Marine Environment Risk Assessment: A Survey on the Disutility Cost of Oil Spills

Christos A. Kontovas [1], Harilaos N. Psaraftis [2]
[1] National Technical University of Athens, Greece, xkontovas@gmail.com
[2] National Technical University of Athens, Greece, hnpsar@mail.ntua.gr

Abstract

"Formal Safety Assessment" (FSA) was introduced as a tool to help in the evaluation of new regulations for maritime safety and the protection of the marine environment and is currently, the major risk assessment tool that is being used for policy-making. However, there is not much work done in FSA as regards the protection of the marine environment and especially the prevention of sea pollution. Taking into account that a major harm to the sea is the accidental spillage of oil and by acknowledging that there is no significant work on this matter, this paper attempts a literature review on the issue and comments on alternative approaches. To that effect, prior research on oil spill damage cost assessment is placed within context, and various alternative approaches are presented. This work is also viewed within the framework of recent IMO developments in this area.

Keywords
Marine Risk Assessment; Formal Safety Assessment; Cost of Averting a Tonne of of Spilled Oil; Cost of Oil Spills; Damage Assessment.

1. Introduction

The purpose of this paper is to investigate possible approaches to incorporating environmental risk evaluation criteria within IMO's guidelines for Formal Safety Assessment (FSA). To be more specific, we focus on methods that can be used to arrive at a commonly accepted threshold to evaluate the cost-effectiveness of Risk Control Options (RCOs) that will avert an oil spill or mitigate its consequences. To that effect, prior research on oil spill damage cost assessment is placed within context, and various alternative approaches are presented. This work is also viewed within the framework of recent IMO developments in this area.

We clarify that it is not the purpose of this paper to comment on FSA limitations or deficiencies or suggest ways to improve it. The reader is referred to Kontovas (2005), Kontovas and Psaraftis (2006a,b), Kontovas et al (2007a,b) and Zachariadis et al (2007) for a discussion on these issues.

The rest of this paper is structured as follows. Section 2 deals with Formal Safety Assessment and the relevant risk acceptance and evaluation criteria. Section 3 reports on the discussion of the environmental aspects of FSA at the IMO. Section 4 talks about the prior research on the cost of oil spills. Sections 5 to 7 present the latest approaches to estimate the total cost of oil spills including the CATS criterion, Psaraftis' Framework and Japan's IOPCF approach and Section 8 presents the conclusions.

2. Formal Safety Assessment (FSA)

As is known, Formal Safety Assessment (FSA) was introduced by the 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" (see FSA Guidelines in document MSC circ. 1023, MEPC circ. 392). In MSC 81 (May 2006), an FSA 'drafting group' proposed some amendments to these guidelines (see Annex 1 of document MSC 81/WP.8). These amendments were approved by the MSC and were subsequently sent on to the MEPC for approval, which happened at MEPC 55 (October 2006). Further, MSC 83 (October 2007) consolidated the FSA guidelines in the Annex to document MSC 83/INF.2[1].

To achieve the above objectives, IMO's guidelines on the application of FSA entail a five-step approach, consisting of:

1. Hazard Identification
2. Risk Assessment
3. Risk Control Options
4. Cost-benefit Assessment
5. Recommendations for decision making

In brief, FSA aims at giving recommendations to relevant decision makers for safety improvements under the condition that the recommended measures (risk control options) reduce risk to the "desired level" and are cost- effective.

The notion of desired level is linked with the so-called risk acceptance criteria and the ALARP principle.

[1] We use the standard notational scheme of IMO documentation throughout this paper. Document MEPC x/y/z means a document presented at the x^{th} session of the MEPC, agenda item y, document number z. A similar notation holds for MSC (Maritime Safety Committee) documents. IMO documents do not appear in the reference section.

According to the Health and Safety Executive's (HSE, United Kingdom) Framework for the tolerance of risk, there are three regions in which risk can fall into (HSE, 2001). Unacceptable Risk (for example resulting from high accident frequency and high number of fatalities) should either be forbidden or reduced at any cost. Between this region and the Acceptable Risk region (where no action to be taken is needed) the ALARP (As Low As Reasonable Practicable) region is defined. These regions are illustrated in Figure 1 below.

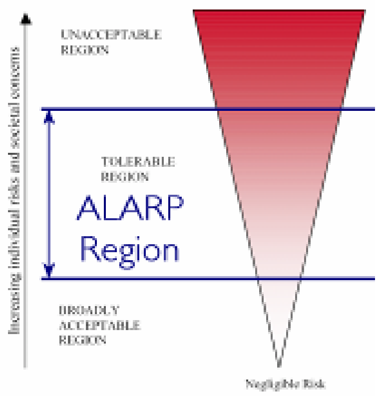

Fig. 1: The ALARP Concept [HSE, 1999]

It is interesting to note that IMO's FSA guidelines provide no explicit Risk Acceptance Criteria. Currently decisions are based on those published by the UK Health & Safety Executive (HSE,1999) and we note that in the recently adopted amendments to the FSA guidelines (see Annex to doc. MSC 83/INF.2), it was made clear that all of these numbers are only indicative. Risks below the tolerable level but above the negligible risk (for crew members, passengers and third parties) should be made ALARP by adopting cost-effective Risk Control options (RCOs).

2.1 Cost Benefit Assessment

There are several indices to evaluate the effectiveness of an RCO. A simple acceptance criterion from an economic perspective that is being used in FSA Cost Benefit Assessments (CBA) is that the costs to implement an RCO should be lower than the benefits that arise from its use.

However, currently only one such criterion is being extensively used in FSA applications. This is the so-called Cost of Averting a Fatality (CAF) and can be expressed in two forms: Gross and Net.

Gross Cost of Averting a Fatality (GCAF)

$$GCAF = \frac{\Delta C}{\Delta R} \quad (1)$$

Net Cost of Averting a Fatality (NCAF)

$$NCAF = \frac{\Delta C - \Delta B}{\Delta R} \quad (2)$$

where
ΔC is the cost per ship of the RCO under consideration.
ΔB is the economic benefit per ship resulting from the implementation of the RCO
ΔR is the risk reduction per ship, in terms of the number of fatalities averted, implied by the RCO.

2.2 The USD 3M criterion

The dominant yardstick in all FSA studies that have been submitted to the IMO so far is the so-called "USD 3m criterion" which is the Implied Cost of Averting a Fatality (ICAF), as described in MSC 78/19/2. According to this, in order to recommend an RCO for implementation this must give a CAF value -both NCAF and CGAF- of less than USD 3 million. If this is not the case, the RCO is rejected. It has to be noticed that the CAF value (Cost of Averting a Fatality) is based on statistical analysis of the LQI (Life Quality Index) for OECD countries (see MSC 72/16 or Kontovas (2005) for updated CAF values).

The Life Quality Index (LQI) is intended as a social indicator that reflects the expected length of "Good Life", in particular the enhancement of the quality of life by good health and wealth. The original LQI definition is given by Nathwani, Lind and Pandey (1997). A way of expressing it is as follows:

$$LQI = g^{w} \cdot e^{1-w} \quad (3)$$

The ICAF value is determined by assuming that an option is accepted as long as the change in LQI owing to the implementation of the option (=RCO) is positive. This means that

$$ICAF = \frac{g \cdot e}{4} \cdot \frac{1-w}{w} \quad (4)$$

where
g is the Gross Domestic Product per capita
e is life expectancy at birth
w is the proportion of life spent in economic activity.

3. Environmental Aspects and the Discussion at the IMO

We now come to a subject that is very important for environmental protection but for which the current state of knowledge is lacking. FSA was introduced as a tool to help in the evaluation of new regulations for maritime safety and protection of the marine environment. FSA is, currently, the major risk assessment tool that is being used for policy-making, however, until now its main focus was on assessing, primarily, the safety of human life and, secondarily, that of the ship itself–as a property. No environmental considerations have been incorporated thus far into FSA guidelines (incidentally, the same is true for the value of the cargo, but this is another matter).

In MEPC's 55th session an invitation was issued to "members and international organizations to consider the draft environmental risk evaluation criteria during the intersessional period and submit comments thereon to MEPC 56, for further consideration prior to referring the agreed text to the MSC for appropriate action." (see also documents MEPC 55/18, MEPC 55/23, MSC 82/24 and MEPC 56/18). In response to this invitation, Greece submitted document MEPC 56/18/1 on FSA, with a focus on environmental risk evaluation criteria. In MEPC's 56th session (July 2007) it was agreed to form a 'correspondence group', coordinated by the second author of this paper, and tasked to look into the matter in more detail and report back in time for MEPC's 57th session (April 2008).

After several months of deliberations, this report was submitted in December 2007 (doc. MEPC 57/17) and was presented at MEPC 57 in April 2008. The divergence of views on some important facets of the problem confirmed that the topic was found to be of non-trivial complexity and perhaps even could not be viewed as a simple extension of FSA.

In view of the issues still left open after the CG's deliberations, MEPC 57 renewed the terms of reference of the CG until MEPC 58. After two rounds of input by CG members, the second CG report on this subject (doc. MEPC 58/17) was submitted in June 2008 and is to be presented at MEPC 58 in October 2008. The report includes a proposal to the CG by the second author of this paper, on a general methodological framework that can be used as a way forward. This mainly concerns Steps 3 and 4 of the FSA and integrates environmental risk evaluation criteria within IMO's guidelines for FSA. The proposed approach can also combine environmental criteria with criteria already in use in FSA. The approach is readily implementable as long as data for the model described is readily available. Details of this framework can be found in Psaraftis (2008) and are summarized in Section 6 of this paper.

4. Prior Research - the Cost of Oil Spills

Even though the discussion at the IMO on environmental risk evaluation criteria for FSA has just started, the subject itself is not new, and substantial work has been performed over at least the last 30 years, mostly in the context of analyzing the economic impact of oil spills and contemplating measures to mitigate their damages. We note that an important part of this work concerns oil spill damage assessment. Among many other researchers, White and Nichols (1983) reported on the various components of the oil spill costs and on the significant difficulties in estimating these costs. Grigalunas et al (1986) reported on the socioeconomic costs of the AMOCO CADIZ oil spill (1978, France). In the context of the 'MIT oil spill model', the second author of this paper and his colleagues at MIT used a 'damage assessment model' to estimate the damages of an oil spill in the context of optimizing oil spill response alternatives. They used damage cost estimates for various strategic spill response scenarios in the US New England region that ranged from about 29,000 USD/tonne (1983 dollars) for very small spills that typically occur close to shore to less than 300 USD/tonne for very large offshore spills (Psaraftis et al, 1986). More recently, the work of Etkin (1999, 2000, 2001,2004), White and Molloy (2003), Shahriari and Frost (2008), and others provide significant material as regards both the methodology to compute oil spill costs and actual numbers to document these costs.

The authors of this paper feel that is important to take stock at this prior work and build upon it, rather than reinvent the wheel. We thus attempt to highlight some of the main points of this prior work in the rest of this section, stressing that our analysis is by no means encyclopedic.

According to Liu and Wirtz (2006), five different categories of costs can generally be identified. We divide them into three groups: cleanup (removal, research and other costs), socioeconomic losses and environmental costs. By adding up these three cost categories we obtain the total cost of an oil spill. Beyond any doubt, the cost of an oil spill is very difficult to estimate.

The total cost of an oil spill can be derived by using at least four different methods. These are the following:

1. Adding up all relevant cost components (cleanup, socioeconomic and environmental). The way to estimate these three cost components will be discussed in Sections 4.1, 4.2 and 4.3.

2. Estimating the clean-up costs through modeling (see Section (4.1) and then assuming a comparison ratio for environmental and socioeconomic costs. Vanem et al (2007a) assumed a ratio of 1,5 and according to Jean-Hansen (2003) environmental costs, including socioeconomic costs, are almost 2 times the cleanup costs in Norwegian waters.

3. Using a model that estimates the total cost such as the Etkin BOSCEM approach (see Section 4.4).

4. Assuming that the total cost of an oil spill can be approximated by the compensation eventually paid to claimants. Compensation information is reported by the International Oil Pollution Compensation Funds (IOPCF) which publishes annual reports. These have been used by Grey (1999) and, recently, by Yamada and Kaneko (2007). The latter was submitted to IMO and is to be presented at MEPC 58 in October 2008. This approach will be discussed in Section 7 of this paper.

4.1 Removal, Research and Other Costs

The first cost group covers the cleanup costs, research costs and other various costs such as loss of cargo and vessels, repairs etc.

The International Tanker Owners Pollution Federation (ITOPF) has presented a description of the fate of an oil spill. When spilled at sea, oil normally breaks up and is dissipated or scattered into the marine environment as a result of a number of processes that change the compounds of oil. Thus, there is a general agreement (Etkin,1999; Grey, 1999; White and Molloy, 2003) that the main factors influencing the cost of oil spills are:

- **Type of oil**

Moller et al (1987) found that cleanup costs for light oils and refined products tend to be below the average cost. Light products, in most of the cases, are more toxic than heavier oils, however, they disperse more readily. For example, according to an analysis of cleanup costs of US and non-US spills by oil type (Etkin,1999) the average cleanup cost for light crude oil is 4,265.94 USD per tonne while when involving Marine Heavy Fuel Oil (MFO) the cleanup cost is 23,893.28 USD per tonne.

- **Location**

A spill occurring far from the coast tends to cause minor damages as oil will de dispersed before reaching the shore. The ATLANTIC EMPRESS accident off the coast of Tobago in 1979 was the reason of a 280,000 tonnes spill but caused little damage because of its location and also due to favorable wind and weather conditions.

- **Weather and sea conditions**

Obviously, favorable wind can prevent the oil from reaching the shore which could lead to higher costs. Furthermore, good weather would result in a more rapid clean-up process. Added to this are the limitations on oil collection systems imposed by bad conditions such as wind, waves and currents.

- **Amount spilled and rate of spillage**

There is definitely a relation between the costs of a spill and the amount of spilled oil. In general, larger spills imply higher costs but the relation is not linear as shown by Etkin (1999) who came to the conclusion that the clean-up costs on a per tonne basis decreased significantly with increasing amounts of oil spill. White and Molloy (2003) have discerned a similar trend in their analysis using ITOPF's data and insist that simple comparisons between the costs of individual spills based only on a per volume unit can be highly misleading. Furthermore, the rate of spillage is also an important factor because, for example, the clean-up operation required in response to a single spill may be considerable but will be completed in a matter of days or weeks. However, the same quantity if lost over several months require repeated cleaning and will have long-term effects. This was the case of BETELGEUSE, a tanker that sank at a terminal in Ireland and because of the ongoing release from the various parts of the wreck the clean-up respond lasted for some 21 months although the total amount of oil spilled wan no more than 1,500 tonnes.

- **Clean-up Response**

Quite understandably, as an immediate response to an oil spill, all the effort is devoted to deal with the spilled oil in an attempt to prevent the damage and the public outcry -which is mostly associated with pollution of shorelines. In most of the cases, well-organized operations and rapidity of response are fundamental to limit the clean-up costs. The management of response operations is being extensively discussed in White and Molloy (2003).

Estimating the Clean-Up Cost

One of the early studies on oil spill costs was performed by Cohen (1986). For example, based on data owned by the USCG (regarding 95 accidents between 1973 and 1981) he proposed the use of the following correlation for the cost of the recovery of the oil spilt:

$$C = a_o V^{a_1} f^{a_2} \qquad (5)$$

where C is the cleanup cost, V the volume spilled, f=0.83 and a1=0.439 and a2=-0.789. The last factors depend on the location and above values are those for oil spills that occur at ports.

Later, Etkin (1999) devised a method for estimating clean-up costs (on a per tonne of oil recovered basis) based on location, shoreline oiling, type of oil spilled, cleanup strategy and amount spilled. She further refined the model by adding two more variables: the specific type of location (allowing for three type of spills: offshore, coastal and port spills) and the country location. This new model by Etkin (2002) was based on a number of spills that happened worldwide while her previous models were based on US spills only. Her analysis (Etkin, 2001) showed that average costs could vary by at least one order of magnitude. Thus, the average clean-up cost (in 1999 USD per tonne) for an oil spill in Lithuania is 78.12, in Malaysia 76,589.29 and 25,614.63 in the United States.

The model proposed by Etkin (2000) is the following

$$C_u = C \cdot l \cdot t \cdot o \cdot m \cdot s \qquad (6)$$
and $C_l = r \cdot 1 \cdot C$
and $C_e = C_u \cdot A$

where Cu is response cost per unit, C_l the cost per unit spilled, Cn the general cost per unit spilled in nation, n and Ce the estimated total response cost.

The values of modifier factors (t,o,m,s,r,l) are shown in Table 1 and give an idea of how important factors like oil type, location, size, etc. affect the cleanup cost. More specifically t is the oil type modifier, o the shoreline oiling modifier, m is for the cleanup methodology, s for spill size, r for regional and l for local location and, finally, A is the specified spill amount for scenario.

Table 1: Cost Modifiers [Etkin,2000]

Cost factor	Modifier
Oil type	
No. 2 fuel (diesel)	0.18
Light crude	0.32
No. 4 fuel, No. 5 fuel	1.82
Crude	0.55
Heavy crude	0.65
No. 6 fuel	0.71
Spill size	
<10,000 gal (<34 t)	2.00
10,000–100,000 gal (34–340 t)	0.65
100,000–500,000 g (340–1,700 t)	0.27
500,000–1,000,000 gal (1,700–3,400 t)	0.15
1–10 million gal (3,400–34,000 t)	0.05
(>10 million gal (>34,000 t)	0.01
Location type	
Nearshore	1.46
In port	1.28
Offshore	0.46
Primary method cleanup	
Dispersants	0.46
In situ burning	0.25
Mechanical	0.92
Manual	1.89
Natural cleansing	0.10
Shoreline oiling	
0–1 km	0.47
2–15 km	0.54
20–90 km	0.61
100 km	1.06
500 km	1.53

Finally, Shahriari and Frost (2008) have, very recently, developed a mathematical method to estimate cleanup costs based on regression analysis of 80 incidents during the period 1967-2002. The model parameters are spill quantity, oil density, distance to shore, cloudiness (used as a measure of how much sunlight reaches the oil which is the main factor that affects evaporation) and level of preparedness based on ITOPF estimations on how well different world regions cope with oil spills.

In order to reach predictions as reliable as possible it was decided to create a composite model although this is statistically unorthodox.

$$\text{Spill cost [US dollars]} = 156.5934 \times (\text{spill amount [tonnes]}) + 56{,}781{,}000 \times (\text{oil density [kg/dm}^3]) + 2{,}303{,}500 \times (\text{level of preparedness}) - 49{,}979{,}000 \quad (7)$$

$$\text{Spill cost [US dollars]} = (29{,}471 \times (\text{oil density [kg/dm}^3]) + 863.0906 \times (\text{level of preparedness}) - 24{,}060) \times (\text{spill amount [tonnes]}) \quad (8)$$

A model user must use both equations and then decide which prediction to use, based on the cost interval [4×10^6 to 4×10^7]. In the case that both predictions end up within the interval, it is advised to use Eq.7. In any other case Eq. 8 should be used, which has a slightly better performance overall, or it is advisable to pick whichever equation that predicts higher, to err on the side of caution if need be.

4.2 Socio-economic Losses

According to Liu and Wirtz (2006) socio-economic losses consist of property damage and income losses. The property damage can be estimated by adding up all costs of repairing or cleaning facilities including vessels. On the other hand, the income losses take into consideration damages from various sectors such as fishery and tourism. The total economic losses are the sum of foregone incomes during the recovery period. This part of the total cost is very straightforward to estimate and needs no more explanation.

As regards this category, one thing is clear: This is not an easy subject. It is clear that the value of lost oil should count as part of the damage cost of a spill (and this is the easiest part to compute). Also, income lost by fishermen in the vicinity of a spill should be counted as part of the socioeconomic cost of that spill. The same is true for income lost by hotels, restaurants, and other tourist shops whose turnover is reduced as a result of a spill in their area. But what if tourists spend money in a restaurant to which they came to dine in an excursion to take a look at the spill? Should this count as a plus? Even attempts to calculate lost income as a result of people having a lower IQ because they systematically ate shellfish contaminated by oil have been recorded (see for instance Intertanko's comment in doc. MEPC 58/17). All this points out that estimating socioeconomic spill costs is generally very difficult and is never likely to be an exact science.

4.3 Environmental Costs

This part of the total cost of an oil spill is the most difficult to evaluate since most of environmental goods or services are non-market. Economists have developed a range of approaches to estimate the economic value of non-market impacts. In order to measure environmental damages economists either indirectly link environmental resources to some market goods or even construct a hypothetical market in which people are asked to pay for these resources. It is out of the scope of this paper to analyze these methods, however, one of them has been used in order to estimate the damages from the EXXON VALDEZ oil spill and some other spills and will be presented in this section .

There was a rapidly growing interest in passive use values in the US which was heightening at the time of the study by the passage of the Oil Pollution Act (OPA) and the regulations that National Oceanic and Atmospheric Administration (NOAA) enacted under it for natural resource damage assessments. The regulations stated the "the trustees should have the discretion to include passive use values as a component within the natural resource damage assessment determination of compensable values".

The Contingent Valuation (CV) method is a widely used non-market (or passive use) valuation method especially in the areas of environmental cost-benefit analysis (CBA) and environmental impact assessment (EIA). CV is a survey approach designed to create the missing market by determining what individuals or households are willing to pay (WTP) for specific changes in quantity or quality of environmental goods or, more rarely, by asking responders for their willingness to accept (WTA) in compensation for a specified degradation in the provision of these goods (Hanemann ,1999). The name for this form of valuation arose because the elicited values are contingent upon the particular scenario described to survey respondents.

An important benchmark in the history of the CV is that of the EXXON VALDEZ oil spill. The oil spill due to the grounding of the oil tanker EXXON VALDEZ in the Prince William Sound on March 24, 1989 was the largest oil spill from a tanker in US history which affected more than 1,300 kilometers of coastline and caused the death of 23,000 birds. After the oil spill, the State of Alaska appointed an interdisciplinary group of researchers to design and implement a national CVM study to measure the loss of non - use values to US. This study was coordinated by Richard Carson and constitutes one of the major contingent valuation applications and represents an important methodological reference for all contingent valuation researchers' work. The loss of non - use values resulting from the EXXON VALDEZ oil spill was estimated at 2,8 billion dollars (Carson, 1992). As a reaction to this study Exxon commissioned a group of researchers to verify whether non - use values could be accurately measured by means of CV. The main argument of critics of CVM is that this method is not capable of resulting in valid and reliable monetary measures of non - use values. Hausman's well-know argument "is some number better than no number" fully expresses the skepticism toward this method. Therefore, according to Hausman, assessments of lost non - use values by means of the CVM method should not be used in court (Diamon and Hausman, 1994). In order to address the criticism, National Oceanic and Atmospheric Administration (NOAA, 1993) set a group of experts, with Nobel laureates Kenneth Arrow and Robert Solow as chairmen, in order to evaluate the reliability of the use of CVM in the natural resource damage assessments.

Despite the criticism, Contingent Valuation is the most popular and the most controversial of the methods that environmental economists use to value environmental goods and services and has been used to assess the impacts of many oil spills from tankers such as the EXXON VALDEZ (Carson et al, 1992, 2003) , the NESTUCCA and, very recently, the PRESTIGE (Loureiro, 2007). However, nowadays, the most commonly applied method especially by the National Oceanic and Atmospheric Administration (NOAA) in the United States is the so-called Habitat Equivalent Analysis (HEA). This method is specifically designed to determine the compensation the public is due to reconcile injuries to the ecosystem and the lost services that the ecosystem provides to the biotic component. According to the 1996 final rule of the Oil Pollution Act (OPA 90), "when injured resources and/or services are primarily of indirect human use (e.g., species habitat or biological natural resources for which human uses are primarily off-site) the appropriate basis for evaluating and scaling the restoration is Habitat Equivalency Analysis (HEA)" (King, 1997). The principal concept underlying HEA is that the public can be compensated for past losses of habitat resources through habitat replacement projects providing additional resources of the same type. The reader can find more information on this topic in NOAA (2000).

4.4 Total costs model

Another credible method that can estimate the total costs of an oil spill is EPA's BOSCEM (Basic Oil Spill Cost Estimation Model). This was developed by Etkin for the US Environmental Protection Agency (EPA) and provides a methodology for estimating oil spill costs, including response costs and environmental and socioeconomic damages for actual or hypothetical spills. EPA BOSCEM was developed as a custom modification to a proprietary cost modeling program, ERC BOSCEM, created by extensive analyses of oil spill response, socioeconomic, and environmental damage cost data from historical oil spill case studies and oil spill trajectory and impact analyses (Etkin, 2004).

The inputs are the following:

1. amount of oil spilled (in gallons)
2. basic oil type category
3. primary response methodology and effectiveness
4. medium type of spill location
5. socioeconomic and cultural value of spill location
6. freshwater vulnerability category of spill location
7. habitat and wildlife sensitivity category

Using BOSCEM, to calculate the total response costs one has to multiply a per-gallon cost (based on oil type, volume and response method and effectiveness) with the spill volume and a medium modifier.
For socioeconomic damages to multiply the base per-gallon socioeconomic cost based on oil type/volume, by the appropriate socioeconomic and cultural damage cost modifier and by the spill amount and for environmental damages to multiply the base per-gallon environmental damage cost based on oil type/volume by the freshwater vulnerability modifier added to the habitat/wildlife sensitivity modifier and multiplied by 0.5, all multiplied by the spill amount.

This model was used to estimate the costs of oil spills in navigable US inland waterways (in the EPA Jurisdiction Oil Spill Database. The data set included 42,860 spills of at least 50 gallons that occurred during the years 1980 through 2002.

It can be noted that the estimated costs for all spills into EPA's jurisdiction during 1980 through 2002 are in 2002 USD million as follows:

Response Costs : 22,025
Socioeconomic Damage: 30,592
Environmental Damage: 10,588
Total: 63,205

This means that for this particular case the ratio of cleanup cost compared to environmental and socioeconomic damages is 1.87.

4.5 Nature Willingness Preservation Index

Friis-Hansen and Ditlevsen (2003) presented an index (Nature Willingness Preservation Index - NWPI) similar to the Life Quality Index that could measure the quality of the environment. As is known, the Implied Cost of Averting a Fatality (ICAF) is a commonly accepted risk evaluation criterion that has been used in quite all Formal Safety Assessments that have been submitted to the IMO. Therefore, extracting an "Implied Cost of Averting a Tonne" using the Friis-Hansen and Ditlevsen approach seems interesting. The philosophical basis for the willingness concept is that Nature has value because it is the necessary frame for human life and that Nature from the human point of view has no value without human life. It is therefore assumed that the value of a nice and clean environment increases proportional to the time for the human to enjoy a clean Nature.

It is assumed that a person who lives at location x is experiencing a pollution event at location y and is willing to spend some fraction per time unit of the reduced Gross Domestic Product I(x, y)g to avoid residual pollution after incomplete cleanup. The dimensionless reduction factor (influence factor) I(x, y) is a measure of concern that in general decreases with the distance between the two locations x and y. The factor is defined such that $I(x, x)\equiv 1$ and $I(x, y)<1$ for $x \neq y$. To decide about over how long time and how big a fraction of I(x, y)g the person is willing to spend, a time measure enters the formula by the definition of the quality of Nature that is defined as the ration $q=t/l$, where *t* the expected time in a life time to enjoy Nature without perception of pollution and *l* is the expected life time at birth.

The Nature Preservation Willingness Index (W) is defined as follows:
$W(x,y)=I(x,y)\cdot g\cdot q$ (9)

where:
I(x,y) is the dimensionless reduction factor,
g the Gross Domestic Product of the area
q is the ration $q=t/l$, where *t* the expected time in a life time to enjoy Nature without perception of pollution and *l* is the expected life time at birth.

The paper does not explicitly provide a formula to calculate an implied Cost of Averting Nature Damage or something similar but it gives a cost effectiveness criterion which is out of the scope of this paper to present. However, it is worth mentioning that according to their approach the socially justified monetary amount (μP) for the society to spend to prevent a pollution event uniformly extended over a domain Ω with a population density p(x) and gross domestic product g(x) is:

$$\mu_p = \int_{all\,x} p(x)g(x)\Delta q(x)l\left[1-\left(1+\frac{\Delta q(x)}{q(x)}\right)^{-1}\right] \frac{1-\exp\left[-\gamma(x)\Delta q(x)l\right]}{\gamma(x)\Delta q(x)l} I(x,y_0)dx \quad (10)$$

where y_0 is the point in Ω closest to x and γ is the interest rate.

As stated, this formula is written in a general form to illustrate that it can be applied to polluted domains of any size, not to mention that the same formula can be used for air pollution as well.

5. The CATS criterion

We now come back to the issue of how such environmental criteria can be used within FSA. A major topic in Annex 3 of doc. MEPC 55/18 and also in a report by EU research project SAFEDOR (Skjong et al, 2005; Vanem et al, 2007a) was the definition and analysis of risk evaluation criteria for accidental releases to the environment, and specifically for releases of oil. To that effect, the criterion of CATS (for "Cost to Avert one Tonne of Spilled oil") was defined as an environmental criterion equivalent to CAF, "Cost to Avert a Fatality". 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 is below a specified threshold, otherwise that particular RCO should not be recommended.

$$CATS = \frac{\Delta C}{\Delta R} \quad (11)$$

where
ΔC is the cost per ship of the RCO under consideration.
ΔR is the risk reduction per ship, in terms of the number of tonnes of oil averted, implied by the RCO.

In the SAFEDOR report (Skjong at al,2005), a threshold of USD60,000 per tonne of spilled oil was postulated for CATS, based on a series of modelling and other assumptions.

5.1 The CATS Approach

Vanem et al (2007a, 2007b) adjusted (in accordance with the changes in US Consumer Price Index) to 2006 dollars the regional average cleanup costs presented by Etkin (2000). These costs were weighted according to oil tanker traffic density distributions derived from the AMVER data for 2000-2001 (Endresen et al, 2004) and arrived at a world average cleanup cost of 16,000USD per tonne (see Table 2 below) . Finally, taking into account the work of Jean-Hansen (2003), McCay et al (2004) and Etkin (2004) they concluded that a ratio of 1.5 should be assumed for socioeconomic and environmental costs as compared to cleanup cost. Thus, the total oil spill cost is 2.5 times the cost of cleanup, which means 40,000 USD per tonne of oil spilled.

Table 2: Average Cleanup Costs [Vanem et al. 2007a]

Region	USD/tonne	Traffic share (%)
Middle East	1,300	7
South America	3,800	18
Africa	3,900	18
Oceania	6,900	2
Europe	13,100	11
North America	24,000	19
Asia	33,300	24
Weighted average	*15,900*	*100*

The implementation criterion that was proposed is the one presented by DMA and RDANH (2002) according to which the following fundamental approach is valid for measures implemented on ships:

Cost of averting a spill < F × Cost of an occurred spill

It was suggested that risk reduction measures are to be implemented if the costs of averting a spill are less than the costs of an occurred spill multiplied by F, where F is an "assurance parameter" postulated to be between 1 and 3 (1<F<3). According to the above authors, this parameter, reflects the fact that spending resources on preventing oil spills is preferable to spending the same resources in the aftermath of a spill and recommended that a factor of 1.5 is a good one to be used in a global criterion.

To sum up, according to SAFEDOR the average global cleanup cost is 16,000USD per tonne, plus 24,000 USD per tonne to cover the socioeconomics and environmental costs, giving a total of 40,000 USD per tonne of oil spilled. Then, applying the 1.5 assurance factor they arrive at a CATS threshold value of 60,000 US dollars per tonne.

5.2 Discussion

The authors of this paper were probably the first to question the SAFEDOR approach, both on the use of any single dollar per tonne figure and on the 60,000 dollar threshold (see for example Kontovas and Psaraftis (2006)). In fact, various spill cost data over the years suggested the following average cleanup costs worldwide (USD/tonne, 1999 dollars): 6.09 (Mozambique), 438.68 (Spain), 3,082.80 (UK), 25,614 (USA) and even the extreme value of 76,589 for the region of Malaysia (Etkin, 2000). The EXXON VALDEZ 37,000-tonne oil spill had a cleanup cost of 107,000 USD/tonne (2007 dollars), whereas the cleanup cost of the BRAER 85,000-tonne oil spill was as low as 6 USD/tonne. In addition, there is ample reference in the literature (see for instance Etkin (1999), among others, and even in Annex 3 of MEPC 55/18 itself and Vanem et al (2007a, 2007b)) that the cost of oil spills on a dollar per tonne basis depends on a variety of parameters and has a broad variance. The main thrust of Greece's position in doc. MEPC 56/18/1, pointing out the deficiencies of basing cost calculations on spill volume, was by and large supported by various arguments by the United States, the International Association of Independent Tanker Owners (Intertanko), the United Kingdom, and to some extent by ITOPF (see the report of the correspondence group as presented in MEPC 57/17).

We also note that an implicit assumption in the weighting scheme of Table 2 is that regional oil traffic share (however that is defined) is an appropriate weight with which to multiply regional cleanup cost. The direct way to compute global average cleanup cost would be to divide global total cleanup cost by total tonnes spilled globally, that is, divide the sum of the products of the average cleanup cost in each region times the volume of oil spilled in that region by the sum of the tonnes of oil spilled regionally. Using oil traffic share in each region as the weight in Table 2 implicitly assumes that the total volume of oil spilled in a region is proportional to the total oil traffic through that region. However, this assumption may not be true, as certain regions may spill more than their traffic share, and others less. This is a product of different environmental conditions, different regulatory regimes, perhaps different technologies (ships, traffic control schemes, etc), or just the statistical behavior of oil spills, given that most of the oil is spilled in a handful of very large spills. For instance ,we would speculate that oil spill volume in North America is probably lower than that in Africa for the same level of oil traffic. In fact, the poor statistical correlation between total volume of oil spilled in a region and regional oil traffic has been documented long time ago, among others, in Devanney and Stewart (1974), who argued that finding an appropriate "exposure variable" for the distributions of the number and volume of spills is certainly a non-trivial subject. Computing global average cleanup cost by the direct way would change the weighted average of Table 2 (and in our opinion downwards).

But even if a single global cleanup average value could be commonly accepted, the ratio of 1.5 that is assumed to account for socioeconomics and environmental costs as compared to cleanup costs seems unsubstantiated. And, finally, if an 'assurance parameter' F (different from 1) is introduced, its appropriate value should only be ascertained after a quantitative assessment of society's willingness to pay to avert oil pollution. By contrast, the value of F in the CATS approach was inferred 'in reverse', that is , chosen so as to certify that previous legislative action (in this case, OPA 90) to prevent pollution had been correct. Note that even Vanem et al (2007) state that "reservations should be made regarding the exact values that are suggested "(referring to the 40,000 USD per tonne figure) and that "when new and updated cost statistics become available the criteria should be modified accordingly".

We also note that the CAF criterion, as currently applied in FSA, uses no F factor, or implicitly assumes F = 1. But one could make a similar (or an even stronger) argument with the one used for CATS, that one would be willing to pay a cost higher than the estimated economic value of human life to save a fatality. The question why one should use the F factor for the environment whereas it is not used for human life is one that needs to be answered.

Leaving aside the issue that F, if used, should be determined by society or the maritime policy-makers and not by FSA analysts, it comes as no surprise that neither the postulated upper bound of F (3), or its lower bound (1) are necessarily valid. For instance, how can one be sure, beyond any reasonable doubt, that F is absolutely below 3? Society (or maritime policy-makers) may conceivably decide to spend 4 times as much upfront in the form of capital or other costs, so as to avert a given expected spill cost. In Psaraftis et al (1986), a weighting factor as high as 15 between damage costs and system costs was used to investigate strategic spill response alternatives, but no attempt to estimate what this weight might be was made.

That F should above 1 beyond any reasonable doubt is also debatable. Society may very well prefer to pay whenever oil spills occur, instead of paying an amount equal to the expected cost of these spills upfront. Also, and as those stakeholders who will bear the burden of cleanup and environmental costs are not the same who will pay for measures to prevent oil spills, the whole issue of the F factor is much more difficult than it appears in the first place.

Last but not least, the threshold of 60,000 USD/tonne may skew the cost-benefit balance in unexpected ways. Such a threshold might divert the limited financial resources that are available, toward those RCOs that would mainly limit the outflow of oil, instead of other RCOs that would mainly limit fatalities.

The authors of this paper are not the only ones who have raised concerns on the CATS approach. The reader is referred to the MEPC Correspondence Group reports (docs. MEPC 57/17 and MEPC 58/17) for a sample of other reactions. Yet, and even though this issue is currently open and serious concerns have been raised, a full-fledged FSA study on crude oil tankers using the CATS threshold of 60,000 USD/tonne was recently completed by the SAFEDOR project and submitted to the IMO by Denmark (docs MEPC 58/17/2 and MEPC 58/INF.2), for discussion at MEPC 58. The study recommends, among other things, increased side tank widths and double bottom heights on double-hulled tankers as cost-effective RCOs. Due to time and space limitations, we shall not comment on this FSA study in this paper, except note that neither the CATS criterion not the 60,000 threshold are part of the official IMO FSA guidelines. Plus, the importance of using a proper threshold value is paramount, as some RCOs that may be found cost-effective under a high USD/tonne threshold would actually be non-cost effective if the threshold is significantly lower.

6. Psaraftis's Framework

Psaraftis (2008) presented a general framework to incorporating Environmental Risk Evaluation Criteria for the case of oil pollution within IMO's Guidelines for Formal Safety Assessment. A version of this paper was presented for the first time to the MEPC Correspondence Group and has been submitted to MEPC 58 (in the Annex of the CG report: doc. MEPC 58/17).

The approach assumes two scenarios: (a) the status quo, and (b) a scenario in which a specific RCO is applied to waterborne transport on a global basis. The purpose of this RCO is to reduce the risk of oil pollution, and this can be done by either reducing the probability of oil pollution or mitigating its consequences, or both.

Define E(TOT) as the expected annual total cost of oil spill worldwide of the status quo. To reduce this cost, a specific risk control option (RCO) with a total cost of ΔK (which is a function of what the RCO is and how it is applied) is introduced. Effects of the RCO may generally include the following:

1) The spill frequency may change because of it (presumably it will be reduced).
2) The probability distribution of the spill volume may change (presumably less oil is likely to be spilled because of the RCO, and the expected spill volume will be reduced).

So the new situation, with the specific RCO under consideration implemented, and for the specific way that this is carried out, will achieve a different (presumably lower) expected annual total cost of all spills worldwide, $E_{RCO}(TOT)$

With the above in mind, once the E(TOT) and $E_{RCO}(TOT)$ are known, the expected cost differential can be calculated as follows:

$$\Delta E(TOT) = E(TOT) - E_{RCO}(TOT) \qquad (12)$$

For use in the Cost-Benefit Assessment (Step 4 of the FSA) the following can be said :

- The specific RCO under consideration is cost-effective globally if its total cost $\Delta K < \Delta E(TOT)$, otherwise it is not.
- Among alternative RCOs that pass this criterion, the one that achieves the highest positive difference $\{\Delta E(TOT)-\Delta K\}$ is preferable.

Note that the criterion refers to the RCO that achieves a maximum positive difference $\Delta E(TOT)-\Delta K$, *not* the one that maximizes the ratio of $\Delta E(TOT)/\Delta K$. As a general rule, one should exercise caution on ratio tests, since they ignore scale.

What is interesting with this framework is that it is possible to combine fatality and environmental criteria. In this case:

- The specific RCO under consideration is cost-effective globally if its total cost ΔK < ΔE(TOT)+VHL*ΔR (in the case one uses the Gross CAF) and ΔK < ΔE(TOT)+VHL*ΔR+ ΔB (for Net CAF)

- Among alternative RCOs that pass this test, choose the one that achieves the highest positive difference {ΔE(TOT) +VHL*ΔR – ΔK} or {ΔE(TOT) +VHL*ΔR+ ΔB –ΔK} accordingly.

where

ΔR is the expect reduction of fatalities due to the RCO (on an annual basis), ΔB accounts for expected benefits due to the RCO (environmental-wise and fatality-wise) and VHL is an estimate of the statistical value of human life (the value currently used in FSA studies is the ICAF which is equal to 3 million USD per person).

This approach can also be extended to cover environmental criteria other than oil pollution.

7. Japan's IOPCF Approach

Last but not least, a recent alternative approach to compute oil spill costs is illustrated by the work of Yamada and Kaneko to the Correspondence Group on Environmental Risk Evaluation Criteria and also submitted officially by Japan to MEPC 58 (doc. MEPC 58/17/1).

Regression analyses were carried out using historical data of 101 oil spills that happened between 1979 and 2005 which were reported to the International Oil Pollution Compensation Funds- IOPCF (2006). A non-linear regression formula between the cost of oil spills and the weight of oil spilled was estimated, and was compared with the formula obtained by using the original value of CATS.

The linear regression formula in log-log axes was transformed into a non-linear curve in normal axes and arrived at the following equation:

$$C=35{,}951 \cdot W^{0.68} \quad (13)$$

where C is the total cost of an oil spill and W the weight of the oil spilled.

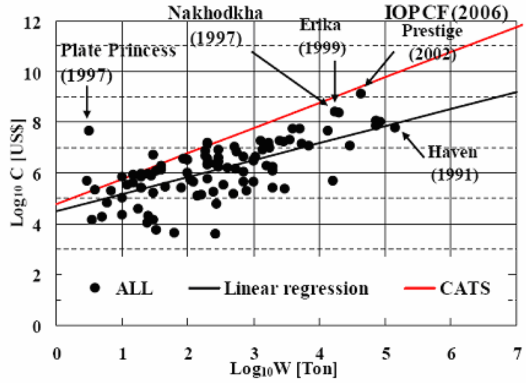

Fig.2 : Log-Log relation between the cost of oil spill (C) and oil spill weight (W) [MEPC 58/17/1]

7.1 Discussion

We understand that the motivation of the authors of this non-linear approach was to document the non-linearity of oil spill costs and at the same time present an alternative approach to CATS. To that effect, they pointed out that oil spill weight is one of the most influencing factors on the cost of oil spills, in addition to spill location and oil type.

.

It is important to point out that costs that IOPCF reports to the public are not "real" oil spill costs. They refer to the amount of money that was paid for compensation to 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.

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. 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 IOPC Fund, "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." We further note that admissible claims cannot be paid in full, especially in the case of large spills, since the total compensation paid is limited by the 1992 Civil Liability Convention (CLC) and the 1992 Fund to a maximum of 203 million Special Drawing Units(SDR), this is approximately US$327 million (as at April 2008). For example, in the case of PRESTIGE totally 172 million Euros were paid from the 1992 Fund and CLC (IOPCF, 2005) which is only 2% of the total long term oil spill costs (Liu and Wirtz, 2006). To be more accurate, limits depend on the gross tonnage of the ship- more information can be found in the IOPCF(2005).

It is also worth to note that the United States as well as China (not including Hong Kong) are not part of the IOPCF. Therefore, spills like the EXXON VALDEZ are not included in the analysis. Furthermore, as of July 2003, only 21 States are part of the Supplementary Fund Protocol which increased the maximum payable compensation to approximately USD 1,210 million (based on the conversion rate of the SDR to USD in April 2008).

Taking into consideration all the above, one might argue that IOPCF data may 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 anyone. Plus, it is clear that this analysis can be amended with additional data, to the extent such data become available. We also note that a similar approach of estimating oil spill costs by using IOPCF data can be found also in Grey (1999) and Friis-Hansen and Ditlevsen (2003).

This approach also exhibits some other interesting features. The CATS marginal cost value obtained by using Japan's non-linear relationship can be obtained by differentiating Eq. 13:

$$CATS_{non\text{-}linear} = dC/dW = 24{,}591 \cdot W^{-0.32} \qquad (14)$$

It can be seen that for anything but very small values of W, $CATS_{non\text{-}linear}$ is always less than 60,000, and most of the time much less. In fact, according to Eq. 14, for a hypothetical spill of only one tonne, the equivalent cost to avert one tonne of oil spilled ($CATS_{non\text{-}linear}$) is USD 24,591, whereas, for a spill of 2,000 tonnes the CATS value is just USD 2,160, and for a spill of 20,000 tonnes it is USD 1,034. According to Japan's study, these marginal cost values are consistent with the results of Etkin (2000). They are also in line with averages used by Psaraftis et al (1986) and in any event are significantly lower in comparison to the constant value of USD 60,000/tonne proposed by SAFEDOR.

Whatever the reason (assurance factor F, higher estimations of average cleanup-costs in comparison to using the IOPCF compensation data, or other), and in spite of its various limitations, our opinion is that the Japanese study's oil spill costs seem to be more realistic than the ones produced by the CATS approach. Therefore, it would be unwise to rush to adopt the 60,000 threshold value and use it for IMO regulatory or other policy formulation, before a discussion of the alternative approaches takes place.

8. Conclusions

We have presented an analysis of what we think are the most important issues as regards possible approaches to incorporating environmental risk evaluation criteria within IMO's guidelines for Formal Safety Assessment (FSA). We focused on methods that can be used to arrive at a commonly accepted threshold to evaluate the cost-effectiveness of Risk Control Options (RCOs) that will avert an oil spill or mitigate its consequences. To that effect, prior research on oil spill damage cost assessment was placed within context, and the pros and cons of various alternative approaches were presented. This work was also viewed within the framework of recent IMO developments in this area.
There is no question that this is a difficult subject, on which serious work has been done, but which certainly involves more work ahead. At the time of writing of this paper, the issue of how the general subject of environmental risk evaluation criteria in FSA would further proceed within the IMO, both for oil pollution, and, a fortiori, for other environmental consequences, is open. The relevant discussion would continue at MEPC 58 (October 2008) and most certainly beyond.

Acknowledgement

The authors are indebted to Dr. Yasuhira Yamada of Japan's National Maritime Research Institute for his comments on a previous version of the paper.

References

Carson, R.T., et al., (1992), "A Contingent Valuation Study of Lost Passive Use Values Resulting From the Exxon Valdez Oil Spill," A Report to the Attorney General of the State of Alaska.

Carson,R.T., N.E. Flores and N.F. Meade, (2001), "Contingent valuation: controversies and evidence", Environmental and Resource Economics 19, pp. 173–210

Carson, R., Mitchell, R.C., Hanemann,M., Kopp, R.J., Presser, S. ,Rund,P.A., (2003), "Contingent valuation and lost passive use: damages from the Exxon Valdez oil spill, Environmental and Resource Economics 25 (2003), pp. 257–286.

Cohen, M.A., (1986), "The Costs and Benefits of Oil Spill Prevention and Enforcement", Journal of Environmental Economics and Management, 13(2), pp. 167-188. doi:10.1016/0095-0696(86)90034-3

Devanney, J.W,. R. Stewart (1974), Bayesian Analysis of Oil Spill Statistics, Marine Technology 11, 365-382.

Diamon, P.A.and Hausman, J.A., (1994), "Contingent Valuation: Is Some Number better than No Number?", The Journal of Economic Perspectives, Vol. 8, No. 4. (Autumn, 1994), pp. 45-64

Ditlevsen O, (2004), "Life Quality Index revisited", Structural Safety 26 (2004), pp. 443–451.

Etkin, D.S. (1998),. " Financial costs of oil spills in the United States. Cutter Information Corporation, MA, USA.

Etkin, D.S.(1999), "Estimating Cleanup Costs for Oil Spills", Proceedings, International Oil Spill Conference, American Petroleum Institute, Washington, DC.

Etkin, D.S. (2000), "Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors", Arctic and Marine Oil Spill Program Technical Seminar.

Etkin, D.S. (2001), "Analysis of oil spill trends in the US and worldwide", Proceedings of the 2001 International Oil Spill Conference, 1,291–1,300. Environmental Research Consulting, USA (2001).

Etkin, D.S., (2004)," Analysis of Past Marine Oil Spill Rates and Trends for Future Contingency Planning",in Proceedings the 25th Arctic and Marine Oil Spill Program Technical Seminar, pp. 227-252.

Friis-Hansen,P., Ditlevsen,O., (2003),"Nature preservation acceptance model applied to tanker oil spill simulations",Journal of Structural Safety, Vol. 25, Issue 1,pp 1-34.

Grey, C., (1999), "The Cost of Oil Spills from Tankers: An Analysis of IOPC Fund Incidents", The International Oil Spill Conference 1999, 7-12 March 1999, Seattle, USA. ITOPF, London .

Grigalunas,T.A., Anderson,R.C., Brown, G.M., Congar,R., Meade,N.F. and P.E. Sorensen, (1986), "Estimating the Cost of Oil Spills: Lessons from the Amoco Cadiz Incident", Marine Resource Economics, pp. 239-262.

Helton, D., Penn, T.(1999)," Putting response and natural resource damage costs in perspective. In: Proceedings of the 1999 international oil spill conference, 1999.

HSE (1999), "Reducing Risks, Protecting People", Discussion document, Health & Safety Commission.

HSE (2001), "Reducing Risk, Protecting People :HSE's decision-making process", Health & Safety Commission, 2001.

IOPCF, (2003), "IOPC Funds Annual report 2002",International Oil Pollution Compensation Funds, London, UK.

IOPCF, (2006), "IOPC Funds Annual report 2005",International Oil Pollution Compensation Funds, London, UK.

IOPCF(2007), "Annual report 2006". International Oil Pollution Compensation Funds, London, UK .

Jean-Hansen V.(2003)," Skipstrafikken i området Lofoten—Barentshavet", Kystverket, Transportøkonomisk institutt, 644/2003, 2003 (in Norwegian), ISBN:82-480-0341-8.

King, D.M., (1997), "Comparing Ecosystem Services and Values", National Oceanic and Atmospheric Administration. Silver Spring, MD.

Kontovas, C.A., (2005) "Formal Safety Assessment: Critical Review and Future Role", Diploma Thesis supervised by H.N. Psaraftis, National Technical University of Athens, July 2005 (available at www.martrans.org).

Kontovas, C.A. and H.N. Psaraftis (2006a), "Assessing Environmental Risk: Is a single figure realistic as an estimate for the cost of averting one tonne of spilled oil?," Working Paper NTUA-MT-06-101, National Technical University of Athens, February (available at www.martrans.org).

Kontovas, C.A., and H.N. Psaraftis (2006b), "Formal Safety Assessment: A Critical Review and Ways to Strengthen it and Make it More Transparent", working paper NTUA-MT-06-102c, National Technical University of Athens, November (available at www.martrans.org). A version of this paper was submitted by Greece to MSC 82 (MSC 82/INF.3).

Kontovas, C. A., H.N. Psaraftis, and P. Zachariadis (2007a), "The Two C's of the Risk Based Approach to Goal-Based Standards: Challenges and Caveats," International Symposium on Maritime Safety, Security and Environmental Protection (SSE07), Athens, Greece, September.

Kontovas, C. A., H.N. Psaraftis, and P. Zachariadis, (2007b), "Improvements in FSA Necessary for Risk-Based GBS," PRADS 2007 Conference, Houston, USA, October.

Liu,X.,Wirtz, K.W., (2006), "Total oil spill costs and compensations, Maritime Policy and Management 33 (2006), p. 469-60.

Loureiro, M. L. et al, (2007) "Estimating the Non-Market Environmental Damages caused by the Prestige Oil Spill", IDEGA-Universidade de Santiago de Compostela, working paper.

McCay, D.F., Rowe, J.J. ,Whittier, N. , Sankaranarayanan, S. and Etkin, D.S., (2004), "Estimation of potential impacts and natural resource damages of oil", Journal of Hazardous Materials 107 (2004), pp. 11–25.

Nathwani J.S., Lind N.C., Pandey M.D.,(1997), "Affordable safety by choice: the life quality method", Institute for Risk Research, University of Waterloo; Ontario, Canada.

NOAA - National Oceanic and Atmospheric Administration, (1993) "Report of the NOAA Panel on Contingent Valuation", Federal Register, Vol 58, no. 10, US, 4601-4614.

NOAA -National Oceanic and Atmospheric Administration, (2000), "Habitat Equivalency Analysis: An Overview", Damage Assessment and Restoration Program, National Oceanic and Atmospheric Administration. Silver Spring, MD.

Pandey,M.D., Nathwani,J.S.,(2004), "Life quality index for the estimation of societal willingness-to-pay for safety", Structural Safety 26 (2004), pp. 181–199.

Psaraftis,H.N., G.G.Tharakan, A.Ceder, "Optimal Response to Oil Spills: The Strategic Decision Case,"_Operations Research 34, No.2, 203-217, 1986.

Psaraftis, H.N., (2008), "Environmental Risk Evaluation Criteria", WMU Journal of Maritime Affairs, October 2008 issue (in press).

Purnell, K., (1999), "Comparative Costs of Low Technology Shoreline Cleaning Methods", The International Oil Spill Conference 1999, 7-12 March, Seattle, USA.

Rackwitz, R.,(2002),"Optimization and risk

acceptability based on the Life Quality Index",Structural Safety 24 (2002), pp.297-331.
Shahriari, M., Frost,A., (2008),"Oil spill cleanup cost estimation—Developing a mathematical model for marine environment" ,Process Safety and Environmental Protection, Volume 86, Issue 3, pp 189-197
Skjong, R., E. Vanem, Ø. Endresen (2005), "Risk Evaluation Criteria" SAFEDOR-D-4.5.2-2005-10-21-DNV, October (available at www.safedor.org).
Thébaud, O., D. Bailly, J. Hay, and J.A. Pérez Agundez, (2005)," The cost of oil pollution at sea : an analysis of the process of damage valuation and compensation following oil spills", in Economic, Social and Environmental Effects of the Prestige Oil Spill de Compostella, Santiago. 2005. p. 187-219.
Vanem, E., Endresen, Ø., Skjong, R., (2007a), "Cost effectiveness criteria for marine oil spill preventive measures", Reliability Engineering and System Safety, doi:10.1016/j.ress.2007.07.008
Vanem, E., Endresen, Ø., Skjong, R.,(2007b), "CATS – Cost-effectiveness in Designing for Oil Spill Prevention", PRADS 2007 Conference, Houston, USA, October.
White, I.C, (2002), "Factors Affecting the Cost of Oil Spills", GAOCMAO Conference, Muscat, Oman, 12-14 May 2002. ITOPF, London.
White, I.C., Molloy, F. (2003), "Factors that Determine the Cost of Oil Spills", International Oil Spill Conference 2003, Vancouver, Canada, 6-11 April.
Zachariadis, P., H.N. Psaraftis, C.A. Kontovas (2007), "Risk Based Rulemaking and Design: Proceed with Caution", RINA conference on Developments in Classification and International Regulations, London, January.

Cite paper as:

Kontovas, C.A., H.N. Psaraftis, "Marine Environment Risk Assessment: A Survey on the Disutility Cost of Oil Spills," 2nd International Symposium on Ship Operations, Management and Economics, SNAME Greek Section, Athens, September 2008.