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Expert elicitation for deriving input data for probabilistic risk assessment of shipwrecks

Landquist H.[a], Norrman J.[b], Lindhe A.[b,*], Norberg T.[c], Hassellöv I.-M.[a], Lindgren J.F.[a], Rosén L.[b]

[a] Department of Mechanics and Maritime Sciences, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
[b] Department of Architecture and Civil Engineering, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
[c] Department of Mathematical Sciences, Chalmers University of Technology, University of Gothenburg, SE-412 96 Gothenburg, Sweden

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ABSTRACT

The necessity of having a process in place for adequate risk assessment of shipwrecks that pose a threat to the marine environment is today internationally acknowledged. However, retrieving the desired data for such a risk assessment can prove challenging. One means of addressing this problem is to make use of experts' knowledge and experience. The purpose of this paper is therefore to present and analyse data for risk assessment of shipwrecks derived by expert elicitation. The main outcome is the experts' estimations of (i) the generic probability of an opening in a shipwreck due to the occurrence of a number of activities and (ii) estimations of the degree to which site-specific and wreck-specific indicators affect the probability of opening. Results show that the derived information is applicable in probabilistic shipwreck risk assessment and that the VRAKA framework now contains needed information for integrating generic and site-specific information using Bayesian updating.

1. Introduction

Vast numbers of shipwrecks, approximately 8600 (> 400 gross tonnes), around the world threaten to pollute the marine environment. Many of them originate from the Second World War and have thus been deteriorating for > 70 years. It is estimated that these shipwrecks contain 2.5–20.4 million tonnes of petroleum products and constitute a major risk to the marine environment (Michel et al., 2005). There are several uncertainties associated with the potential environmental risk of these shipwrecks. Is there still oil present in the wreck and what is the volume? If so, when will the wreck begin to leak? What receptors will be affected by a potential discharge? Some of these questions can be answered through a combination of archive studies and in situ inspections. Answers to other questions will remain uncertain due to natural variability, the high cost of obtaining data or other factors. A possible way to support the management of these wrecks is an environmental risk assessment that can provide decision support in the prioritisation of risk mitigation measures.

Landquist et al. (2016) state that earlier attempts to develop risk assessment methods specific for shipwrecks failed to provide a holistic and probabilistic assessment of wrecks, implying that uncertainties are not properly managed. Landquist (2013; Landquist et al., 2014; Landquist et al., 2015; Landquist et al., 2016; Landquist et al., 2017) therefore developed VRAKA, a model adopting a Bayesian approach for risk assessment of shipwrecks, which explicitly considers uncertainties and comprises three parts: (I) estimation of the probability of discharge of hazardous substances; (II) approaches for consequence assessment of a discharge, and (III) risk evaluation where, among other things, the risk levels associated with different wrecks can be compared.

To fully embrace the risk posed by a shipwreck, it is not only the documented information that should be taken into account. Also, information based on experience and expert judgment can provide important, and sometimes necessary, input. Some information needed for a risk assessment of a wreck may be incomplete, or even non-existent for a specific case, giving rise to uncertainty that should be reflected in the calculations in VRAKA. There is e.g. uncertainties concerning the damage a specific hazardous activity can inflict and how wreck-specific and site-specific conditions affect the probability that any given activity causes an opening in a wreck. This kind of data is needed in VRAKA and has proven difficult to obtain. Furthermore, a Bayesian approach requires input data in the form of prior probabilities but also information regarding how the updating process is performed. Typically, data is not easily available in these formats.

* Corresponding author.
E-mail addresses: hanna.landquist@chalmers.se (H. Landquist), jenny.norrman@chalmers.se (J. Norrman), andreas.lindhe@chalmers.se (A. Lindhe), tommy.norberg@chalmers.se (T. Norberg), ida-maja@chalmers.se (I.-M. Hassellöv), f.lindgren@chalmers.se (J.F. Lindgren), lars.rosen@chalmers.se (L. Rosén).

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1.1. Expert elicitation

A possibility when data for some reason is difficult to acquire, is to derive that data by means of expert elicitation. Elicitation can be expressed as the process of formulating probability distributions from a person's knowledge about uncertain quantities (Garthwaite et al., 2005). In elicitation, an expert is seen as a person from whom judgements are to be elicited and who has considerable knowledge of the subject in question (O'Hagan et al., 2006). Experts should ideally possess both normative (knowledge related to expressing the uncertainty correctly) and subjective (subject knowledge and experience) expertise. Apart from the challenges associated with selecting experts (e.g. Meyer and Booker, 2001; Hora and Von Winterfeldt, 1997); there are also challenges related to the experts and heuristics (e.g. Garthwaite et al., 2005; O'Hagan et al., 2006; Tversky and Kahneman, 1974).

In order to obtain the required input data for part I of VRAKA, the probability estimation, an expert elicitation workshop was organised where > 20 experts with knowledge in relevant fields were brought together. The input data derived from the experts were the probabilities of an opening in a shipwreck occurring due to each of eight identified activities, and estimates of the influence of the status of site-specific and wreck-specific parameters, such as time since sinking, salinity and temperature of the adjacent environment, on the probability of an opening occurring. The elicitation focused on data associated with wrecks in Swedish waters.

1.2. Aim of paper

To put the expert elicitation in the actual context, the VRAKA model will be briefly presented, followed by the elicitation and thereafter the elicitation workshop results. The aim of this paper is to present (i) how the expert elicitation was designed, prepared and carried out, (ii) the results from the expert elicitation process (the raw data, i.e. derived uncertainty distributions), and (iii) an analysis of the derived data in VRAKA to investigate whether the input data provide reasonable outputs in the model. The paper also contains a discussion on the specific difficulties associated with deriving the required type of input data by means of expert elicitation. The elicited data is applied in four example cases to investigate the range of output results in VRAKA.

2. The VRAKA model

Here, a brief description of the VRAKA model and its mathematical framework is provided. The model is thoroughly described in Landquist (2013; Landquist et al., 2014; Landquist et al., 2015; Landquist et al., 2016; Landquist et al., 2017).

2.1. Overview of the VRAKA model

VRAKA is a risk assessment model for potentially polluting shipwrecks. The model includes three parts (Fig. 1): Part I – A method for estimation of the probability of discharge; Part II – Consequence assessment, an approach that combines existing methods and tools, and; Part III – Risk evaluation, performed based on input from Parts I and II.

Part I is based on a Bayesian approach and requires input data in the form of prior information as well as data for the updating procedure. The prior information needed is the generic probability of opening (a, Fig. 1), which is derived from the expert elicitation process described in this paper. The user of VRAKA provides rates or intensities of hazardous activities (b, Fig. 1) and values of the site-specific and wreck-specific indicators (if information is available) that describe the environment around the wreck and the structural status of the wreck (c, Fig. 1). Part I then provides an updated probability of discharge of hazardous substances by using information about how the different site-specific and wreck-specific indicators relate to the hazardous activities. This relationship, which is needed to make a Bayesian updating, is also derived by means of expert elicitation as reported in this paper.

Part I of the VRAKA model is based on a fault tree to structure the problem and link the considered events to enable failure probabilities to be calculated (Landquist et al., 2014; Landquist et al., 2017). What is termed the top event describes the analysed failure and basic and intermediate events describe components or events that have possibly contributed to that failure. The events are combined by means of logic gates (Bedford and Cooke, 2001). In VRAKA, two gate types are used: the AND gate, where the output occurs only if all the input events occur, and the OR gate, which occurs if any of the input events occur (Burgman, 2005). In VRAKA, the top event is defined as a discharge of hazardous substances (Fig. 2).

Discharge of hazardous substances occur if there is an opening in the wreck (Op) and there are still hazardous substances present in the wreck (Haz). Event (Haz) is estimated as the probability that the contained substances are hazardous and the probability that hazardous substance is still present in the wreck. Guiding matrices provide assistance to the user when assigning values for (Haz) (Landquist et al., 2017). An opening (Op), is assumed to potentially arise due to a number of hazardous activities, i.e. independent basic events in the fault tree, as shown in Fig. 2.

The probability of the hazardous activities causing an opening is influenced by (a) a generic probability of an opening in a wreck due to the activity, (b) the intensity of the activity during the course of a year, and (c) a number of wreck-specific and site-specific indicators that influence the state of a specific shipwreck and the probability of an opening (see notations a, b and c in Fig. 1). As stated earlier, the generic probability of an opening (a) is estimated by experts as presented in this paper and the intensity of the activity (b) is defined by the user of VRAKA. In the case of (c), the specific values of the indicators at the wreck and site are estimated by the user of VRAKA whereas the influence of the status of indicators on the probability of an opening is derived from the expert elicitation process. Both activities and indicators are identified based on the Swedish wreck population. The wreck-specific and site-specific indicators that describe the physical environment and structural status of the wreck are listed in Table 1.

Part II of VRAKA is a consequence assessment approach in three tiers depending on available resources and data. A simple tier 1 consequence estimation can be made using the method developed in Part I, where the probability of discharge is combined with the volume of hazardous substances present in the wreck. The tier 2 assessment involves consequence estimation through a sensitivity matrix, taking into account the volume of hazardous substance present, the distance to the nearest shore and the sensitivity of the shore type. The tier 3 assessment combines results from an oil spill trajectory modelling tool with sensitivity mapping of the coastline to estimate the consequences of a spill (Landquist et al., 2016).

Part III of VRAKA, the risk evaluation, can be performed by comparing the estimated risk posed by one or several wrecks to risk posed by other wrecks. It can also be applied to model the probability of discharge with changes in input information and the relative effects of mitigation measures. If, for example, *Shipping traffic* is found to have a high probability of causing an opening in the analysed wreck, Parts I and II of VRAKA can be used to model and estimate the risk reduction achieved by limiting *Shipping traffic* in the vicinity of the wreck (Landquist et al., 2016). More details of the entire model are presented in Landquist (2013); Landquist et al., 2014; Landquist et al., 2015; Landquist et al., 2016; Landquist et al., 2017) while the focus from here onwards is on the required input data to Part I.

2.2. Mathematical description of VRAKA part I

The aim of the expert elicitation workshop was to derive generic quantitative input to the (Op) part of the VRAKA fault tree. The Bayesian calculations and input variables are introduced below (Eqs. 1–4) and for a full description we refer to Landquist et al. (2014) and