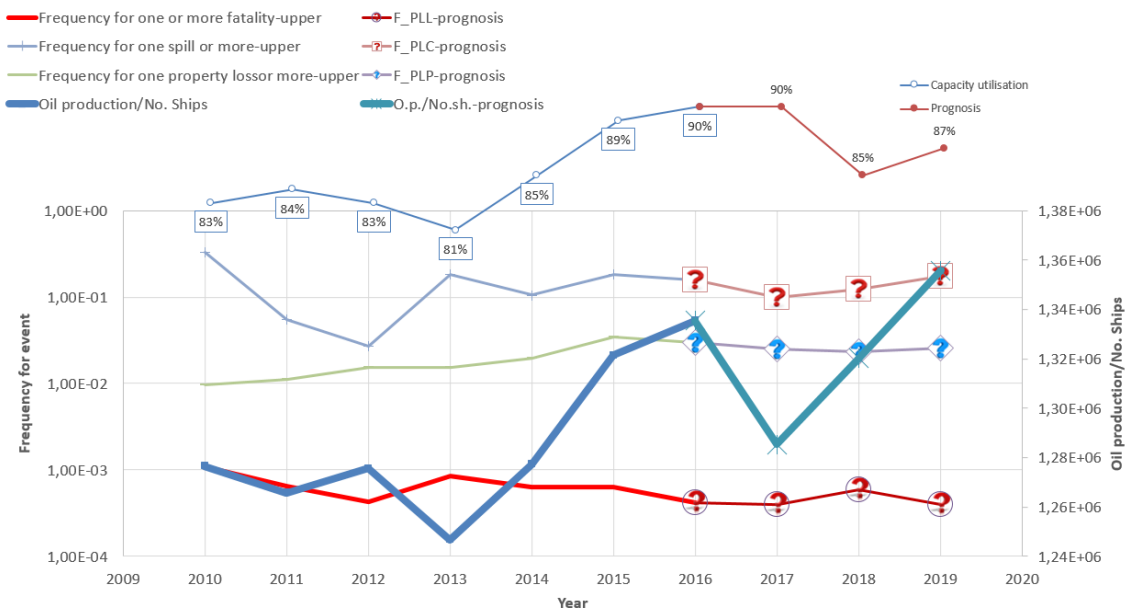


Figure 3: Calculated upper border of ALARP region per year

2.5 Oil tanker accident statistics

The review of the last three and a half decades shows a dynamic of accidents trend, presented in Figure 4. The review takes into account high-risk accidents only; contact-collision, fire, grounding and sinking. From 2011 to 2015, 6403 cargo ships were involved in 5942 marine casualties and incidents, 670 of these were oil tankers [5], [29], [30]. Among the large number of reported accidents, about 15 are classified as high-risk. The graph shows an increase of the average accident frequency from 2008. A very important consideration is the reliability of data before this year. Only from 2005 did EMSA begin the systematic collection of accident data. The data takes into account the significant increase in the number of ships that have entered the market during the previous decade – particularly for vessels > 60,000 GRT.

Figure 4 shows the increase of accident frequency that is related to the increase of ships on trade. The future is unknown, but the trend shows an increase of the tanker fleet in the coming years.

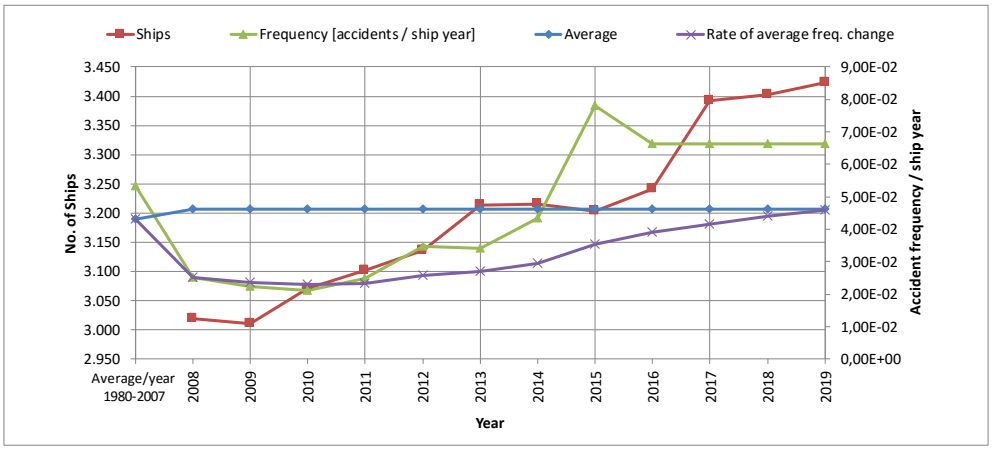


Figure 4: Accident frequency, year-by-year (per ship)

The threat to crew depends on the type of accident. The accidents registered on oil tankers from 1980 to 2016 are presented in Figure 5. "Other" accidents refer mostly to hull and machinery related incidents which have generally been low in fatalities over the years. "Fire/Explosion" and "Collision/Contact" have been the most serious of relevant historical events.

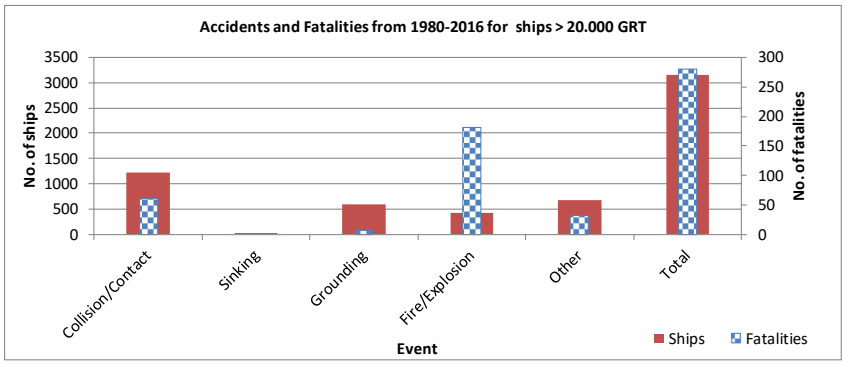


Figure 5: Cruise ship accidents by type from 2005-2014

The EMSA overview of marine causalities and incidents for 2016 shows that the distribution of marine casualties and incidents is similar across the voyage segments for all cargo ship types. The

departure phase remained the safest over the period. About 45% of the casualties took place in port areas, followed by 22% in coastal waters. Of all accidental events, shipboard operation appeared to be the most significant contributing factor (70%). Failures mostly occurred due to human error in highly congested waters or time-pressure operations.

Figure 6 shows the distribution of marine casualties in EU waters and the density of marine traffic. The number of causalities and incidents in the EU represents about 80% of all those in the world. Most of them occur in congested waters, both coastal and internal. Northern Europe is the most affected. The largest ports like Antwerp, Rotterdam, Amsterdam, Hamburg and the UK ports create a high traffic density from the English Channel to the Waden sea. Through its short history, relevant oil spills occurred in these waters. The most well-known accidents are: Torrey Canyon, Amoco Cadiz and Sea Empress, which are in the top 20 list of largest oil tanker spills.

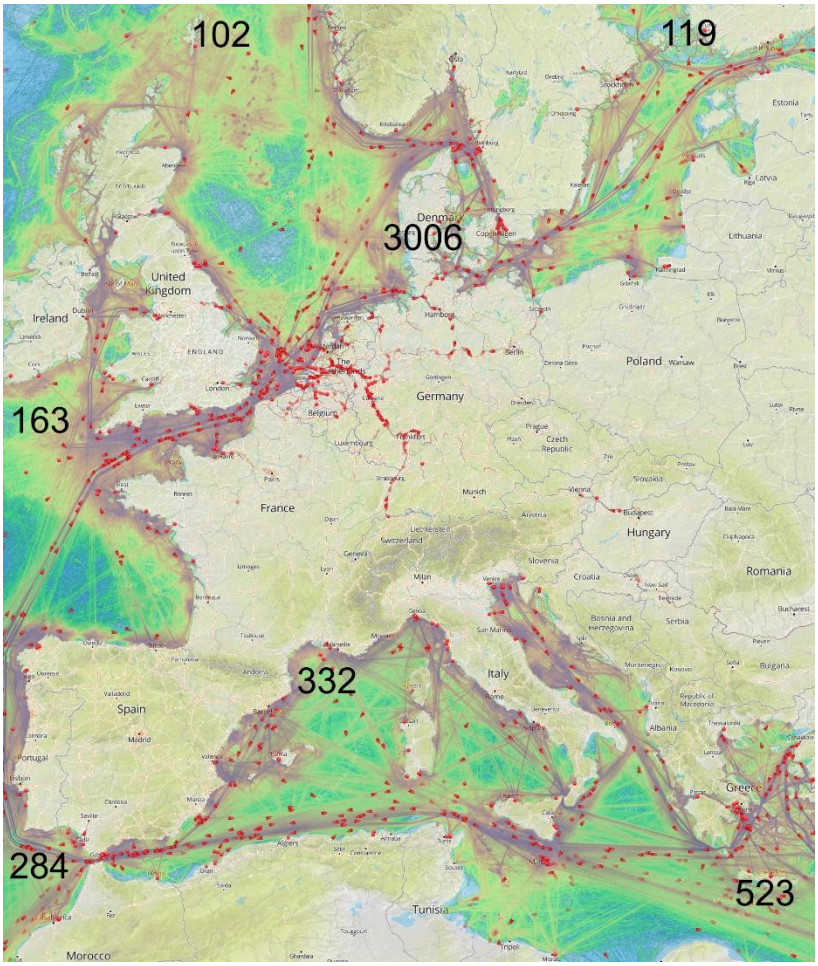


Figure 6: Distribution of marine casualties and incidents within the territorial sea and internal waters of EU States 2011-2015 and traffic density [Marine Traffic]

2.6 Accident frequency calculation

The exposure during the 1980-2016 period has been 71,422 ships-years and will be used for the accident frequency calculations. The frequency calculations can be summarized as the fraction of accidents per accident type and the total number of accidents. However, the number of accidents with fatalities is too few to represent any significant accident trend. As already mentioned in paragraph 2.5

the frequency of accidents is increasing: the average frequency value from 1980 to 2008 was $4.3 \cdot 10^{-2}$/year, but has increased to $4.6 \cdot 10^{-2}$/year over the last decade. That is a relatively small change that yet confirms the statistical relation between seaborne trade growth and accidents occurrence.

Table 2: Accident frequency calculations for oil tankers between 1980-2016

Oil tenker	Collision/Contact	Sinking	Grounding	Fire/Exp.	Other	SUM
Ships >20,000 GRT						
Accidents recorded 1980-2016	1222	6	599	435	678	2940
Ship years 1980-2016 [ship years]	66423.2	66423.2	66423.2	66423.2	66423.2	66423.2
Tanker accident frequency [per ship year]	**1.84E-02**	**9.03E-05**	**9.02E-03**	**6.55E-03**	**1.02E-02**	**4.43E-02**
Return period [no. of ship years per accident]	54	11071	111	153	98	23
Number of fatalities, 1980-2016	61	0	6	181	32	280

On the other hand, the consequences of these accidents have been reduced. Table 3 indicates that an average oil spill frequency has been reduced by factor 10 in the last decade, compared to the period between 1980 and 2007.

Table 3: Oil spill frequency calculations for oil tankers between 1980-2016

Oil tanker	Collision/Contact	Grounding	Fire/Exp.	Other	SUM
Ships >20.000 GRT					
No. of spills 1980-2016	447	343	124	120	1034
Ship years 1980-2016 [ship years]	66423.2	66423.2	66423.2	66423.2	66423.2
Tanker spill frequency [spill per ship year] 1980-2007	**1.10E-02**	**8.43E-03**	**2.90E-03**	**2.80E-03**	**2.52E-02**
Tanker spill frequency [spill per ship year] 2008-2016	**9.57E-04**	**7.44E-04**	**4.61E-04**	**4.61E-04**	**2.62E-03**
Return period [no. of spills per ship years]	148.60	193.65	535.67	553.53	64.24
Oil spilled [tonns] 1980-2016	229778	377282	844051	220991	1672102
Tanker spill frequency [tonns per ship year]	**3.46E+00**	**5.68E+00**	**1.27E+01**	**3.33E+00**	**2.52E+01**

3 Consequences

The consequence of an accident is defined as the expected number of fatalities, if such an accident occurs. In order to perform consistent and comparable consequence assessments, fixed bands of expected numbers of fatalities are defined. As proposed by MEPC [8], bands are defined to suit the reference vessel. In our case tanker ships are ranged by their sizes from Handysize to VLCC. Each vessel band is further divided into 13 fatality bands cover the full range of accident severities, from a minor scenario to a catastrophic accident resulting in a large number of fatalities. The same approach is applied for consequences of oil spills and for consequences of property loss. Bands of each consequence category are based on the average characteristics of the ship and are visible in Table 4, as the values for a specific band size. The second table presents category bands only for Panamax ship size, but any ship size in Table 4 has a similar band distribution based on its cargo capacity, ship value and number of crew members. We can observe that the value of the ship in the two tables is different. The reason is that the second table includes the value of the transported cargo calculated on its export price.

Table 4: Ship size characteristics and consequence bands

	Capacity 100% [m3]	Capacity 95% [m3]	Ship value	Crew members
Other	4200	4116	10,000,000.00 €	
Handysize	30000	29400	25,000,000.00 €	20
Handymax	55000	53900	35,000,000.00 €	24
Panamax	79000	77420	50,000,000.00 €	26
Aframax	122600	120148	65,000,000.00 €	28
Suezmax	170000	166600	85,000,000.00 €	32
VLCC	340000	333200	130,000,000.00 €	32

Panamax	**% of fatalities on board**	**Panamax**	**% of cargo spilled**	**Panamax**	**% Damage extent**
CREW		**Environment**		**Property**	
0	0.00%	0	0.00%	**- €**	0.00%
1	4.00%	77	0.10%	**74,193.00 €**	0,10%
2	10,00%	193	0,25%	**185,484.00 €**	0.25%
3	15.00%	387	0.50%	**370,968.00 €**	0.50%
5	20.00%	774	1.00%	**741,937.00 €**	1.00%
6	25.00%	1935	2.50%	**1,854,843.00 €**	2.50%
9	35.00%	3871	5.00%	**3,709,687.00 €**	5.00%
13	50.00%	11613	15.00%	**11,129,062.00 €**	15.00%
15	60.00%	19355	25.00%	**18,548,437.00 €**	25.00%
18	70.00%	23226	30.00%	**22,258,125.00 €**	30.00%
20	80.00%	38710	50.00%	**37,096,875.00 €**	50.00%
23	90.00%	54194	70.00%	**51,935,625.00 €**	70.00%
26	**100.00%**	**77420**	**100.00%**	**74,193,750.00 €**	**100.00%**

It is important to note that the identified fatality bands only apply to the referenced vessels defined for this study. Each final event is connected to an estimated number of fatalities. The expected number of fatalities is selected from one of the thirteen possible bands, as defined before. The event tree and probabilities for each event have been carried out together with other participants involved in the Hazard Identification process. The basic structure of the event tree is based on the MEPC report [8]. The same event tree and calculated frequencies for each branch is used for the calculation of PLL, PLC and PLP. The assumption of fatalities, spill quantity and property loss is based on Table 4. The event tree for an oil spill occurring near a cruise ship is presented in Figure 7.

										Frekvency	%	Expected fatalities per accident	%	Consequences to environment	%	Consequences to property	Risk (People) PLL_fat/ship year	Risk (Environment) PLC_tonn/ship year	Risk (Property) PLP_€/ship year
									Sinking	0,00E+00	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
								Severe da	0			0		0		- €	0,00E+00	0,00E+00	0,00E+00
						No breach		0,31	No sinking	1,77E-04	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
						0,68			1			0		0		- €	0,00E+00	0,00E+00	0,00E+00
								No severe damage	No sinking	3,93E-04	4%	1	0,00%	0	0,10%	74.193,00 €	3,93E-04	0,00E+00	2,92E+01
								0,69				0		0		- €	0,00E+00	0,00E+00	0,00E+00
									Sinking	0,00E+00	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
								Severe da	0			0		0		- €	0,00E+00	0,00E+00	0,00E+00
							No breach db	0,83	No sinking	1,74E-04	0%	0	0,10%	77	0,25%	185.484,00 €	0,00E+00	1,34E-02	3,22E+01
							0,78		1			0		0		- €	0,00E+00	0,00E+00	0,00E+00
				Loaded		Breach hull		No severe damage	No sinking	3,56E-05	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
				0,8		0,32		0,17				0		0		- €	0,00E+00	0,00E+00	0,00E+00
									Sinking	0,00E+00	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
								Severe da	0			0		0		- €	0,00E+00	0,00E+00	0,00E+00
							Breach db	0,83	No sinking	4,90E-05	0%	0	10,00%	3871	5,00%	3.709.687,00 €	0,00E+00	1,90E-01	1,82E+02
							0,22		1			0		0		- €	0,00E+00	0,00E+00	0,00E+00
		Terminal areas						No severe damage	No sinking	1,00E-05	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
		0,14						0,17				0		0		- €	0,00E+00	0,00E+00	0,00E+00
									Sinking	0,00E+00	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
	Powered							Severe da	0			0		0		- €	0,00E+00	0,00E+00	0,00E+00
	0,83					No breach		0,31	No sinking	4,42E-05	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
Grounding						0,68			1			0		0		- €	0,00E+00	0,00E+00	0,00E+00
9,02E-03				Ballast				No severe damage	No sinking	9,83E-05	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
				0,2				0,69				0		0		- €	0,00E+00	0,00E+00	0,00E+00
									Sinking	0,00E+00	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
								Severe da	0			0		0		- €	0,00E+00	0,00E+00	0,00E+00
							No breach db	0,83	No sinking	4,34E-05	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
							0,78		1			0		0		- €	0,00E+00	0,00E+00	0,00E+00
								No severe damage	No sinking	8,89E-06	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
						Breach hull		0,17				0		0		- €	0,00E+00	0,00E+00	0,00E+00
						0,32			Sinking	0,00E+00	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
								Severe da	0			0		0		- €	0,00E+00	0,00E+00	0,00E+00
							Breach db	0,83	No sinking	1,22E-05	10%	2	0,10%	77	0,10%	74.193,00 €	2,45E-05	9,43E-04	9,09E-01
							0,22		1			0		0		- €	0,00E+00	0,00E+00	0,00E+00
								No severe damage	No sinking	2,51E-06	0%	0	0,00%	0	0,00%	- €	0,00E+00	0,00E+00	0,00E+00
								0,17				0		0		- €	0,00E+00	0,00E+00	0,00E+00

Figure 7: Tanker ship grounding event tree (part)

The percent value represents the share of the total number of crew on the analyses ship band. Similarly, the percent of spill quantity is used in the second column and the percent of cargo loss in the third column. The initial frequency of the accident event in Figure 7 for grounding is calculated using statistical data from 1980 to 2016 and is explained in Table 2. The intermediate probabilities of tree branches are used as in MEPC, however further improvement of them is possible applying wider HAZOP assessment. In the proposed event tree, the percent of fatalities, oil spill quantity and property loss for each event is predicted on a qualitative basis, proposed by the HAZID group of experts; in our case the authors and port safety department. Those values could therefore be enhanced. Data is also partially based on a review of several oil tanker accident reports, available on EMSA and the ITOPF database.

4 Risk levels

Based on the calculated individual risk frequencies the societal (collective) risk is computed. Integrating the probability of death for each event over the population specified N_u, represents the number of people killed by a given event. **Error! Reference source not found.** illustrates the modelled risk level for tanker ships in the F-N diagram. The risk level is calculated as the sum of the frequency per ship year for analysed accidents. The risk control options taken into consideration in recent decades by the international community allowed the reduction of the tolerable risk by almost

40%, from $1.1x10^{-3}$ to $4.16x10^{-4}$ fat/year [Figure 3]. As noticed above the risk limit is not only a calculated value, but also a matter company and country policy.
The presentation of results allows us now to observe F-N curves for each accidental event and each tanker size considering three main risks: loss of life, loss of containment and loss of property. Only the F-N curves for grounding are presented in the paper because of limited space.

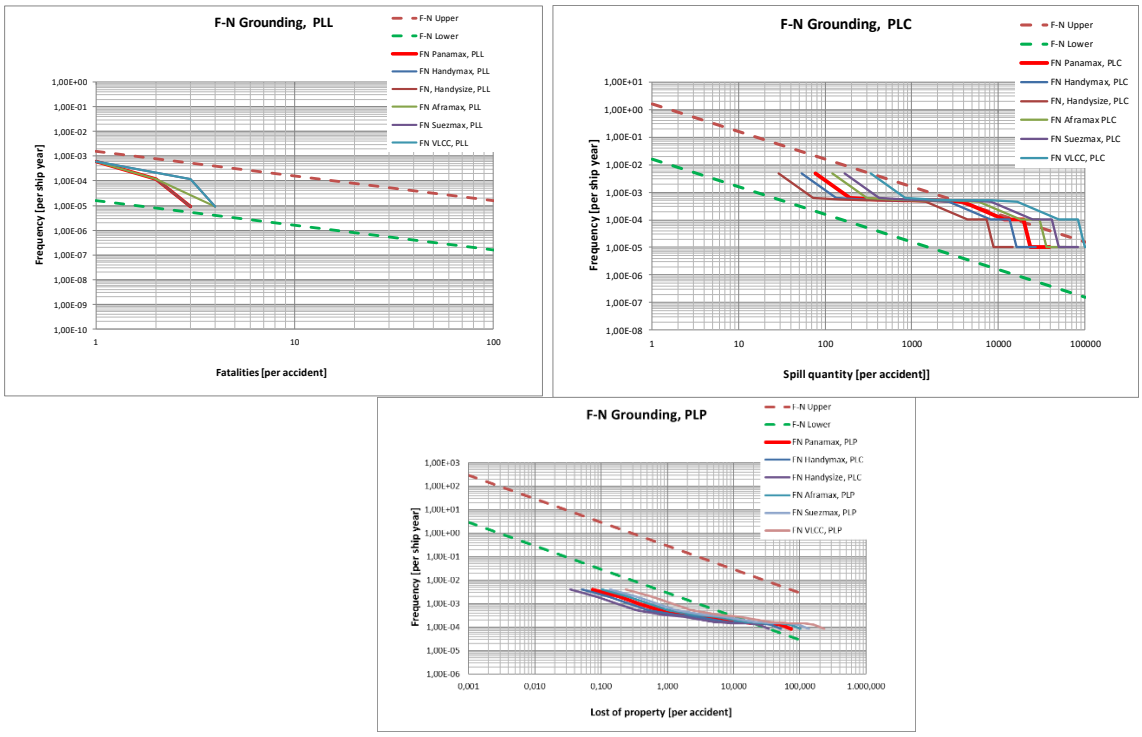


Figure 8: Collective risk level based on tanker category for grounding event

We can observe that the risk curves are within the ALARP boundary for loss of life risk and loss of property risk. The risk for the loss of containment is placed on the upper margin for Panamax tankers for spills between 2,000 and 20,000 tons spilled.
The PLC risk for larger ships exceeds the tolerable risk mainly because of larger ship capacity. The actual investigation assumes the same percent of oil spill for the same accident in the event tree independently regarding the ship size. In a real seagoing situation the probability of events evolution is different and also depends on ship size. The main differences are operational procedures requested by national authorities, VTS coordination, pilot requirements depending on size and local conditions and so on. Because of these specifics further improvement of the event tree is possible and the actual model could be implemented locally for a specific navigational area. Panamax tanker size is in our case the average ship size in the group and could therefore be considered as the average risk curve for tankers.
The results of the assessment have produced risk curves for all the relevant accident types. Most relevant in sense of consequences are further collision, fire and explosion [28]. Contact accident and NASF (Non-accidental structural failure) are presented only in the summary of results.

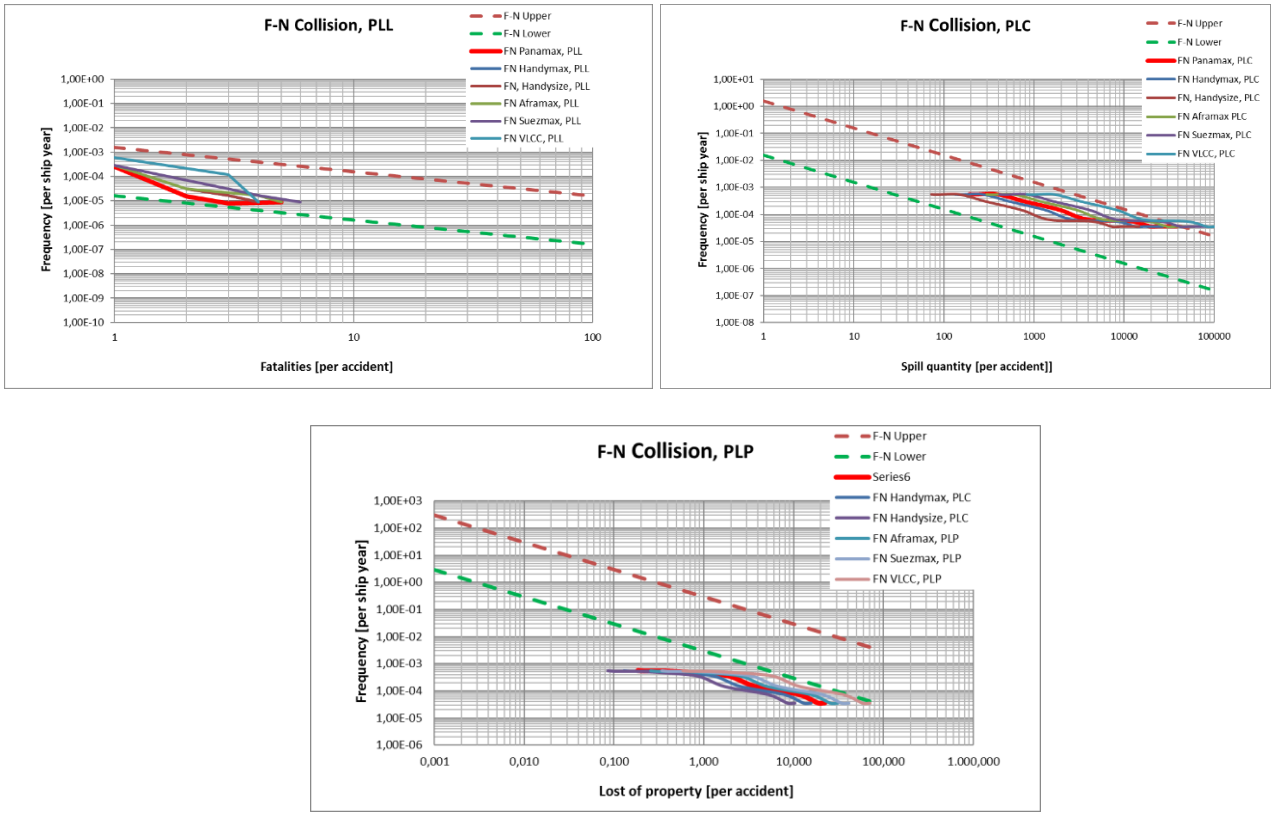


Figure 9: Collective risk level based on tanker category for collision event

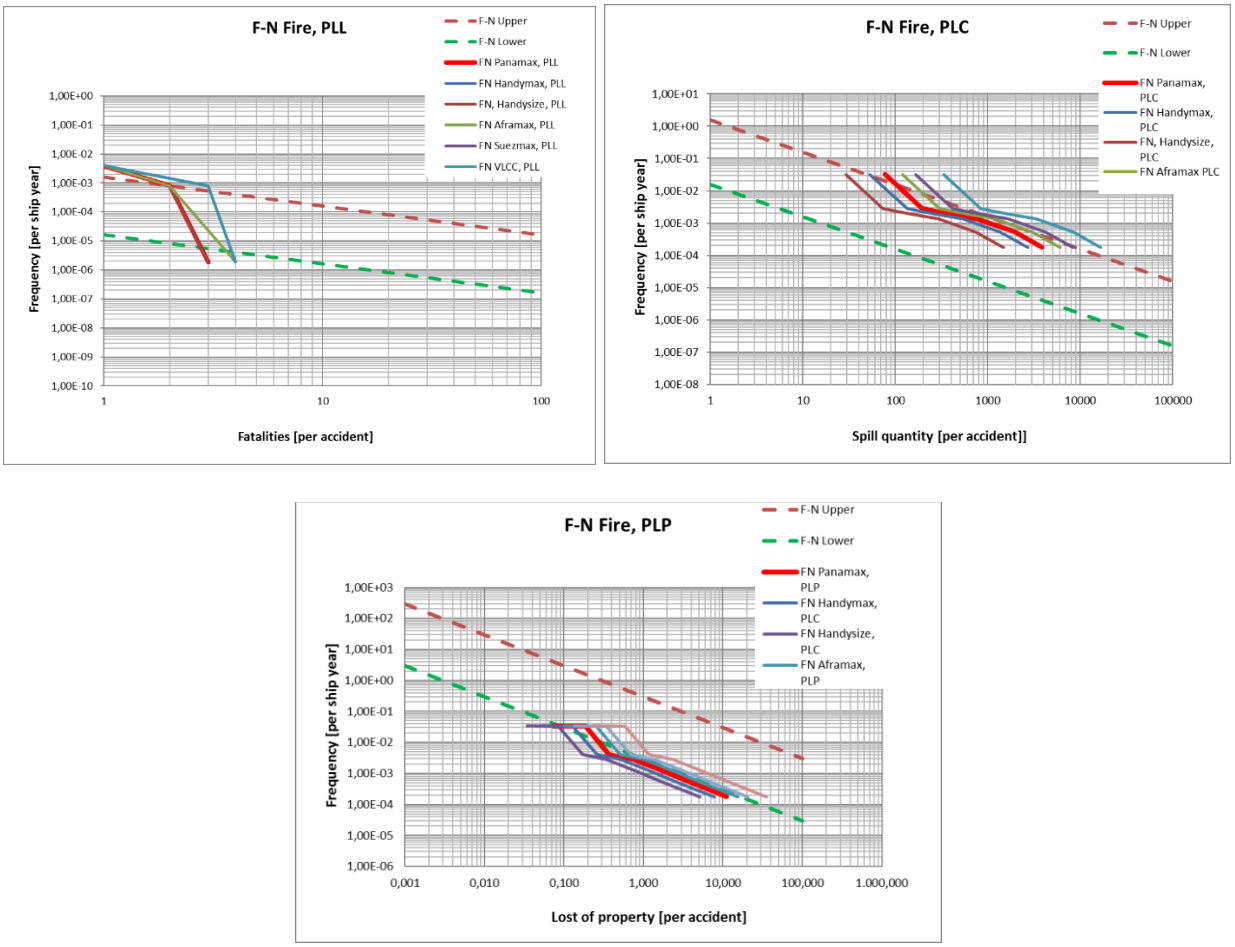
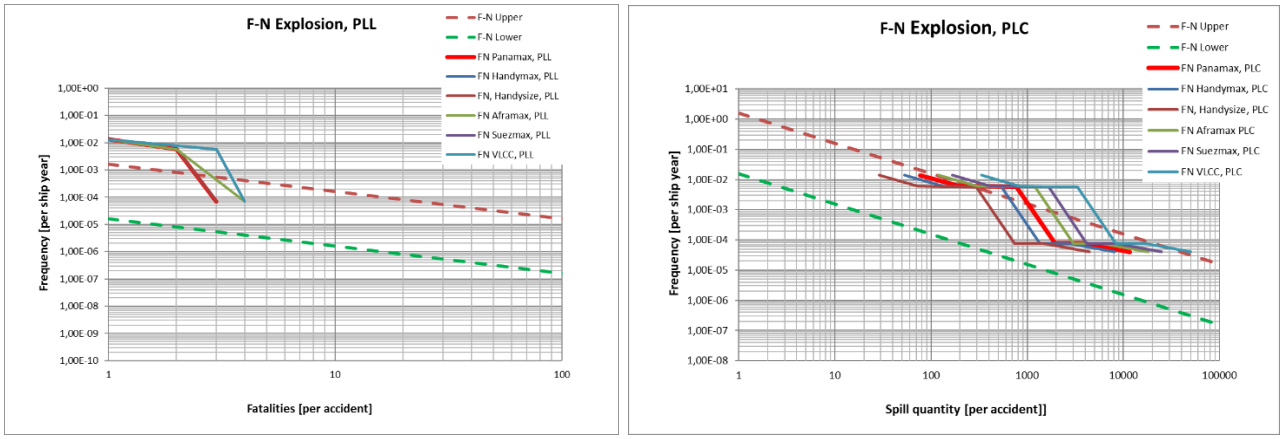


Figure 10: Collective risk level based on tanker category for fire event



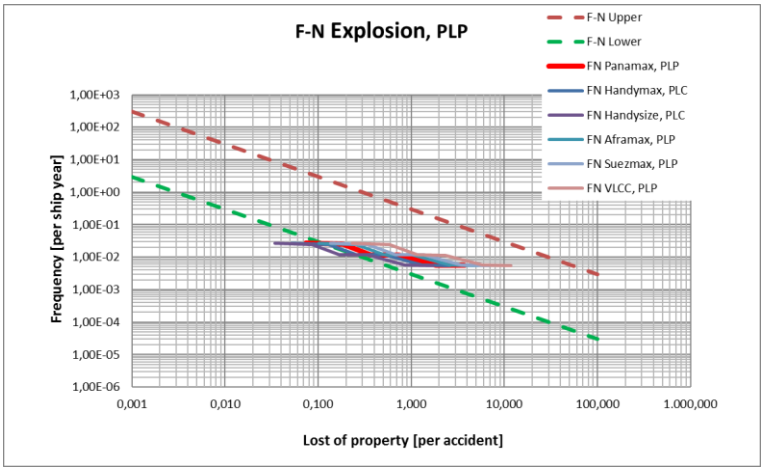


Figure 11: Collective risk level based on tanker category for explosion event

According to the risk curves above the oil spill risk is relevant and critical compared to other risks. Oil spills happen as consequences of accidental events. In the majority of cases small and medium spills are problematic and at risk. PLC graphs lead to conclusions that large spills have been systematically treated in recent decades with the introduction of modern navigation systems, navigation control in restricted areas and new tanker construction rules. Considering the applied risk investigation approach the risk for oil spill persists and demands further consideration.

Next is the risk to crew members: loss of life that is found to be acceptable for large accidents, because their like hood in marginal. All the graphs show the risk exceeds the acceptable limit for one to two fatalities. But we should consider that the assessment approach is not reliable for small numbers (statistically). Fatalities are counted in natural numbers (1,2…) but the statistics could consider real positive numbers (0.1 fat/year). The model intentionally applies round-up numbers to expose that fatalities in practice derive mainly from unexpected (force majeure or human failure) accidents, rather than technical or predictable event. In this way we could consider that the risk for the crew on tankers is acceptable too.

Finally, there is the economic aspect of the risk where all PLP graphs above show that property loss consequences, due to accidents, do no produce relevant economical risk. Explosion and fire accidents are calculated within the acceptable boundaries, meaning that risk control options should be maintained to keep the risk at acceptable levels. Other accident risks are calculated below the lower risk criteria and, from the economic point of view, do not require special precautions. It should be

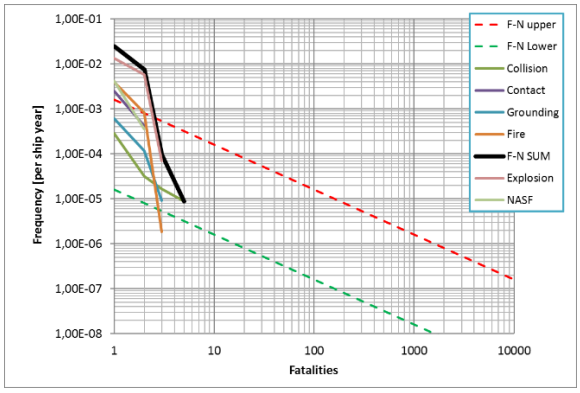
noted that all three risks should be considered together, especially PLC and PLP, which are directly related with the cost benefit.

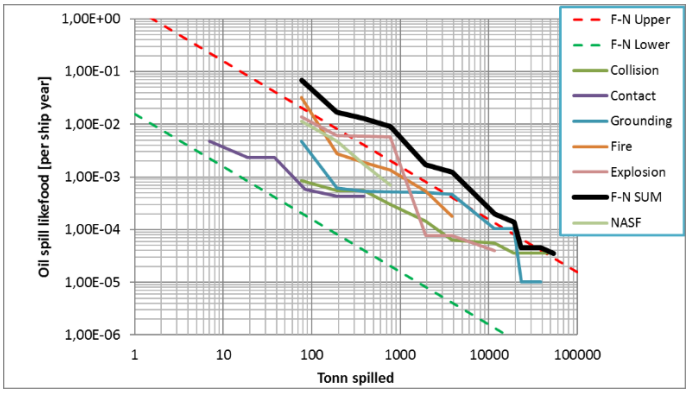
4.1 Overall risk for the oil tanker fleet

The overall risk is the sum of all individual risks of accidents. Risk curves in Figure 12 are considered for Panamax tanker size, because it's the average size in a fleet. The comparison of events risk yields the information that explosion accidents have a potential unacceptable risk for spills between 200 and 800 tons and grounding accidents have a potential unacceptable risk for spills between 4,000 and 20,000 tons. Other accidents are within the acceptable range. The sum of risk curves locates the overall F-N curve above the acceptable level. The conclusion regarding PLC risks is that risk control activities should be implemented with a particular focus on explosion and grounding accidents. A deeper digging into particular accidents within the event tree model provides the information regarding which accidents are critical. These are accidents in loaded or ballast condition that occurs in cargo or slope areas (including the pump room and pipe lines) where severe damage occurs. Further investigation into the nature of such accidents and the reason for their occurrence could lead to control options. A consideration could be that more concise and preventive maintenance is required for critical equipment and the crew members in charge should focus on the understanding of risks that occur during the transfer procedure and focus more attention on these procedures.

Similar digging into the event tree could be done for grounding. Grounding in loaded and powered condition is the most critical where the hull and double bottom is breached. The result is quite obvious. The majority of grounding at high risk occurs in limited to congested waters, which indicates required control options. On the system level, this implies the need for marine traffic control through VTS and the requirement of updated nautical charts, mandatory ECDIS with on-line charts updated and trained (experienced) officers in charge on navigation watch.

The application of control actions would change the probabilities in a sequence of the event tree or the magnitude of consequences. Values themselves could be estimated qualitatively by expert rating, calculated as probabilities through ship data analysis (AIS trajectory data) or statistically analysed in the near future.





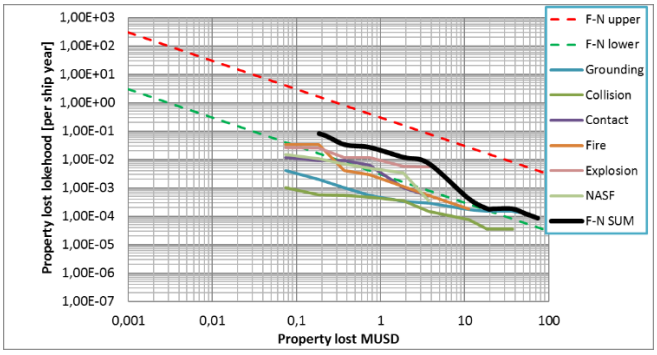


Figure 12: Overall collective risk level based on accident event

5 Conclusion

Safety assessments are currently the integral part of any transport activity, mainly because of a need for transport reliability, which is strongly related with a service revenue. Tanker trade activity is particularly sensitive to safety issues mainly due to potential ecological risks in coastal areas that could strongly influence the life and economy of the related location. The paper presents the methodology applying different approaches, mainly statistics, deterministic, partially qualitative, along with others to obtain more reliable answers regarding transportation risks. Operational (technical) risks are analysed and discussed for further improvement in their management. Risks for different kinds of accidental events like collision/contact, grounding, fire/explosion and structural failures are analysed statistically on a global scale to obtain an overview of the changes of risk over the last decade compared to previous decades. The calculated acceptable risk is calculated for the potential loss of lives, potential loss of containment and potential loss of property. The most significant finding is that containment risk exceeds acceptable levels and therefore requires control actions to reduce smaller and medium size accidental and operational spills. The relation between risk evaluation for loss of containment and loss of property is relevant because the strong economic influence of the oil trade is prevalent in the ecological realm. As the economic aspect is more related with oil trade companies, the ecological aspect is more related with regulatory parties, especially IMO. The paper findings could indicate that concerning the revenue of the oil trade business the additional control actions should be taken by regulatory parties to reduce the risk of the global loss of containment from ships. The main findings have been stated above; however, on the system level control actions implies mandatory marine traffic control through VTS, the requirement of updated nautical charts, mandatory ECDIS with on-line charts updated and trained (experienced) officers in charge of navigation and engine watches.

6 Reference

[1] Burgherr P., In-depth analysis of accidental oil spills from tankers in the context of global spill trends from all sources, Journal of Hazardous Materials 140 (2007) 245–256

[2] Eliopoulou E., Papanikolaou A., Casualty analysis of large tankers, Journal of Marine Science and Technology, 2007, 240-250

[3] Skjong R., Vanem E., and Endresen Ø., SAFEDOR, Design, Operation and Regulation for Safety, Integrated Project Report, DNV 2005

[4] EMSA, Maritime Accident Review (2007 – 2016), European Maritime Safety Agency, (http://www.emsa.europa.eu/)

[5] EMSA, Annual Overview of Marine Casualities and Incidents 2016, European Maritime Safety Agency, (http://www.emsa.europa.eu/)

[6] Etkin D., Low probability high consequence events and risk of oil spills, 2015 (http://vancouver.ca/images/web/pipeline/David-Etkin-estimating-oil-spill-risk.pdf)
[7] Etkin D., Methodologies for Estimating Shoreline Cleanup Costs, Proceedings of 24th Arctic and Marine Oilspill Program Technical Seminar: pp. 647-70
[8] International Maritime Organization, MEPC 58/INF.2, Formal Safety Assessment – Crude Oil Tankers, 2008.
[9] Goerlandt F., Montewka J., A framework for risk analysis of maritime transportation systems: A case study for oil spill from tankers in a ship–ship collision, Safety Science 76 (2015) 42–66
[10] Montewka J., Weckström M., Kujala P., A probabilistic model estimating oil spill clean-up costs – A case study for the Gulf of Finland, Marine Pollution Bulletin 76 (2013) 61–71
[11] Gucma L. (2007). Evaluation of oil spills in the Baltic Sea by means of simulation model and statistical data. International Maritime Association of Mediterranean, Balkema.
[12] Vidmar P., Perkovič M., Methodological approach for safety assessment of cruise ship in port, Safety Science 80 (2015) 189–200
[13] ISL (ISL Institute of Shipping Economics and Logistics), Shipping Statistics and Market Review (SSMR), World Tanker Market 2007 – 2016
[14] Penelope T., Andreas M., International Shipping and World Trade, University of Piraeus, 2012 (http://dione.lib.unipi.gr/xmlui/bitstream/handle/unipi/4680/Tsaini.pdf?sequence=2)
[15] Crénès M., Hafner M., Criqui P., Global Energy Scenarios to 2040, Understanding our Energy Future 2017 (https://www.enerdata.net/publications/reports-presentations/world-energy-forecasting-scenarios-2017-edition.html)
[16] Whelan R., Ship Owners Cut Oil Tanker Orders, The wall street journal, 2016 (https://www.wsj.com/articles/ship-owners-cut-oil-tanker-orders-1462815137)
[17] The International Tanker Owners Pollution Federation (ITOPF=, Oil Tanker Spill Statistics 2016, UK 2016 (http://www.itopf.com/fileadmin/data/Photos/Publications/Oil_Spill_Stats_2016_low.pdf)
[18] International Maritime Organization (2000). MSC 72/16, Formal Safety Assessment – Decision Parameters Including Risk Acceptance Criteria –Submitted by Norway''.
[19] Bottelberghs, P.H., Risk analysis and safety policy developments in the Netherlands, Journal of Hazardous Materials, Volume 71, Issues 1–3, 7 January 2000, Pages 59-84
[20] Bichard E. M., Health & Safety Executive, Risk criteria for land-use planning in the vicinity of major industrial hazards, UK 1989
[21] Trbojevic, V.M., 2005. Risk criteria in EU, ESREL'05. Poland, 27–30.
[22] Cornwell, J.B., Meyer, M.M., 1997. Risk Acceptance Criteria or ''How Safe in Safe Enough''. Risk Control Seminar, Venezuela.
[23] Lohansen, I.L., 2009. Foundations and Fallacies of Risk Acceptance Criteria, Norwegian University of Science and Technology (NTNU). Department of Production and Quality Engineering, Norway.
[24] Spoure J., Harmonised Risk Acceptance Criteria for Transport of Dangerous Goods, DNV-GL Project Report, UK 2014
[25] International Association of Oil & Gas Producers, Water transport accident statistics, Report No. 434-10, UK 2010 (www.ogp.org.uk)
[26] Cross R. B., A Quantitative Risk Assessment Model for Oil Tankers, ABS TECHNICAL PAPERS 2003 (https://www.eagle.org)
[27] Shahriari M., Frost A., Oil spill cleanup cost estimation—Developing a mathematical model for marine environment, process safety and environment protection 86 (2008) 189–197
[28] Ugurlu O., Analysis of fire and explosion accidents occurring in tankers transporting hazardous cargoes, International Journal of Industrial Ergonomics 55 (2016) 1-11
[29] UNCTAD, Raview of Maritime Transport 2015, United Nations Conference on Trade And Development, Genova 2015 (http://unctad.org/en/PublicationsLibrary/rmt2015_en.pdf)

[30] UNCTAD, Raview of Maritime Transport 2016, United Nations Conference on Trade And Development, Genova 2016 (http://unctad.org/en/PublicationsLibrary/rmt2016_en.pdf)