Estimating the Consequence Costs of Oil Spills from Tankers

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In the last decade, both worldwide and in the United States, the number of oil spills and the total quantity of oil spilled into the seas have declined. However further improvements are still desirable. Clearly, the cost of oil spills to be avoided is one of the most important parameters in evaluating ship designs, measures and policies to reduce oil pollution. The approach used in this work is based on the assumption that the cleanup and the total cost of an oil spill can be approximated by the compensation eventually paid to claimants regarding the relative cost categories. To that extent, this paper reports on various analysis of oil spill cost data for spills. These analyses and their results can provide useful insights to the ongoing discussion on environmental risk evaluation criteria within Formal Safety Assessment (FSA). Additional uses are also suggested and some examples are given.

KEY WORDS: tankers; oil spills; pollution; damage assessment; regulations

INTRODUCTION

According to the latest statistics, a downward tendency is apparent in the total annual quantity of oil spilt by crude oil carriers during the last decade as well as in the number of oil spills worldwide, see ITOPF (2010) and Kontovas et al. (2010). The same is valid for oil spills in US territorial waters, mainly due to the enactment of the Oil Pollution Act of 1990 (Ramseur, 2010) oil spill legislation after the Exxon Valdez. However, there is a constant need for designing and operating ships that will lead to minimal consequences to the environment and society in case of an accident. A crucial parameter in evaluating designs and policy measures to reduce pollution is the estimation of oil spill cost.

Beyond any doubt, the cost of an oil spill is a very difficult quantity to estimate. However, there is a general agreement (Etkin, 1999; Grey, 1999; White and Molloy, 2003) that the main factors influencing the cost of oil spills are the type of oil, location, weather and sea conditions and the amount spilled and rate of spillage. Given the above parameters are highly variable and cannot be predicted in advance, a usual approach taken in the literature is to connect the cost of an oil spill to its volume. In that sense, a larger oil spill is expected to have a higher cost, all else being equal. Estimates of the cleanup cost and the total oil spill costs which may include the costs for response, third party claims and environmental damages as a function of the oil spill size have been extensively analyzed in the literature and substantial work has been performed over at least the last 30-35 years, mostly in the context of analyzing the economic impact of oil spills and contemplating measures to mitigate their damages. For a short literature review the reader is referred a previous work of the authors, see Kontovas et al. (2010)

Lately, the subject of estimating the cost of oil spills has been in the center stage of discussions at the International Maritime Organization (IMO) in regards to the establishment of Environmental Risk Evaluation Criteria within the context of Formal Safety Assessment (FSA). During the 55th session of Marine Environment Protection Committee (MEPC) that took place in 2006, the IMO decided to act on the subject of environmental criteria. At the 56th session of MEPC (July 2007) a correspondence group (CG), coordinated by the third author of this paper on behalf of Greece, was tasked to look into all related matters, with a view to establishing environmental risk evaluation criteria within Formal Safety Assessment (FSA). FSA was introduced by the International Maritime Organization (IMO) as *"a rational and systematic process for accessing the risk related to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks"* (IMO, 2007).

An issue of primary importance was found to be the relationship between the spill volume and the spill cost. The work within the IMO has focused, among other things, on the use of oil spill cost data assembled by the International Oil Pollution Compensation Fund (IOPCF). Deriving cost functions by using the IOPCF data is by itself not new and has been performed by Friis-Hansen and Ditlevsen (2003), Ventikos et al. (2009), Hendricksx (2007), Yamada (2009), Kontovas et al. (2010 and Psarros et al. (2011). The core of the last three papers was also submitted to the MEPC that deals with the issue as discussed above.

In addition, a much earlier work performed under the SNAME T&R Ad Hoc Panel on the Environmental Performance of Tankers used the IOPCF database to estimate the cost of spills as a function of spill size. The cost could be used against the oil outflow and the probability for hypothetical damage cases in order to estimate the total mean oil spill cost for alternative tanker designs (Sirkar et al., 1997). The same paper states the IOPCF database *"is generally considered to be the most accurate with regard to the cost information available for the spills it contains"* which is still valid today.

The approach used in this work is based on the assumption that the cleanup and the total cost of an oil spill can be approximated by the compensation eventually paid to claimants regarding the relative cost categories. The paper reports on recent analyses of oil spill cost data assembled by the International Oil Pollution Compensation Fund (IOPCF). Furthermore, analyses of the cleanup cost based on data of spills that were covered by the US Oil Spill Liability Trust Fund (OSLTF) are also presented. Note that the US is not a member of the IOPCF and, as a result, no US spills are included in the IOPCF dataset. More specifically the OSLTF dataset includes cost data provided by the National Pollution Funds Centre (NPFC) and volume data from the U.S. Coast Guard's Marine Information for Safety and Law Enforcement (MISLE) system. These data were also the basis of an analysis on oil spill costs that was submitted to the IMO by the United States (IMO, 2010b). In addition, an analysis of the combined dataset that includes spills in US territorial waters and worldwide spills included in the IOPCF dataset was also performed. Preliminary results of these analyses were performed by the authors and submitted to the IMO by Greece (IMO, 2010c).

The next Section of this paper presents an introduction to the IOPC Fund and the regression analyses that were carried out to derive functions to estimate the cleanup and total cost of oil spills as a function of the oil spill size. Next, response cost data based on the Oil Spill Liability Trust Fund (OSLTF) are used to carry out various analyses. These data are also validated against the formulas derived by the IOPCF dataset and regressions based on the combined dataset are also carried out. The penultimate Section presents the ways that the cost formula can be used within cost benefit analysis, risk assessment methods and in evaluating the performance of tanker designs. Finally, the last Section describes the main conclusions of this work.

OIL SPILL VALUATION BASED ON THE IOPCF

Compensation for oil pollution caused by tankers is governed by four international conventions: the 1969 and the 1992 International Convention on Civil Liability for Oil Pollution Damage (“CLC 1969” and “CLC 1992”) and the 1971 and 1992 conventions on the Establishment of an International fund for Compensation for Oil Pollution Damage (“1971 Fund” and “1992 Fund”). These conventions together create and international system where reasonable costs of cleanup and damages are met, first by the individual tanker owner up to the relevant CLC limit through a compulsory insurance and then by the international IOPCF, if the amounts claimed exceed the CLC limits. More on compensation for oil pollution damage can be found in Jacobsson (2007), ITOPF (2010) and Liu and Wirtz (2009).

Literature review

One way to estimate the total cost of oil spills is by using compensation data. The most widely accepted public source that covers compensations paid is provided by the International Oil Pollution Compensation Fund (IOPCF). A couple of recent cases where the IOPCF data was analyzed were known to the authors prior to their own analysis.

Friis-Hansen and Ditlevsen (2003) used the 1999 Annual Report (except those accidents that belonged to the categories “loading/unloading”, “mishandling of cargo”, and “unknown reason” which were removed from their analysis) and converted all amounts into Special Drawing Units (SDR) by an average annual exchange rate taken from the International Financial Yearbook. Then, historic interest rates for money market rates were applied to capitalize all costs into year 2000 units followed by a conversion into 2000 USD.

Hendrickx (2007) performed an analysis based on data of the 2003 Annual Report and analyzed 91 cases by converting each compensation amount into US Dollars using for each accident the exchange rate on Dec. 31 of the year of occurrence. Exchange rates of the Bank of England were used for the currencies available and for the others an online website (OANDA.com) was used. There is no report that an inflation rate was used to bring these latter amounts into current Dollars**.**

Yamada (2009) performed a regression analysis of the amount spilled and the total cost by using the exchange rate provided in the IOPCF Annual Report. These rates can be used for conversion of one currency into another as of Dec. 31, 2007 and do not take into account the time of the accident nor is any inflation taken into account. Note that spills less than 1 tonne were excluded by the analysis. His analysis formed the basis of Japan’s submissions to the MEPC and, to a large extent, the basis of the MEPC decision to recommend a volume-based approach.

Last but not least, Psarros et al. (2011) used combined data from two datasets, namely the IOPCF report and the accident database developed by EU research project SAFECO II. A regression analysis on the 183 oil spill incidents was performed. It is not immediately clear from their analysis what the SAFECO II database is and what (if any) biases it introduces to the analysis. The amounts were converted into 2008 US Dollars taking into account the inflation rate.

Regression analyses based on the IOPCF

The 2008 IOPCF Annual report presents the claims that the IOPCF dealt with in the past (IOPCF, 2009). This report includes 107 accidents that are covered by the 1971 Fund and 33 by the 1992 Fund. For each accident the time and the place of accident are known and for most of the cases the volume of oil spilt, as well as, the costs claimed and eventually covered by the Fund are recorded.

In order to perform the regression analysis, the steps below were followed:

1. All incomplete entries (mainly the cases where no information regarding either the cost or the oil spill volume) and claims that were not eventually paid were removed.
2. All claims for the cleanup and the total cost categories (in the case of multiple claims) were added up by converting them to US Dollars at the time of the accident based on available exchange rates. We note that we are aware of the fact that the year of the accident and the year when the amount agreed was paid are not the same but this was the only available information.

3. The cost deviations from the previous step were capitalized into 2009 US Dollars by using conversion factors based on the Consumer Price Index (CPI).

This way we arrived at two datasets, one having data on the Cleanup Cost (CC) and the Volume (V) and another on the Total Cost (TC) and the Volume (V). These datasets were not disjointed. In fact, the first dataset contained 84 entries, the second had 91 entries, and 68 spills reported both CC and TC.

According to Friis-Hansen and Ditlevsen (2003), the logarithm of the oil spill volume and the logarithm of the total spill cost are positively correlated, having a very high correlation coefficient. This was also observed by Hendrickx (2007), Yamada (2009) and shown in an earlier version of Psarros et al. (2011). Our analysis of possible fits concluded that the double logarithmic, the multiplicative and the double reciprocal have the highest correlation coefficients. Therefore, to be consistent with the analyses performed by others the Costs (TC and CC) and Volumes (V) were Log-transformed and linear regressions were performed for the two cases.

Cleanup Cost

After removing incomplete entries, a dataset of 84 spills for the period 1979-2006 was used for this regression analysis. The minimum volume was 0.2 tonnes and the maximum was 84,000 tonnes. The average spill was 4,055.82 tonnes with a standard deviation of 14,616.15 tonnes and the median was just 162.5 tonnes. Even without a histogram one could easily realize that most claims came from relatively small spills. There were only 10 spills above 5,000 tonnes and, thus, one should be very careful when using the regression formulas to extrapolate the cost of large spills.

The equation of the fitted model using linear regression was:

$$\text{Cleanup Cost} = 44{,}435\ V^{0.644} \qquad (1)$$

The R-Squared statistic indicates that the model as fitted explains 61.5254% of the variability in LOG10(Cleanup Cost). The correlation coefficient (Pearson's correlation coefficient p) equals 0.7844, indicating a strong relationship between the variables.

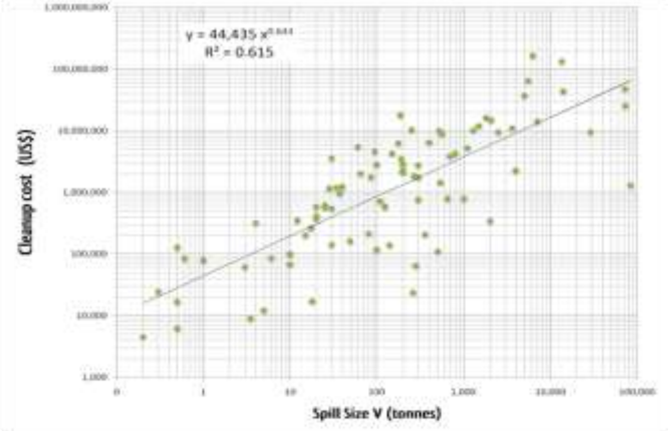

Fig 1. Linear Regression of Log(Spill Size) and Log (Cleanup Cost).

Furthermore, an average per tonne oil spill cleanup cost using the IOPCF database was calculated by dividing the total amount paid by the Fund for cleanup by the total amount of oil that was spilled. According to our analysis, this value came to 1,639 USD (2009) per tonne.

Total Cost

Following the same methodology, a regression analysis of log(Total Cost) and log(Spill Size) was performed initially for 91 spills. The analysis of the residuals revealed the existence of a total number of 8 possible outliers. These outliers were removed. After three consecutive regressions we arrived at the final dataset of 83 spills. The minimum volume was 0.1 tonnes and the maximum was 84,000 tonnes. The average spill was 4,854.29 tonnes, with a standard deviation of 16,064 tonnes and the median is just 140 tonnes. There are only 11 spills above 5,000 tonnes.

The equation of the fitted model using linear regression was:

$$\text{Total Cost} = 51{,}432\ V^{0.728} \qquad (2)$$

The R-Squared statistic indicated that the model as fitted explains 78.26% of the variability in LOG10(Cleanup Cost). The correlation coefficient (Pearson's correlation coefficient p) equals 0.8846, indicating a strong relationship between the variables.

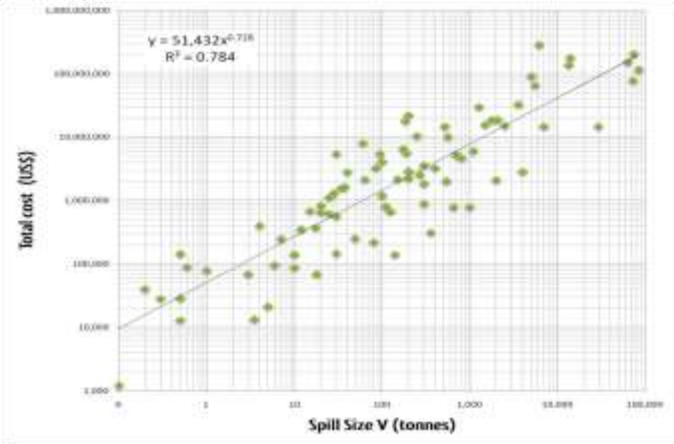

Fig 2. Linear Regression of Log(Spill Size) and Log (Total Cost).

An average per tonne oil spill total cost using the IOPCF database was also calculated by dividing the total amount paid by the Fund by the total amount of oil that was spilled. According to our analysis, this value comes to 4,118 USD (2009) per tonne.

Total Cost to Cleanup Cost Ratio

The data provided by the IOPCF Annual report can be used to estimate an average total cost/cleanup cost ratio, for the sample of spills for which the values of both CC and TC are available. Since we are only interested in the ratio, there is no need to do the conversions discussed before (i.e to use the exchange rate and the CPI index). Furthermore, accidents for which the claimed costs were only clean-up costs have to be removed. If cleanup cost is the only cost category available, this means that the total cost (as in the analysis performed above) would be equal to the total cost and in this case the ratio will be equal to 1. In order to remove this bias, all ratios equal to 1 have been removed, although this probably biases the analysis towards higher total cost to cleanup cost ratios. In addition a ratio of 87 (from the 'Braer' accident) was also removed as an outlier. The dataset of the N=68 ratios that were left has a mean of 1.929 and a median of 1.287. The median is the measure of center (location) of a list of numbers. Unlike the mean, the median is not influenced by a few very large values in the list and may be a more appropriate criterion for this purpose.

ANALYSES BASED ON THE US OSLTF DATASET

The US submitted to the IMO/MEPC committee (IMO, 2010) raw data regarding the response cost of oil spills that were covered by the *Oil Spill Liability Trust Fund (OSLTF)*. More specifically, the cost data were provided by the National Pollution Funds Centre (NPFC) and volume data from the U.S. Coast Guard's Marine Information for Safety and Law Enforcement (MISLE) system. Data are for spills occurred from October 1990 through September 2009. Note that we capitalized all costs to 2009 USD prices by using the GDP deflator in line with the way that the US performed a preliminary analysis that was submitted to the CG. Furthermore, note that the response cost presented by the US includes cleanup cost and cost for prevention and mitigation. In the following Section when referring to US cleanup cost we actually refer to the response cost and thus we overestimate the cleanup cost paid by the Fund.

Cleanup Cost

The OSLTF dataset consists of 486 cases which are mainly extremely small spills. The median spill size of the dataset is 0.16 tonnes and the average just 168.29 tonnes. According to a preliminary regression analysis performed by the US, results failed to demonstrate a statistically significant relation between response cost (in 2005 USD) and spill volume (in tonnes). The initial regression showed a very weak relationship (R^2=0.1817) between response (or mainly cleanup) cost and oil spill volume. Outliers were identified and removed and a better fit was achieved (R^2=0.2405). Still the results are not satisfactory. Note that no other model achieves a better result than the linear regression between the logarithms of both factors.

The regression formula based on the US dataset is the following:

$$US \quad \text{Cleanup Cost} = 13{,}814 \quad V^{0.2733} \qquad (3)$$

By removing all spills below 1 tonnes we arrive at a dataset with just 116 spills and the regression formula becomes

$$US \quad \text{Cleanup Cost} = 11{,}106 \quad V^{0.3953} \qquad (4)$$

Analysis of OSLTF data from 1998-2002, taken from National Pollution Funds Center, were reported in Hendrickx (2007). Contrary to the IOPCF, the OSLTF does not deal exclusively with spills from oil tankers. In fact, between 1990 and 2002, in only around 2% of cases in which the source of the spill could be established, were oil tankers are culprits, accounting for less than 4% of total costs (NPFC, 2002). The different sources of spills may be the reason for the weak relationship between the cleanup cost and oil volume.

Total Cost

The dataset of US spills, as discussed above, includes only the response cost. In order to arrive at the total cost of an oil spill a total cost to cleanup cost ratio can be used. One may argue that this ratio is not constant for oil spill sizes but it depends on the oil spill volume. While this may be true, in this work a constant value will be used. This is in line with Vanem et al. (2007a, 2007b) who taking into account the work of Jean-Hansen (2003), McCay et al. (2004) and Etkin (2004), concluded that a ratio of 1.5 should be assumed for the ratio of socioeconomic and environmental costs divided by cleanup costs. Thus, the total oil spill cost is 2.5 times the cost of cleanup, according to their analysis. Furthermore, recall that for the IOPCF dataset this ratio has a mean of 1.929 and a median of 1.287.

In a submission of the US to the MEPC (IMO, 2010b), a value of $ 40,893.64 (in 2005 USD) was given as the 'best estimate' of the avoided volumetric response cost and $ 102,287.95 for the total avoidance cost. Based on the figures above the ratio of total costs to cleanup costs is 2.5. This total cost 'best estimate' is based on literature review. The 4 sources that were used are ICF Kaiser (1997), Brown & Savage (1996), Helton & Penn (1999) and Mercer Management Consulting (1992). Although it is out of the scope of this work to comment on the literature, the 'best estimate' for the per ton response cost ($40,893.64) is based on the median spill size of 0.16 tonnes. The median, as well as, the average of ratios should be used with caution, see Psaraftis (2011). In our opinion, these statistics do not make too much sense. Nor does it make sense to extrapolate to large spills cost statistics derived from very small spills. Furthermore, for third party costs the only data used come from 31 spills, a sample which is much smaller than the original 486 spills used for the estimation of the response costs. The Helton and Penn (1999) paper that was also used to arrive at the total 'best estimate' bases its analysis on a sample of 48 spills, many of these spills are pipeline, well, facility and fishing vessel spills, raising questions as to why they should be included in the sample. Counting only those spills that come from maritime sources, the total cost to cleanup cost for the 21 cases presented in Helton and Penn(1999) was nearly 2.44. Note that in the analyses presented by the authors there are no non-maritime spills and one should be cautious avoid taking such spills into consideration.

In any case, as a conservative estimation, we assume a total cost to response cost ratio based on the US 'best estimate' of 2.501. Therefore, based on this ratio a 'best estimate' total cost of each oil spill in the OLSTF dataset can be estimated by multiplying the response cost by this figure.

Figure 3 presents the total cost of the spills in OLSTF dataset as cleanup cost provided multiplied by a factor of 2.501. Again, the response cost provided by US contains more cost categories than just the cleanup cost and, therefore, this function is conservative.

The regression formula based on the US dataset is the following:

$$\text{US Total Cost} = 35{,}044 \quad V^{0.274} \qquad (5)$$

By removing all spills below 1 tonne we arrive at a dataset of just 116 spills and the regression formula becomes

$$\text{US Total Cost} = 23{,}212 \quad V^{0.5138} \qquad (6)$$

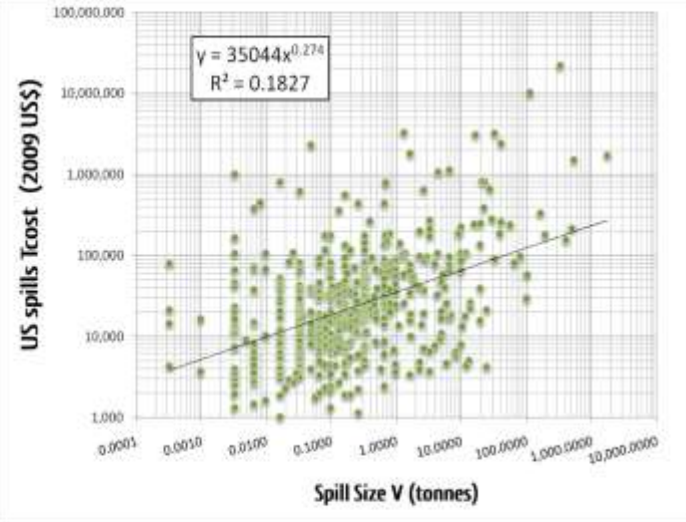

Fig 3. Linear Regression of Log(Spill Size) and Log (Total Cost).

VERIFICATION AND UPDATE OF THE IOPCF REGRESSION FORMULA BASED ON THE US DATASET

At MEPC 60, the Working Group (WG) on environmental risk evaluation criteria decided that the total cost regression formula (Eq. 2) derived by the IOPCF dataset (Kontovas et al. 2010) and proposed by Greece (IMO, 2009b) *"would serve as a basis for deriving the total cost of an oil spill"*, see IMO (2009c). Furthermore the group recommended that *"Member Governments or interested organizations having their own additional data, attempt to verify, and adjust as necessary, the said regression formula by incorporating their additional (chosen) data in the analysis"*. Based on the above, it would be interesting to know what the results would be if we applied our formula (the one derived by the IOPCF, see Eq. 1) to estimate the response cost of the spills that were covered by the OSLT Fund. After all verifying the formula is a recommendation of the MEPC WG. To that extent, given the oil spill sizes provided in the US data one may estimate the cleanup cost by using the formula derived by the IOPCF data (see Eq.1) and compare the results with the cleanup costs provided by the US. Furthermore, one could multiply the cleanup costs provided by the 'best estimation' ratio of 2.501 and arrive at a 'best estimate' total cost and compare it with the estimates based on the regression formula derived by the IOPCF data (see Eq.2). Furthermore, following another recommendation of the MEPC WG (see IMO (2009c)) the regression line proposed by Greece is adjusted by incorporating the additional data provided by the US. The next Section presents the results of regression analyses for both the cleanup and total cost based on a combined dataset, one that included the IOPCF and OLSTF datasets.

Use of formulas derived by IOPCF in US OSLTF data

It would be interesting to know what the results would be if we applied our formula (the one derived by the IOPCF, see Eq. 1) to estimate the response cost of the spills that were covered by the OSLTF.

First of all, the IOPCF covers only spills from tankers, and, thus, in theory our model should not be used to estimate costs for spills by other sources as the ones presented in the US dataset. However, with that in mind we calculated the cleanup cost (in 2009 USD) for all those spills that are included in the OSLTF dataset.

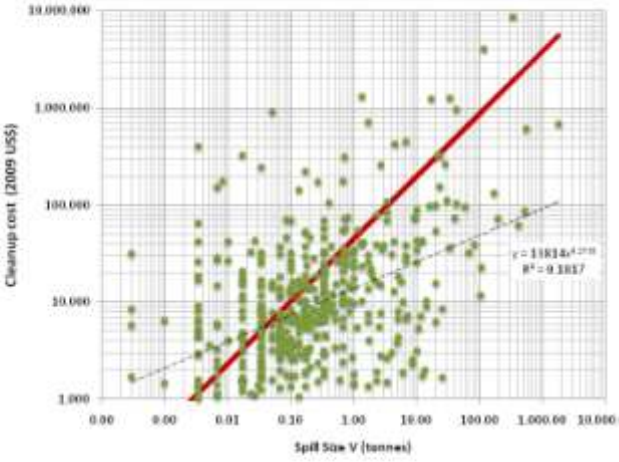

Fig 4. Comparison of the cleanup cost estimated by the IOPCF cost formula with the US response cost.

Figure 4 presents the response cost that was actually paid by the OSLTF. The solid line represents the cleanup cost based on our regression formula (see Eq. 1) and the black dashed line is the result of the regression analysis of the OSLTF data (see Eq. 3). It is therefore obvious that the nonlinear curve (as derived by the IOPCF analysis) overestimates the cleanup cost of oil spills that were covered by the OSLTF – that is, most of the spills (green dots) lie below the red line. In more detail, our formula overestimates the cleanup cost for 327 out of the 486 US spills (67.29%). This goes up to 80% of the cases for spills greater than 0.1 tonnes. Note again that our non-linear curve was estimated for spills higher than 0.2 tonnes and that our formula estimates the cleanup cost which is less than the response cost.

Regarding the total cost based on the US dataset, Figure 5 presents the total cost of the spills in OLSTF dataset as the response cost provided multiplied by a factor of 2.501. The solid line represents the total cost based on our regression formula (see Eq. 2) and the dashed line is the result of the regression analysis of the 'best estimate' total costs. As a result, our formula based on the IOPCF dataset overestimates the total cost of oil spills (in comparison to the 'best estimate' total cost) for 40% of all cases. However, for spills above 0.1 tonnes this figure goes up to 57% and to 78% for spills above 1 tonne. Although there are reservations for the total cost to response cost 'best estimate' ratio of 2.501 it is clearly that our formula overestimates the total cost for about 80% of spills above 1 tonne.

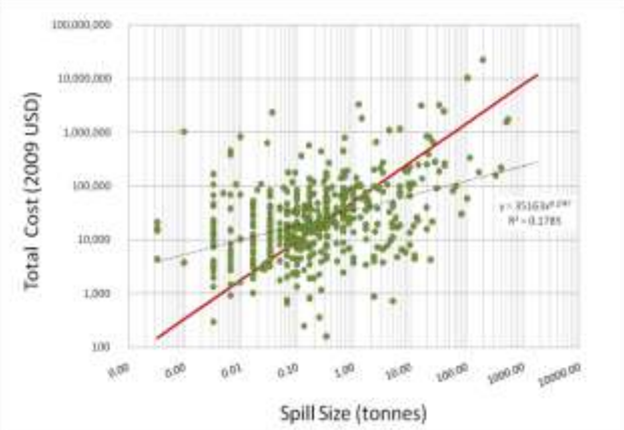

Fig 5. Comparison of the total cost estimated by the IOPCF cost formula with the US response cost.

Formulas based on the combined dataset

Although these datasets come from two different spill sources, it could be interesting to investigate the combination of the two. One reason to do so is that the IOPCF dataset includes mainly large spills and the OSLTF dataset contains mainly small spills. This is also in line with the recommendation stated in IMO (2009c) that our regression formula could be adjusted by incorporating oil spill data provided by other Member Governments.

Given that the dataset provided by the US included only response cost our analysis focuses on combining this dataset with the IOPCF cleanup cost data. Thus, we arrive at a data set of 570 spills. The median oil spill has a size of 0.25 tonnes whereas the average is 749.38 tonnes. By combining all data we arrive at a new trend line that lies well below the cleanup trend line derived from the IOPCF dataset, especially for large spills. The reason as discussed before is that the OSLTF dataset contains extremely small spills and about 3 times more data than the IOPCF dataset. Note that any curve derived by regression analysis of the combined dataset will grossly underestimate spills over 1,000 tonnes.

By removing outliers (data points with an absolute residual of above 2) a better fit can be achieved. The equation of the fitted model is:

$$\text{Cleanup Cost} = 24{,}936\ V^{0.5271} \qquad (7)$$

Given that the IOPCF dataset contains spills greater that 0.1 tonnes we also performed a regression analysis of the combined dataset for spills greater that 0.1 tonnes, see Fig. 6. The number of spills in the final dataset is N=350 and they vary from 0.1 to 84,000 tonnes with a median of just 0.97 tonnes and an average of 969 tonnes. The fit is better than the one derived by the IOPCF dataset alone. The trend line derived by this regression is the solid one. By carefully looking at the scatter plot, it is obvious that this model overestimates spills at the lower end and underestimates spills at the higher end.

To sum up, our analysis of the combined data for oil spills greater than 0.1 tonnes (after removing the outliers) resulted in the following equation of the fitted model using linear regression:

$$\text{Cleanup Cost} = 18{,}113\ V^{0.6816} \qquad (8)$$

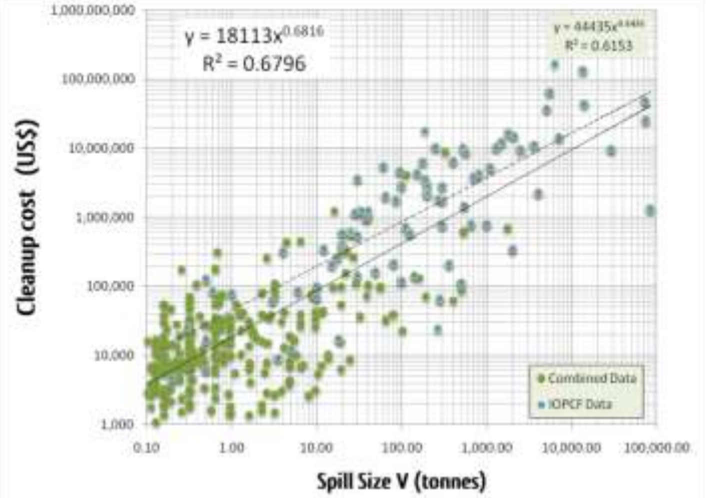

Fig.6: Linear Regression of Log(Spill Size) and Log (Cleanup Cost) Combined dataset (spills greater than 0.1 tonnes – outliers excluded).

Similarly regression analyses were carried out based on a combined dataset consisting of total costs based on the IOPCF dataset (Fig 7, dashed line) and total costs for the US spills that were estimated by multiplying the response cost with the factor of 2.501 as discussed above.

The analysis of the combined data resulted in the following total cost equation of the fitted model using linear regression:

$$\text{Total Cost} = 58{,}830\ V^{0.5} \qquad (9)$$

By removing all spills below 0.1 tonne (since the IOPCF dataset contains only spills above 0.1 tonnes) we arrive at the following formula (solid line):

$$\text{Total Cost} = 39{,}520\ V^{0.6613} \qquad (10)$$

It can be seen that the dashed trend line (Eq. 2) lies above the solid one (Eq. 10) which means that the regression formula based on the IOPCF overestimates the total costs for oil spills in comparison to one derived from the OSLTF data.

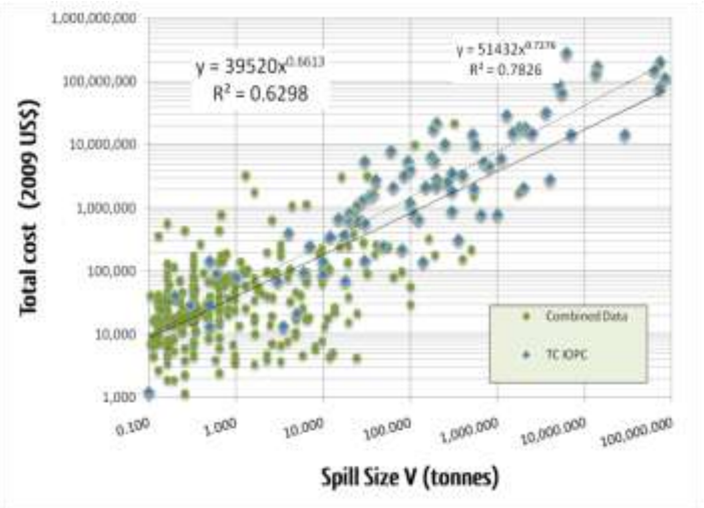

Fig 7: Linear Regression of Log(Spill Size) and Log (Total Cost) for combined dataset (spills greater than 0.1 tonnes – outliers excluded).

USES OF THE COST FORMULA

Cost Formulas and Limitations

It is important to comment on the limitations of the IOPCF dataset. The same is true for all compensation funds. First of all, it should be pointed out that the costs reported to the public are not 'real' oil spill costs. They refer to the amount of money that was agreed to compensate the claimants. Although the IOPCF compensation figures are real and cannot be disputed, compensation figures can be taken as a reasonable approximation for real spill costs, or, failing that, if they can be used as realistic 'surrogates' of these costs.

Estimates of damages calculated by applying economic valuation methodologies, claims for compensation and the compensation eventually paid to claimants can never be equal (Thébaud et al., 2005). Furthermore, IOPCF consists of three intergovernmental organizations (the 1971 Fund, the 1992 Fund and the Supplementary Fund) which provide compensation for oil pollution damage resulting from spills of persistent oil from tankers only. It is further noted that admissible claims cannot be paid in full, especially in the case of large spills, since there exists a limit in total compensation that can be paid. However, such information is usually not disclosed in detail.

In addition, the United States is not part of the IOPCF, which as of November 2009 numbers 103 states. The same is true of China (not including Hong Kong). Therefore, US spills like the 'Exxon Valdez' are not included in the analysis. Furthermore, the most expensive claims (in total unit cost) come from Japan which is the major contributor of the IOPCF and are small spills caused by mishandling of oil supply. However, some of these spills are removed from the final analysis as outliers and in other studies such as the work of Friis-Hansen and Ditlevsen all spills caused by mishandling of oil supply are not taken into account.

Finally, another major issue raised by many researchers is that the IOPCF compensation underestimates the cost of oil spills since they do not include environmental damage costs. Only admissible claims are taken into account to be compensated and, practically, according to historical data, fewer than 1% contained natural resource damage assessments (Helton and Penn, 1999). Not to mention that, according to IOPCF, *"compensation for environmental damage (other than economic loss resulting from impairment of the environment) is restricted to costs for reasonable measures to reinstate the contaminated environment and, therefore, claims for damage to the ecosystem are not admissible"*. Helton and Penn (1999) is among the best sources of costs related to Natural Resource Damage (NRD). NRD assessments are performed in the United States during the last decades and are the best source from which to estimate the environmental damage of the oil spills. The cost data concern 48 spill incidents across the US between 1984 and 1997 and according to the authors are skewed towards larger spills. Complete data are available for 30 cases and include oil spills from facilities and pipelines and even if this dataset cannot offer reliable results one of the main findings of Helton and Penn (1999) is that *"contrary to the public perception, costs for natural resource damages and assessment comprise only a small portion of total liability from an oil spill"*. NRD costs in the original dataset vary from 2.3 % ('Arco Anchorage') to 94.9% ('Apex Houston') of the total cost. It is worth noting that for the 'Nestucca' accident NRD cost was 20.5 % and for the most expensive accident in terms of total cost in the history of US, the 'Exxon Valdez', this figures comes down to 9.7%.

Taking into consideration all of the above, one might argue that IOPCF data does not represent a world-wide dataset, may not include all relevant costs and, by definition, there is an upper limit to the maximum oil spill cost that can be reimbursed. Thus, the use of such data to estimate total oil spill costs may be questioned, even in the case of oil spills caused by tankers only. On the other hand, if there are any actual costs that are paid to victims of oil pollution, this is probably as good a source to document such costs as anywhere. Plus, it is clear that this analysis can be amended with additional data, to the extent such data becomes available.

Table 1: Formulas to estimate cost of oil spills

			Volumes	R^2
Eq	**CLEANUP COST**			
1	IOPCF dataset (outliers removed)	Cleanup Cost = 44,435 $V^{0.644}$	0.1-84,000	0.615
3	US dataset (V>1 tn)	US Cleanup Cost = 13,814 $V^{0.273}$	all sizes	0.18
7	Combined dataset (IOPCF and US)	Cleanup Cost = 24,936 $V^{0.527}$		0.618
8	Combined dataset (IOPCF and US)	Cleanup Cost = 18,113 $V^{0.681}$	0.1-84,000	0.68
	TOTAL COST			
2	IOPCF dataset (outliers removed)	Total Cost =51,432 $V^{0.728}$	0.1-84,000	0.78
5	US dataset	US Total Cost = 35,044 $V^{0.274}$	all sizes	0.18
6	US dataset (V>1 tn)	US Total Cost = 23,212 $V^{0.514}$	>1	
9	Combined dataset (IOPCF and US)	Total Cost = 58,830 $V^{0.5}$	all sizes	
10	Combined dataset (IOPCF and US)	Total Cost = 39,520 $V^{0.6613}$	V>1	0.63

Before commenting on the possible uses of the regression formulas we present them in the table above so that the reader can easily compare them and pick the one that looks more relevant for the particular analysis to be performed.

ADD TABLE AND GUIDANCE / SHORT REVIEW

Formal Safety Assessment (FSA)

FSA aims at giving recommendations to relevant decision makers for safety improvements under the condition that the recommended measures (risk control options) are cost-effective and also reduce risk so that the residual risk is as low as reasonably practicable (ALARP principle). Recall that for a risk to be ALARP, the cost involved in reducing it further should be grossly disproportionate to the benefit gained. FSA is, currently, the major risk assessment tool that is being used for policy-making within the International Maritime Organization (IMO), however, until recently its main focus has been on assessing the safety of human life and that of property. No environmental considerations have been incorporated thus far into FSA guidelines (IMO, 2007). However, MEPC 62 (July 2011) agreed to package the main recommendations of the discussion on this topic in the form of an amendment to the FSA guidelines, and forwarded this to IMO’s Maritime Safety Committee for further action (IMO, 2011).

In addition, note that FSA exhibits some limitations and deficiencies. The reader is referred to Kontovas (2005), Kontovas and Psaraftis (2006 and 2009), Kontovas et al. (2007a,b)) and Giannakopoulos et al. (2007) for a discussion on these issues.

The fourth Step of a Formal Safety Assessment is to perform a Cost-Benefit Analysis (CBA) so as to pick which RCOs are most cost effective. According to the FSA guidelines (IMO, 2007), one stage of this Step is to *“estimate and compare the cost effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option”*.

Up to now in most FSA studies cost effectiveness is assessed by using the so-called Cost Effectiveness Analysis (CEA) and not Cost Benefit Analysis (CBA) both of which will be briefly discussed below. CEA may be considered to be a particular form of CBA, where the benefits are usually not monetized, and therefore, net benefits cannot be calculated, see Mishan and Quah (2007) and Krupnick (2004).

Usually, in CEA, one calculates costs per unit of an effectiveness measure (such as lives saved). Therefore, while CEA cannot help in determining whether a policy increases social welfare, it can help in the choice of policy that achieves the specified goal with the smallest loss in social well-being and help rank alternative policies according to their cost-effectiveness (Krupnick, 2004).

In theory, the analytical tool of Cost Effectiveness Analysis is the **incremental cost-effectiveness ratio** (ICER), also called marginal cost-effectiveness ratio, given by the difference in costs between two actions divided by the difference in outcomes between these two, with the comparison typically being between an action that is proposed to be implemented and the current status. Note that being ratio tests, ICER figures ignore the absolute value (or scale) of risk reduction ΔR, which should always be taken into account as a criterion in itself (Kontovas and Psaraftis, 2009).

In the scope of this paper, the following indices can be formulated:

Gross Cost Effectiveness Index (GCEI)

$$GCEI = \frac{\Delta C}{\Delta R} \quad (10)$$

Net Cost Effectiveness Index (NCEI)

$$NCEI = \frac{\Delta C - \Delta B}{\Delta R} \quad (11)$$

where

ΔC is the cost per ship of the action (eg. measure, risk control option) under consideration ($)

ΔB is the economic benefit per ship resulting from the implementation of the RCO ($), and

ΔR is the risk reduction per ship year, in terms of the number of tonnes of oil averted (or fatalities when assessing human safety).

Currently only one such index is being extensively used in FSA applications. This is the so-called “Cost of Averting a Fatality” (CAF) and is expressed in two forms: Gross and Net. These two indexes are the incremental cost-effectiveness ratios (in gross and net form) for risk reductions in terms of the number of fatalities averted. As part of the EU-funded project SAFEDOR (2005), Skjong et al. (2005) and Vanem et al. (2007a, 2007b) presented an environmental criterion equivalent to CAF. This is nothing new, but an incremental cost effectiveness ratio to assess the case of accidental releases of oil to the marine environment that measures risk reduction in terms of the number of tonnes of oil averted. This criterion was named CATS (for ’Cost of averting a ton of oil spilt ‘, also referred to as ’Cost to Avert one Tonne of Spilled oil’) and its suggested threshold value was 60,000 USD/tonne. According to the CATS criterion, a specific Risk Control Option (RCO) for reducing environmental risk should be recommended for adoption if the value of CATS associated with it (defined as the ratio of the expected cost of implementing this RCO divided by the expected oil spill volume averted by it) is below the specified threshold. Otherwise that particular RCO should not be recommended.

Kontovas and Psaraftis (2006) were probably the first to question CATS as proposed by Skjong et al. (2005), both on the use of any single dollar per tonne figure and on the 60,000 dollar threshold. A submission by Greece based on this paper opened the debate concerning environmental risk evaluation criteria and its uses within FSA. As discussed previously, an issue of primary importance was found to be the relationship between spill volume and spill cost. Within the MEPC the majority of those involved are in favor of a non-linear cost function (IMO, 2009c). Given that the cost of an oil spill depends upon the volume of the spill it is difficult to incorporate the regression formulas within CEA. Besides, most Risk Control Options have multiple effects (for example both in safety and the environment) and in those cases CBA should be preferred as it can combine multiple effects. The next Section will present the technique of CBA along with the way to incorporate CBA into FSA followed by an example.

Cost Benefit Analysis (CBA)

CBA is an accounting technique for capturing the advantages and disadvantages of an action in monetary terms, see Krupnick (2004). This action can be a project, a Risk Control Option (RCO), a medical intervention, a policy or any other measure. Subtracting costs from benefits yields the net benefits to society (also referred to as net improvements in social welfare). Actions that improve welfare or well-being are superior to those that reduce it. Furthermore, CBA can be used to cardinally rank them on the basis of their change in well-being. CBA focuses on the aggregate measures of well-being, taking the existing distribution of income as given. For more details the reader is referred to CBA textbooks such as Mishan and Quah (2007), Boardman et al. (2001) and de Rus (2010).

The basic criterion is that if the discounted present value of the benefits exceeds the discounted present value of the costs then the action is worthwhile. This is equivalent to the saying that the net benefit must be positive or that the ratio of the present value of the benefits to the present value of the costs must be greater than one. Amongst alternatives the one that has the higher net benefit is the better.

In general, the **cost** component consists of the one-time (initial) and running costs of an RCO, cumulating over the lifetime of the system. The **benefit** part is much more intricate. It can be a reduction in fatalities or a benefit to the environment (which is the avoided cost of oil spills) or an economic benefit from preventing a total ship loss. Cost is usually expressed using monetary units. To be able to use a common denominator, a monetary value has to be given for the benefit too. Therefore, CBA can be used as an alternative to CEA even within FSA as discussed in Yamada and Kaneko (2009) and Kontovas et al. (2010), see next Section.

Finally, CBA can be used in **risk analysis within probabilistic oil outflow**. Probabilistic oil outflow models may be used in risk based optimization of crude oil carriers with respect to loss of cargo. These are in line with the IMO regulations regarding the probabilistic oil outflow for bunker tanks (applied to all spills) and cargo tanks regarding oil carriers. Indeed, MEPC has adopted a revised MARPOL Annex I/22 and 23 applicable to all new oil tankers to provide adequate protection against oil pollution in the event of grounding or collision, see IMO (2006a, 2006b, 2006c).

Regulation 23 of MARPOL applies to new oil tankers, which means all tankers delivered on or after 1 January 2010. The probability density functions have been determined for the likelihood of damage being encountered at different points in the length of the ship for both side and bottom damage. An assessment is then made of the expected oil outflow from each damaged tank or group of tanks including tidal effects and accounting for any retained oil. The mean oil outflow parameter is calculated independently for side damage and bottom damage and then combined in non dimensional value as follows:

$$O_{\mathrm{M}} = (0.4 O_{\mathrm{MS}} + 0.6 O_{\mathrm{MB}})/C, \qquad (12)$$

where O_{MS} and O_{MB} are the mean outflows for the side damage and bottom damage respectively and C is the total volume of cargo oil in m^3 for a 98% full tank.

In that case the discounted cost of a measure to be applied could be easily judged against the benefits (in monetary terms) of averting the mean oil outflow which could be estimated by using the cost formulas presented above. The measure could be a device, a structural measure (for example increased double bottoms) or even the whole ship. Estimating the environmental performance of alternative designs weighs the present value design costs against the present value benefits which can be estimated by multiplying the annual probability that a spill would occur by the probability weighted mean avoided cost for each year and discounted for the lifetime of the vessel, see Sirkar et al. (1997). Regarding the annual probability of occurrence, note that this is not an easy task and its detailed estimation is out of the scope of this work. The reader is referred to Montewka et al. (2010) who present the risk of collision and grounding as a random variable. Furthermore, Ventikos and Swtiralis (2011) present a probabilistic formulation of regulation 23 of MAPPOL to calculate the distribution and quantities of oil outflow for all major oil tanker categories and examine numerous cargo tank configurations for tankers by simulating multiple outflow scenarios for the tanker fleet. On top of that, they perform an assessment of the cost of these potential oil spills by using some of the cost formulas discussed above.

Incorporating a non-linear function within FSA

Currently all FSA studies assume a linear relationship between the cost of consequences and magnitude of consequences; thus there is an implied assumption of constant cost per unit of consequence. As discussed above the use of non-linear functions to estimate the damage of oil spills has opened a new chapter for FSA. Some first thoughts on the way that a non-linear function can be used within FSA were expressed by Yamada and Kaneko (2010) and in an earlier submission to the IMO by Japan (IMO, 2009a). This Section will present some initial thoughts on the subject. Then an example based on the FSA on tankers that was prepared by SAFEDOR will be presented. Note that in this Section referring to "FSA on tankers" means the FSA on crude oil carriers that was carried out by SAFEDOR and submitted to the IMO by Denmark, see doc. MEPC 58/17/2 and MEPC 58/INF.2 (IMO, 2008).

First of all, assume that the spill cost function is given by the formula produced after regression analysis of IOPCF data which is as follows (Kontovas et al., 2010):

$$\textbf{Cost (V)} = \mathbf{51{,}432V^{0.728}} \quad \text{(in USD, if V is in tonnes)} \qquad (12)$$

The use of this particular function causes no loss of generality, as any other function of volume can be tried. These include the one used by Yamada (Japan), the one used by Psarros et al. (DNV, Norway) or any other. Note however that the above function was chosen by MEPC 60 as a test case for further analysis (see report of MEPC 60, agenda item 17). The function (Eq. 12) was chosen as it was judged as the most conservative among the 3 non-linear functions, that is, produces higher cost values among all 3 functions.

RCO evaluation by comparing the benefits (derived by using a function) and the costs is, in theory, presented in Psaraftis (2008) and Kontovas et al. (2010). Hammann and Loer (2010) use such non linear cost functions within Cost Benefit Assessment in risk-based ship design and more specifically to optimize the arrangement of cargo holds of crude oil tankers. Finally, Yamada (2009) and Yamada and Kaneko (2010) presented a way to incorporate a non-linear cost function within FSA. The latter paper forms the basis of a relevant submission to the IMO, see IMO (2009a).

In most FSA studies an event tree is presented. For each sequence of the event tree the expected number of tonnes of oil that will be averted is calculated as the product of the frequency of the event (Pi) and the average consequences (V_i) and is presented as E[V]. This is defined as the Potential Loss of Cargo (PLC) value for each sequence. In the case of using a non-linear cost function, this value should then be multiplied with the per tonne cost (which is a function of the spill volume) to estimate the risk (denoted as $E[C_i]$) and by summing all the relevant sequences the total risk may be obtained. Another equivalent way to estimate the expected benefit of averting an oil spill by using the cost function (Cost(V)) is to multiplying the probability Pi with Cost (V_i).

According to Yamada and Kaneko (2010), an RCO can be regarded as cost-effective if the following formula is satisfied

$$\Delta B - \Delta S > 0$$

where ΔB is the benefit by implementing the RCO which is the risk reduction (in monetary units) and ΔS is the cost of implementing the RCO. ΔB is the difference of estimated cost of expected spillage before (E[Corg]) and after the implementation of the RCO (E[Cnew]). Therefore, the criterion becomes

$$\Delta S < \Delta B = E[C_{org}] - E[C_{new}]$$

Note that according to the recommendations of MEPC 62 (IMO, 2011) the cost to avert an oil spill should be equal to the damage cost multiplied by two factors, namely the "assurance factor" and the "uncertainty factor". The so-called "assurance factor" is supposed to represent society's willingness to pay to prevent an oil spill instead of sustaining its damages. The "uncertainty factor" represents the fact that the compensation costs of a spill are not equal to the real costs of that spill. In other words, this factor reflects the fact that some spill costs cannot be captured and are uncertain. However, thus far there has been no agreement on what this factor might be, even though there is a clear belief by some IMO delegations that this factor should be well above 1.0. Taking into account that a commonly accepted and exact estimation of the cost of averting an oil spill is not a trivial issue we assume within this paper that the damage oil spill cost is equal to the cost of averting such a spill. However, it is duly noted that this is a subject of further debate.

We shall now present an example of how to incorporate the non-linear function into FSA.

An example based on the FSA on tankers

FSA on tankers (IMO, 2008) was carried out by the project SAFEDOR and presents a high-level Formal Safety Assessment pertaining to large oil tanker ships. One of the scenarios evaluated is the one that has to do with contact and this is used as an example in the following.

Contact events consist of scenarios where the vessel accidentally comes into contact with a floating object or a fixed installation. The basic causes are because of bad visibility, navigational problems such as human errors or equipment failure such as radar failure, steering or propulsion failure. The following Qualitative risk model presents the event sequence of a contact of a tanker with a floating object (such as iceberg or a boy) or with a fixed installation (for example an offshore terminal or rocks).

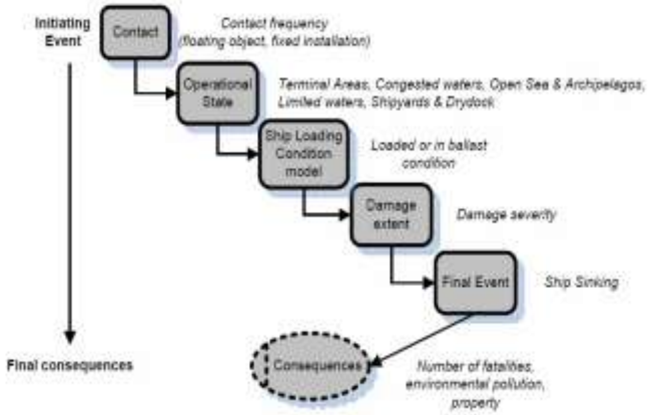

Figure 8 : Event sequence in contact risk model of an Oil Tanker (Source: IMO, 2008)

The high-level event tree model for collision accidents has been elaborated on the basis of the qualitative and quantitative considerations and can be represented by an event tree total of 52 sequential scenario branches with non zero frequency, 7 of which are associated with oil spill occurrence. For simplicity, the event tree with only these 7 braches is presented in the

Figure 9. Most probabilities are estimated by using expert judgment, see IMO (2008) for more information.

For the consequence part, the numerical average size of one tank (10,726 tonnes) is assumed by the authors of that FSA study to be the expected oil outflow in those scenarios, where *"given the accident and the ship is assumed loaded, the inner hull is breached and there is a severe damage without ship sinking"*. For scenarios with non-severe damage the expected oil outflow was calculated as a percentage of DWT of the ships involved and was equal to 912.5 tonnes for contacts with a fixed installation and 0 for a contact with a floating object.

One of the risk control options presented in the FSA on crude oil carriers that could reduce the risk of contact is a docking aid - a Terminal Proximity and Speed Sensor (appears as RCO 5 in the FSA on tankers). For the purpose of the current work we assume a hypothetical RCO that has the same cost as RCO 5 and will lead to the total elimination of the current risk of oil pollution – this means a risk reduction of 100%. In addition we assume that there will be no reduction in the risk of fatalities.

The benefit is assumed to be estimated by the non-linear formula proposed by Greece, see Kontovas et al. (2010). For each sequence the risk is estimated as $R_i = P_i \times Cost(V_i)$ expressed in USD per year. The sum for all scenarios is the estimated benefit for averting the oil spills pertaining to the contact.

The Present Value PV(B) of the benefit for the 25-year lifetime can then be calculated.

Assuming a constant per tonne figure (40,000 $/tonne) :

$$PV(B) = \sum_{i=1}^{N} \frac{\Delta R}{(1+i)^N} = 56{,}311.37 \cdot \frac{(1+5\%)^{25}-1}{5\% \cdot (1+5\%)^{25}} = 793{,}649.29 \ USD$$

By using the non-linear formula proposed by Greece :

$$PV(B) = \sum_{i=1}^{N} \frac{\Delta R}{(1+i)^N} = 6{,}094.91 \cdot \frac{(1+5\%)^{25}-1}{5\% \cdot (1+5\%)^{25}} = 85{,}901.31 \ USD$$

The penultimate column presents the benefit of averting the average spill of each sequence based on the non-linear formula and the last column based on a constant per tonne value; here assumed 40,000 USD per tonne as indicatively used in Kristiansen (2005).

The costs of the hypothetical RCO (assumed same as RCO5), are as following: *“cost of implementing a Doppler type docking system is largely associated with the initial purchase price which is considered to be $70,000 based on industry figures provided by docking aid suppliers. Other perceived costs include an outlay of $4,000 every five years for maintenance during dry docking periods, and an annual figure of $400 for general spares and repairs.”* (IMO, 2008).

The Present Value PV(C) of the cost of implementing our hypothetical RCO which we assume being the same as a docking system is associated with

1. The initial purchase price: $70,000

$$PV(initial) = 70{,}000 USD \quad \$70{,}000$$

2. Outlay of $4,000 every five years for maintenance

$$PV(outlay) = \sum_{i=1}^{5} \frac{4{,}000}{(1+5\%)^{5 \cdot i}} = 10{,}202.60 \ USD$$

(payments on the 5th, 10th, 15th,20th and 25th year)

3. An annual figure of $400 for general spares and repairs

$$PV(spares) = \sum_{i=1}^{25} \frac{400}{(1+5\%)^{25}} = 400 \cdot \frac{(1+5\%)^{25}-1}{5\% \cdot (1+5\%)^{25}} = 5{,}637.58 \ USD$$

The total present value(PV) of the cost is

PV(C) = 85,840.17 USD

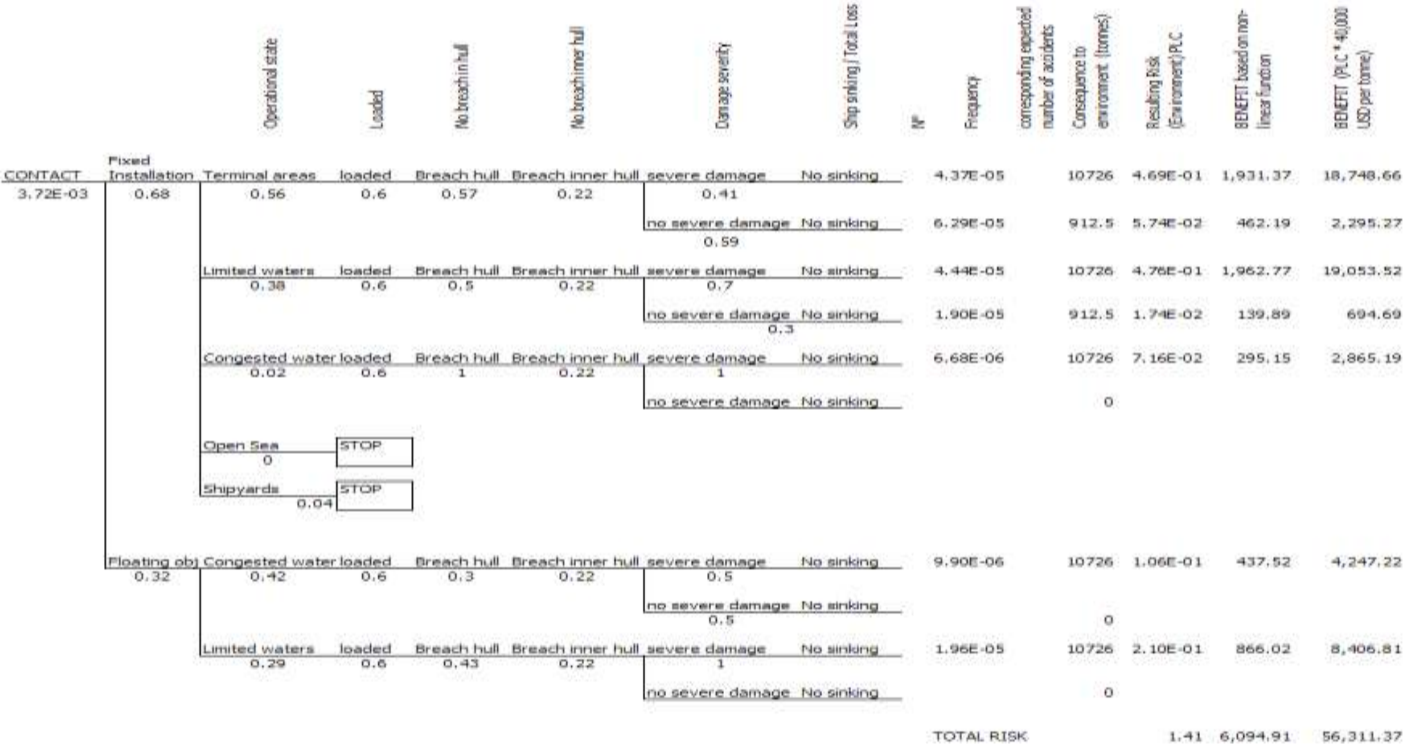

Figure 9:
Estimated Potential Loss of Cargo - Adapted from IMO (2008)

Cost Benefit Criterion

The present value of the cost of the implementation of the RCO is $85,840 and is less than the benefits based on the above calculations. Therefore the RCO should be considered for implementation.

Note that if a high constant per tonne value is used the benefit of averting the oil spill will be grossly overestimated. In the above calculation a constant per tonne value of 40,000, in line with Kristiansen (2005) and Skjong (2005) leads to 10 times the benefit that we estimate by using the non-linear function. Obviously, the greater the per tonne figure the greater the benefit and, thus, more RCOs will be deemed as cost-effective.

CONCLUSIONS

The paper discusses the rather difficult issue of estimating the cost of oil spills. This issue is of primary importance for risk assessment since this cost could be used to estimate the benefit of risk control measures that avert such oil spills. However, beyond any doubt, the cost of an oil spill is a very difficult quantity to estimate. The main factors influencing the cost of oil spills are the type of oil, location, weather and sea conditions and the amount spilled and rate of spillage. In order to be in line with the work done within the IMO the cost of oil spills is expressed as a function of the amount spilled. Furthermore, the approach used in this work is based on the assumption that the cost of an oil spill can be approximated by the compensation eventually paid to claimants by relative funds. The paper reported on recent analyses of oil spill cost data assembled by the International Oil Pollution Compensation Fund (IOPCF). Given that the US in not a part of the IOPCF, analyses of the cleanup cost based on data of US spills that were covered by the US Oil Spill Liability Trust Fund (OSLTF) are also presented.

Caution should be exercised when using these valuation functions since the compensation data refer to the amount of money that was agreed to compensate the claimants. Although the IOPCF compensation figures are real and cannot be disputed, a question is if compensation figures can be taken to reasonably approximate real spill costs, or, failing that, if they can be used as realistic ‘surrogates’ of these costs. Furthermore, the IOPCF contains spills from 0.1 to 84,000 tonnes of which only 11 are above 5,000 tonnes. The data from US spills mainly come from extremely small spills. The median spill size of the dataset is 0.16 tonnes and the average is just 168.29 tonnes. The oil spill size in question should fall within the range of the data that were used to arrive at the regression formula that is to be used Finally, it has been shown that the regression formula derived from IOPCF data (Eq. 1) gives more conservative results than all other formulas and could be used in order to be on the safe side.

Moreover, the paper discusses the uses of these non-linear functions to estimate the cost of an oil spill. These functions could also be used within maritime risk assessment and more specifically within the Formal Safety Assessment. Indeed, there is an ongoing discussion within the Marine Environment Protection Committee (MEPC) starting in 2006 when the IMO decided to act on the subject of environmental criteria. An example of the use of a non-linear cost function based on an FSA study on tankers submitted to the IMO was also presented.

Finally, the paper presented a brief discussion on the uses of oil spill valuation through Cost Benefit Assessment to evaluate the performance of tanker designs taking into account the recent IMO regulations regarding oil carriers and more precisely the revised MARPOL Annex I/23 and 24 applicable to all new oil tankers to provide adequate protection against oil pollution in the event of grounding or collision.

ACKNOWLEDGEMENT

We would like to thank three anonymous reviewers and the lead reviewer for their comments on a previous version of the paper.

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