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SKEMA Consolidation Study

Evaluation of methods to estimate the consequence costs of an oil spill

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SE 3.2 Methods for assessing safety and security performance

SE3.2.1	Review of collision and grounding risk analysis methods which can utilize the historical AIS data and traffic patterns in seawaters
SE3.2.2	**Evaluation of methods to estimate the consequence costs of an oil spill**
SE3.2.3	Dynamic risk management methods – ship risk indexes

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Abstract	Description of the oil spill consequence cost evaluation process. The process includes the following estimations : – oil spill probability in accident – size of oil spill – effectiveness of oil combating operations at sea – oil spreading and width of the contaminated coast area – costs of oil combating operations at sea and shore cleanup costs – costs of environmental damage – costs of damage caused to sea-dependent means of livelihood
Key Findings / Conclusions	There is mutual understanding that the following technical factors have an essential influence on the cost of oil spills: – Type of oil, – Physical, biological and economical characteristics of the spill location, – Weather and sea conditions, – Amount spilled and rate of spillage, and – Time of the year, and effectiveness of clean-up. The unit costs (costs per ton of spilled oil) depend on the size of the spill; the bigger the oil spill is the lower the unit costs are.
Study limitations	
Relevant countries	
Related Documents [title, author, description, type of relationship, PDF]	

Topics Addressed in SKEMA Subject Index	**SE1.6 Regulatory Framework for Maritime and Intermodal Transport** **SE3.3 Strategic Framework for Sustainable Transport**
Relevant Stakeholders	– Environmental authorities – Maritime administrations – Research institutes – Consulting firms – Insurance companies
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Policy implications / recommendations	
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Document PDF or URL	

Summary

The study includes description of the oil spill consequence cost evaluation process. The process includes the following estimations:

– oil spill probability in accident
– size of oil spill
– effectiveness of oil combating operations at sea
– oil spreading and width of the contaminated coast area
– costs of oil combating operations at sea and shore cleanup costs
– costs of environmental damage
– costs of damage caused to sea-dependent means of livelihood.

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Evaluation of methods to estimate the consequence costs of an oil spill

Contents

1. Objectives

The objective of this Consolidation Study is for the purposes of the cost-benefit-analysis in the FSA process to bring out the different factors having an influence on the oil spill and different methods to estimate the consequence costs the oil spill has. Due to the huge scatter in the statistical oil spill cost values it is not possible to give exact monetary values which would be generally valid. Thus the current study is rather a process description than a price catalogue.

2. Target stakeholders

- Environmental authorities
- Maritime administrations
- Research institutes
- Consulting firms

3. Glossary terms

Bunker oil: oil used by vessels as fuel oil

Cargo oil: oil carried by tankers in cargo tanks

Oil spill: An oil spill is the release of a liquid petroleum hydrocarbon into the environment due to human activity, and is a form of pollution.

HELCOM: Helsinki Commission or The Baltic Marine Environment Protection Commission is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention). HELCOM works on protection of the marine environment of the Baltic Sea.

4. Approach

The study is based on literature search and on the material collected during performed FSA projects.

5. Specific issues and topics to be addressed

5.1 Introduction

In collision and grounding accidents the possibility of oil outflow is significant. Depending on the ship type the spilled oil may be bunker or cargo oil. In addition the spilled oil may be crude oil or heavy or light distillates. The size of the oil spill depends on the ship size and structure and damage mechanics. The scatter in the reported damage costs obtained from ship accidents having oil spill is huge. Especially the evaluation of the costs of the environmental damages is difficult.

There is mutual understanding that the following technical factors have an essential influence on the cost of oil spills [1]:

- Type of oil,
- Physical, biological and economical characteristics of the spill location,
- Weather and sea conditions,
- Amount spilled and rate of spillage, and
- Time of the year, and effectiveness of clean-up.

The following estimations have to be made when calculating the consequence costs of an oil spill:

- oil spill probability in accident
- size of oil spill
- effectiveness of oil combating operations at sea
- oil spreading and width of the contaminated coast area
- costs of oil combating operations at sea and shore cleanup costs
- costs of environmental damage
- costs of damage caused to sea-dependent means of livelihood

In order to avoid duplication of costs when using different calculation methods, statistical cost values or other sources of information it has to be made certain which cost items are included in the given figures.

5.2 Probability of an oil spill in an accident

Usually the oil accident has been seen as a result of an oil tanker cargo spill. However, a bigger threat than cargo spills are oil spills from bunker tanks of all vessels. Contrary to tankers transporting heavy oil as cargo, bunker tanks are not required to have a double hull structure as protection. Still in 1995 according to the questionnaire performed by the Finnish Maritime Administration roughly 90% of merchant vessels used heavy fuel oil as bunker fuel [3].

In a detailed study performed by Safetec UK Ltd [2] the average probabilities of cargo and bunker spills in different casualty types were estimated. The results are collected in Table 1.

Table 1 Cargo and bunker spill probability [2].

Spill type	Spill probability (Spills per casualty)	
	Collisions	Groundings
Cargo spill	0.39	0.30
Bunker spill	0.128	0.12

5.3 Estimation of spill size

In case of an accident of such severity that it results in outflow of cargo, a number of cargo tanks will leak. A portion of the tank content will then escape into the sea, the amount depending on the type of damage, the vessel's loading condition, the properties of the cargo and whether the vessel is a single or double hull ship. Some of the collision and grounding risk assessment methods also estimate the amount of spilled oil based on the estimation of the structural damage of the ship, but usually the estimates of the average spill sizes are sufficient.

The average cargo spill size is estimated in a study published by HELCOM [4]. The estimate of the spill in ship to ship collisions is 1/200 of the total cargo for double hull and 1/40 of the total cargo for single hull tankers. In groundings, the estimate of the average size of the cargo spill is 1/130 of the total cargo for double bottom and 1/24 of the total cargo for single bottom tankers. The amounts are for cargoes which are lighter than water and insoluble.

The fuel oil tanks usually locate in the engine room where a double hull arrangement is not required. In the case of bunker spill, all oil is assumed to outflow from tanks penetrated in collision and 50% in grounding assuming that the bunker tanks are 98% full [5].

5.4 Effectiveness of oil combating

According to a Finnish oil combating specialist the costs of shore cleaning operations are ten times more expensive than collecting the oil at sea and hundred times more expensive than pumping the oil from the damaged vessel [6]. Many factors determine the success of oil combating operations at sea: e.g. the location of the oil spill, water depth in the spill area, season, weather conditions, number of available oil combating vessels and their collecting capability, type of oil etc. As an example is the current Finnish oil combating vessels. They are designed to collect heavy oils but their possibilities to collect light oil products at sea are limited. Fortunately, the light oil spills usually evaporate into air with time. The vessels are capable of operating in sea conditions with significant wave heights of 1 – 1,5 metres and their collecting capabilities vary between 60 – 1400 m3/24h [7]. In the Gulf of Finland, the probability of suitable conditions is 80%, in the Northern Baltic 60%.

5.5 Oil drifting

In spite of the oil combating operations, part of the spilled oil is usually drifting ashore. Based on the experimental tests in [11] the drifting speed of oil in water is about 2 – 3% of the wind speed. For the cost estimation, it is essential to get probabilistic estimates of the width of the spill and how fast the oil will reach the shore. Methods to estimate the oil drifting has been developed which take into account the statistics of the wind and current conditions in the sea area considered.

In [10], the state-of-the-art in oil spill modelling is summarized, focusing primarily on the years from 1990 to the present. All models seek to describe the key physical and chemical processes that transport and weather the oil on the shore and in the sea. Current insights into the mechanisms of these processes and the availability of algorithms for describing and predicting process rates are discussed. Advances are noted in the areas of advection, spreading, evaporation, dispersion, emulsification, and interactions with ice and shorelines. Knowledge of the relationship between oil properties, and oil weathering and fate, and the development of models for the evaluation of oil spill response strategies are summarized. Specific models are used as examples where appropriate. Future directions in these and other areas are indicated.

Seatrack Web [8] is a web-based, operational oil drift forecast system applied for the Baltic Sea. The system has been developed in co-operation by several institutes around the Baltic Sea. SMHI (Sveriges Meteorologiska och Hydrologiska Institut) in Sweden is responsible for maintaining and running Seatrack Web in its server. The Seatrack Web graphical user interface has been available for Baltic wide use since 1995.

Seatrack Web contains information from several numerical models as well as some meteorological observations. HIROMB (High Resolution Operational Model for the Baltic Sea) is the name of the hydrodynamic model component in the Seatrack Web system. HIROMB calculates daily forecasts of the Baltic Sea temperature, salinity, currents, ice situation and water levels. It receives also information of river inflows calculated with a river runoff model covering the entire Baltic drainage basin. Atmospheric forcing fields for HIROMB and drift calculation are provided from the Swedish HIRLAM atmospheric model.

In paper [9] the complex of numerical models is presented simulating the wind waves, marine circulation and oil spill dynamics in the coastal zone with very winding coastal line, many islands and inlets and steep banks. Wind, cloudiness and air temperature are given from routine weather forecasting model HIRLAM (together with high resolution models ETA and ETB). Sea currents and water temperature are calculated by 3D non-hydrostatic circulation model FRESCO (Finnish-Russian-EStonian Cooperation) together with two-equation (k-ω) turbulence model. The net current speed caused by wind waves (Stokes drift) is calculated using the narrow-directionality approximation wind wave model. Oil Spill Modelling System OSMS and backward models are applied for offline oil spill simulations using time-averaged flow, sea temperature, and eddy viscosity fields as input data. A set of OSMS models have been developed and incorporated in computer system “SPILLMOD” which can be used in risk assessment due to oil spill accidents and simulate the different strategies of oil spill countermeasures in marine environment.

5.6 Oil combating and cleanup costs

According to [12] the assumed global average per-unit cost of USD 16,000 (Table 2) for cleanup and USD 24,000 for other costs, including environmental damage and socioeconomic costs is proposed, totalling an average cost of USD 40,000/tonne.

However, the fixed cost per ton values are criticised in [18] pointing out that such figures may have important policy ramifications, particularly if adopted by the IMO or other regulatory bodies. It can be seen from Table 2 that the per unit cleanup costs vary by region being highest for Asia 33,300 USD/tonne, followed by the United States (average around 24,000 USD/tonne). The figures are in 2006 US dollars. Also in the Europe the alternation is significant, varying from around 78 to 23,100 USD (2004 values) (***Table 3***) [14]. In addition, the unit costs depend on the size of the spill; the bigger the oil spill is the lower the unit costs are [20].

Table 2 Average cleanup costs per tonne oil spilled [12].

Region	**Cost per tonne spilled (USD per tonne)**	**Share of global oil tanker traffic in region (%)**
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 global average	**15,900**	**100**

Table 3 Average per unit marine oil spill cleanup costs in various European countries [14].

	Cost for oil spill cleanup	
Country	**US$ / gallon**	**US$ / ton**
Denmark	38.04	11,180.41
Estonia	23.20	6,820.62
Finland	7.19	2,115.29
France	7.83	2,301.58
Germany	36.41	10,702.67
Greece	29.03	8,530.29
Ireland	16.35	4,807.49
Italy	22.26	6,541.19
Latvia	31.34	9,212.35
Lithuania	0.26	78.12
Netherlands	22.63	6,655.37
Norway	78.61	23,118.08
Spain	1.48	438.68
Sweden	53.22	15,642.36
UK	10.48	3,082.80
Yugoslavia	5.15	1,541.40
Average	36.75	10,807.83
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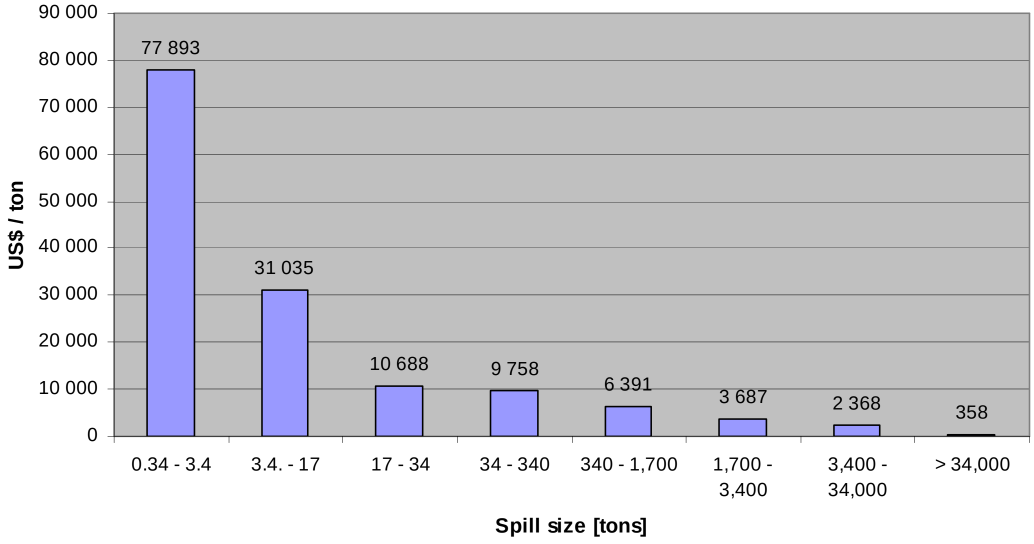

Figure 1 Per-unit marine oil spill clean-up costs by spill size for non-US Spill, in 1999 US$. [20].

As stated earlier the main technical factors influencing the cost of oil spills are:

- Type of oil,
- Physical, biological and economical characteristics of the spill location,
- Weather and sea conditions,
- Amount spilled and rate of spillage, and
- Time of the year and effectiveness of clean-up.

The interactions between factors are complex, making cost predictions based on simple parameters very unreliable. One method that takes at least some of the different factors into account is the formulae and methodology presented by Etkin [13]. The estimation is based on the following formulae:

$Cei = Cui \times Ai$ = estimated total response cost for scenario i,

$C_{ui} = C_{li} \times t_i \times o_i \times m_i \times s_i$ = response cost per unit for scenario i;

$C_{li} = r_i \times l_i \times C_n$ = cost per unit spilled for scenario i,

Symbol	Explanation
C_n	General cost per unit spilled in nation, n,
t_i	Oil type modifier factor for scenario i,
o_i	Shoreline oiling modifier factor for scenario i
m_i	Cleanup methodology modifier factor for scenario i
s_i	Spill size modifier factor for scenario i,
r_i	Regional location modifier for scenario i,
l_i	Local location modifier for scenario i,
A_i	Special spill amount for scenario i,
l_{oi}	Length of oiled shoreline

In the article tables for determining the parameters in the equation are presented taking into account the oil type, spill size, spill location and cleanup method.

5.7 Costs of damage caused by oil spill on sea-dependent means of livelihood

Generally presented spill cost prediction models usually use the spilled quantity as the basis for total cost estimation. However, in reference [17] it has been presented based on Swedish experiences that the total damage and clean up costs correlate better with the total length of the polluted shoreline than with the total spill volume. Tourism and fishery sectors generally represent the sectors suffering the highest economic losses due to the spill. In order to estimate the possible losses within the tourism sector, regional statistics on the total consumption value minus production costs was compiled from official statistics. The figures were then distributed to county or municipal level by using regional or local accommodation statistics as weighting factor. The derived figures for each county or coastal municipality were then divided by the total coast length to form a local sensitivity index. The index multiplied by a relative damage rate and by the contaminated beach length given by the scenario case, then represents the estimated socioeconomic damage cost in the tourist sector of the community. A similar approach was used to formulate a socioeconomic sensitivity index for fishery. The damage costs to tourism were determined using the formula:

$$Damage_{tourism}[€] = Coastdamage[m] \times Sensitivity_{tourism}[€/m] \times Damagerate[\%]/100$$

where:

Damagetourism	= damage costs of an oil spill to tourism in €,
Coastdamage	= the length of polluted coastline in metres,
Sensitivitytourism	= the socioeconomic sensitivity index of tourism in €/metre
Damagerate	= the pollution rate of the coastline

5.8 Model taking also the environmental damage costs into account

The EPA Basic Oil Spill Cost Estimation Model (BOSCEM) was developed to provide the US Environmental Protection Agency (EPA) Oil Program with a methodology for estimating oil spill costs, including response costs and environmental and socioeconomic damages, for actual or hypothetical spills. The model is described in [18]. The model can quantify relative damage and cost for different spill types for regulatory impact evaluation, contingency planning, and assessing the value of spill prevention and reduction measures. EPA BOSCEM incorporates spill-specific factors that influence costs – spill amount; oil type; response methodology and effectiveness; impacted medium; location-specific socioeconomic value, freshwater vulnerability, habitat/wildlife sensitivity; and location type. Including these spill-specific factors to develop cost estimates provides greater accuracy in estimating oil spill costs than universal per-gallon figures used elsewhere. The model's basic structure allows for specification of response methodologies, including dispersants and in situ burning, which may have future applications in freshwater and inland settings. Response effectiveness can also be specified, allowing for analysis of potential benefits of response improvements. The reference [18] includes the formulas and tables of parameters which can be used in cost estimation for specific cases. The method is outlined in Figure 2.

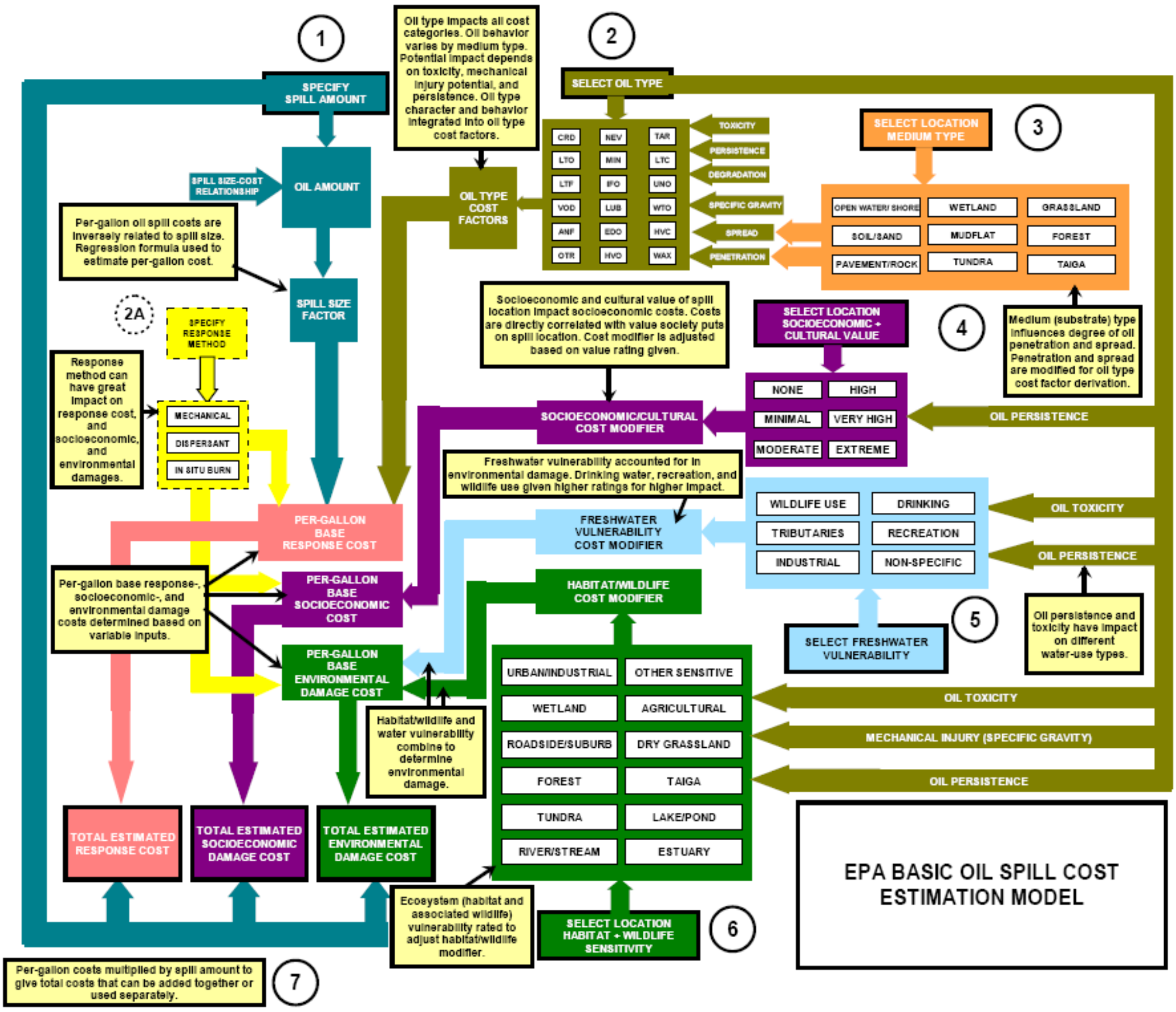

Figure 2 EPA BOSCEM basic interrelationships between oil spill base costs and modifiers. The circled numbers indicate steps of input by user [18].

5.9 Other costs

In addition to the costs mentioned above there are costs all of which are not specific to oil spills but which have to be taken into account when performing the cost-benefit analysis in a FSA study. Some of the costs are collected into

Table 4.

Table 4 Other accident costs.

Cost item	**Explanation**
Costs of the loss of cargo	Specific to oil spills. Depends on the oil type and spill size
Vessel salvage and repair costs of damaged vessel	On the average per accident (2008 price level) [16]: 1,1 M€ collisions 0,8 M€ groundings
Personal injuries (2005 price level) [6]	Loss of life 1752000 € Permanent injury 986000 € Serious temporary injury 227000 € Minor temporary injury 44300 €
Authority services	50000 € / accident [6]

References

1. White, I. C., Molloy, F. C. 2005. Factors that determine the cost of oil spills. International Oil Spill Conference IOSC 2005. p. 10470-10474. May 15-19 2005, Miami Beach, FL, USA. The International Tanker Owners Pollution Federation Limited.
2. Safetec UK. Identification of Marine Environmental High Risk Areas (MEHRAs) in the UK. Doc. No.: ST-8639-MI-1-Rev 01. December 1999.
3. Mäkelä, K. et.al. Calculation system of the emissions of the Finnish water-borne traffic (In Finnish). MEERI 1999. VTT Yhdyskuntatekniikka. Research Report 535. (MOBILE report M2T9916-7). Espoo 2000.
4. HELCOM. Study of the Risk for Accidents and the Related Environmental Hazards from the Transportation of Chemicals by Tankers in the Baltic Sea Area. Baltic Sea Environment Proceedings No. 34. Helsinki Commission 1990.
5. Michel & Winslow 1999. Cargo Ship Bunker Tanks: Designing to Mitigate Oil Spillage. SNAME Joint California Sections Meeting. 1999.
6. Ramboll Finland Oy. Costs of vessel traffic accidents. (In Finnish) Finnish Maritime Administration publication 3/2008. Helsinki 2008.

7. SYKE. Oil pollution preparedness on the open sea – Final report of the working group (in Finnish). The Finnish Environment 41/2007. The Finnish Environment Institute. Helsinki 2007.
8. http://www.ymparisto.fi/default.asp?contentid=190506&lan=EN
9. http://www.ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04625528
10. Mark Reed, , a, Øistein Johansena, Per Johan Brandvika, Per Dalinga, Alun Lewisb, Robert Fioccob, Don Mackayc and Richard Prentkid. Oil Spill Modeling towards the Close of the 20th Century: Overview of the State of the Art. Spill Science & Technology Bulletin Volume 5, Issue 1, April 1999, Pages 3-16
11. Maria Gästgifvars, Annakaisa Sarkanen, Mikael Frisk,Hannu Lauri, Kai Myrberg, Pekka Alenius, Oleg Andrejev,Ossi Mustonen, Heli Haapasaari ja Alexander Andrejev. Surface drifter experiments and drift trajectory forecast in the Gulf of Finland. (In Finnish). Report number: The Finnish Environment 720. The publication is available in the internet: http://www.ymparisto.fi/julkaisut. Helsinki
12. SAFEDOR. Risk Evaluation Criteria. SAFEDOR-D-4.5.2-2005-10-21-DNV. 2005.
13. Etkin, D. S. Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors. Arctic and Marine Oil Spill Program Technical Seminar. June 2000.
14. Etkin, D. S. Comparative methodologies for estimating on-water response costs for marine oil spills. International Oil Spill Conference IOSC 2005, p. 1210-1218. May 15-19 2005, Miami Beach, FL, USA. Environmental Research Consulting. 2005.
15. Ramboll Finland Oy et al. Costs of vessel traffic accidents (In Finnish). Finnish Maritime Administration Publication 3/2008. Helsinki 2008
16. Swedish Club 2005. Main engine damage – an update of the 1998 study. The Swedish Club Sveriges Ångfartygs Assurans Förening. The Swedish Club Highlights. September 2005.
17. SSPA 2005. Socioeconomic impacts of major oil spills. (in Swedish). SSPA report 20033294-2. August 2005.
18. Etkin, D.S. 2004. Modeling oil spill response and damage costs. Proc. 5th Biennial Freshwater Spills Symp. 2004.
19. Christos A. et al. 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. Division of Ship Design and Maritime Transport. School of Naval

Architecture and Marine Engineering. National Technical University of Athens. Athens February 2006.

20. Etkin, D. S. Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors. Arctic and Ma-rine Oil Spill Program Technical Seminar. June 2000.