Marine Pollution Bulletin 76 (2013) 61–71

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

A probabilistic model estimating oil spill clean-up costs – A case study for the Gulf of Finland

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ARTICLE INFO

Keywords:
Oil spill
Clean-up costs
The Gulf of Finland
Maritime traffic
Bayesian Belief Networks
Risk analysis

ABSTRACT

Existing models estimating oil spill costs at sea are based on data from the past, and they usually lack a systematic approach. This make them passive, and limits their ability to forecast the effect of the changes in the oil combating fleet or location of a spill on the oil spill costs.

In this paper we make an attempt towards the development of a probabilistic and systematic model estimating the costs of clean-up operations for the Gulf of Finland. For this purpose we utilize expert knowledge along with the available data and information from literature. Then, the obtained information is combined into a framework with the use of a Bayesian Belief Networks. Due to lack of data, we validate the model by comparing its results with existing models, with which we found good agreement.

We anticipate that the presented model can contribute to the cost-effective oil-combating fleet optimization for the Gulf of Finland. It can also facilitate the accident consequences estimation in the framework of formal safety assessment (FSA).

1. Introduction

As the amount of oil tankers in the Gulf of Finland increases, it raises the public's awareness of the possibility of a large-scale oil accident taking place and leaving this sensitive coastline polluted. However, the economic consequences of said accident have so far not been extensively studied for the Gulf of Finland. This is especially interesting, as the economic cost for an oil accident can be a suitable measure for Cost-Benefit analyses that are commonly used when making decisions about risk control options and future investments, see IMO (2002).

Numerous studies have been carried out on oil spill cost estimations. For the latest review in the field see Yamada (2009). However, the costs of oil spill clean-up operations, which are listed among the top cost categories associated with the total costs of an oil spill have not gained the proper credits yet, see for example Liu and Wirtz (2006, 2009). Moreover, most of the existing models are based on historical data from past oil spills obtained from the IOPCF statistics, which by definition is passive, for the detailed discussion the reader is referred to Psarros et al. (2011). Furthermore, such models are developed with the use of data about spill sizes falling in a certain range, usually with small median value for a spill, see Kontovas et al. (2010), thus applying such models for extrapolation beyond this range is very questionable.

In the scientific literature there are only two models allowing for the estimation of oil spill clean-up costs. One has been proposed by Etkin – Etkin (1999, 2000) – is deterministic but allows rather wide interpretation of the cost factors considered. Another model has been proposed by Shahriari and Frost (2008) it is also deterministic, but with no room for interpretation.

Predictions of both models hold in the context of global oil spill costs, but they have rather low geographical resolution. Therefore, it is not possible to use the models for the purpose of oil-combating fleet optimization or detailed risk management, as the local conditions are not properly reflected.

Moreover, the unique nature of the analyzed sea area of the Gulf of Finland, being classified by the IMO as a Particular Sensitive Sea Area (PSSA), makes it possible for the oil to reach the shore in a very short time with devastating consequences, see for example Lecklin et al. (2011). This means that once the oil spill at sea has occurred, it is almost impossible to prevent it from reaching the coast, see Hietala and Lampela (2007) and Aps et al. (2009). What makes the clean-up operations even more demanding is the fact that the coastline is filled with small islands; making it impossible for the clean-up vessels to navigate in some places even though the sea depth would allow it. Another factor that separates the Gulf of Finland from the larger sea areas is that, according to the HELCOM agreement, use of chemical dispersants or in situ burning are not permitted as oil combating techniques, and the clean-up is mainly performed mechanically, see HELCOM (2012). All these show the complexity of the subject and limitations of existing clean-up cost estimation models. Hence, it is desirable to go to the sources of

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0025-326X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2013.09.031

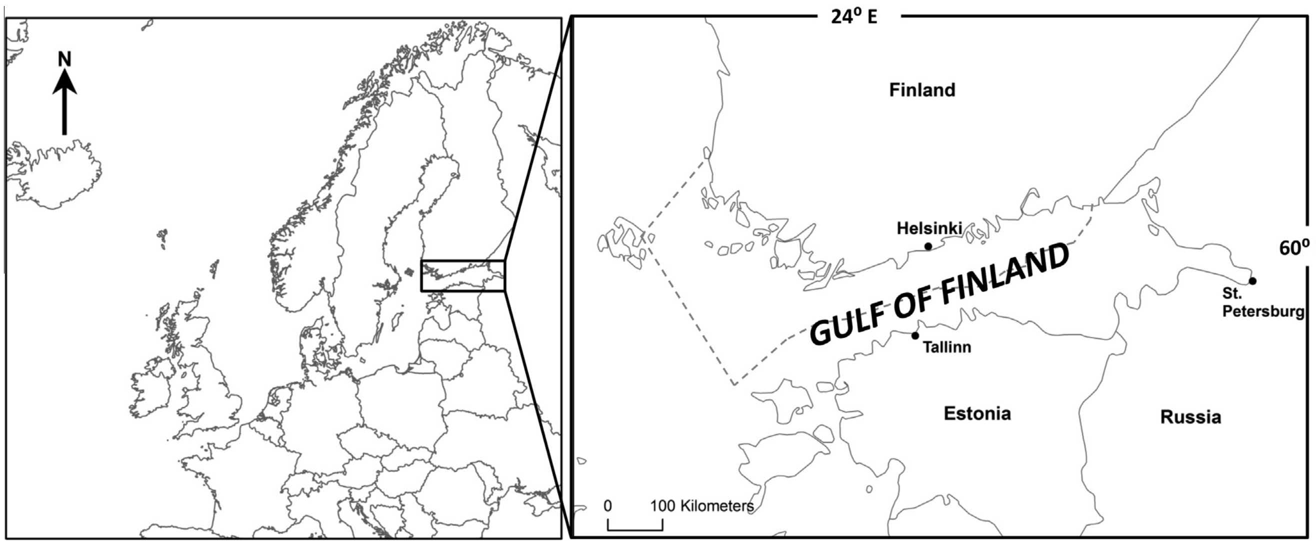

Fig. 1. The analysed sea area – the Finnish response area of the Gulf of Finland.

each of the costs, which together make the total cost of oil spill clean-up operation.

This paper introduces a probabilistic model for accidental oil spill cleanup-cost estimation for the Finnish response area of the Gulf of Finland – see Fig. 1. For this purpose, we adopt a top–down approach, where the clean-up costs are divided into offshore and onshore and then further broken down to smaller individual cost factors, thereby arriving at a model better suited for the analyzed area. To reflect the causal relationships among different factors affecting the clean-up costs in a probabilistic fashion, the Bayesian Belief Networks (BBNs) are used as a medium to propagate the available knowledge through a model. For this purpose, literature survey and expert knowledge are extensively utilized and systematically organized. In order to validate the model, the case studies are performed, whereby the outcome of the model for given scenarios is compared with the result based on the existing models provided in the literature, with which good agreement is found.

The study does not include any socioeconomic and environmental costs, nor does it include waste management procedures. It is also assumed that the oil spill in the model happens all at once, and only three seasons are considered, leaving winter out of the scope of the analysis. Moreover, we assume, that in the case of an oil spill, only the Finnish fleet capability is used, and no assistance from neighboring countries or EMSA is given.

Nevertheless, the presented model quantifies the costs of oil-spill clean-up operations, which can be further utilized for the purpose of oil-combating fleet optimization adopting the cost-benefit analysis. This in turn, can be utilized in the framework of formal safety assessment aimed at enhancing maritime safety – (Hänninen et al., 2013; Goerlandt and Kujala, 2011) – including protection of life and health, the marine environment – (Lecklin et al., 2011; McCay et al., 2004) – and property – (Montewka et al., 2012, 2010) – by using risk analysis and cost benefit assessment.

The remainder of this paper is organized as follows: Section 2 presents methods and describes the probabilistic model. Section 3 shows and discusses the results, which are obtained. Section 4 provides concluding remarks.

2. Methods

2.1. Bayesian Belief Networks

As the oil spill cleanup-cost estimation model consists of many uncertain variables, which very often are of a probabilistic nature, there is a need to adopt a proper modeling technique to handle these uncertainties. For the purpose of this study, we adopted BBNs, which are recognized tools to represent one's knowledge about a particular situation as a coherent network, see for example Darwiche (2009). Moreover, BBNs allow instantaneous reasoning under uncertainty and allows one to effectively update a model when new knowledge is available. This is an increasingly popular method for modeling uncertain and complex domains, see for example Montewka et al. (2012, 2011), Uusitalo (2007), Aguilera et al. (2011). BBNs are especially used to simulate domains containing some degree of uncertainty caused by imperfect understanding or incomplete knowledge of the state of the domain, randomness in the mechanism or a combination of these circumstances, see Bromley et al. (2005), Montewka et al. (2010), Eckle and Burgherr (2013).

BBNs can also be used as a way to facilitate decision making, see Lehikoinen et al. (2013). In some types of networks, known as influence diagrams (ID), the decisions are represented by distinctive decision nodes (DNs) that often are guided by the reaction of utility nodes (UNs) to the network. These two types of nodes (DNs, UNs) are used to automatically help determine the decision to make, which gains the highest expected utility (EU), considering the given circumstances.

For the purpose of this study, an influence diagram is used as a way to transmit our knowledge about an analyzed system, its components and their behavior. The use of an ID to develop the cost model allows us to easily determine the oil-combating actions that minimize the total cost of the clean-up operation. The presented model has been developed with the use of Hugin Researcher 7.8 modeling environment.

2.2. Data acquisition

In order to gather data for the model, both literature sources and expert opinions are utilized. Additionally, some of the conditional probabilities needed for the cost model have already been estimated in previous studies regarding the environmental impact of an oil accident in the Gulf of Finland, see for example Lehikoinen et al. (2013), Partila (2010), Juntunen (2005) and Juntunen et al. (2005).

Usually, when expert solicitation is used as a way of collecting data for BBNs, one should first decide if the expert will be asked to provide both the model structure and the probability distributions, or if expert knowledge is only to be used for the latter. In the case presented in this paper, the structure of the model is based on the