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Towards an evidence-based probabilistic risk model for ship-grounding accidents

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ABSTRACT

Most of the risk models for ship-grounding accidents do not fully utilize available evidence, since it is based on accident statistics and expert opinions. The major issue with such kinds of models is their limitation in supporting the process of risk-management with respect to grounding accidents, since they do not reflect the reality to the extent required. This paper presents an evidence-based and expert-supported approach to structure a model assessing the probability of ship-grounding accidents, to make it more suitable for risk-management purposes. The approach focuses on using evidential data of ship-grounding accidents extracted from the actual accident and incident reports as well as the judgement elicited from the experts regarding the links and probabilities not supported by the reports. The developed probabilistic model gathers, in a causal fashion, the evidential contributing factors in ship-grounding accidents. The outcome of the model is the probability of a ship-grounding accident given the prior and posterior probabilities of the contributing factors. Moreover, the uncertainties associated with the elements of the model are clearly communicated to the end-user adopting a concept of strength-of-knowledge. The model can be used to suggest proper risk-control-measures to mitigate the risk. By running uncertainty and sensitivity analyses of the model, the areas that need more research for making educated decisions are defined. The model suggests the high-level critical parameters that need proper control measures are complexity of waterways, traffic situations encountered, and off-coursed ships. The critical area that calls for more investigation is the onboard presence of a sea-pilot.

1. Introduction

A model of a system is constructed to help the system operators and decision makers to understand and test the way the system and its components behave in various circumstances. This is particularly important for risk managers as they need to predict the behavior of a system against different controlling measures that are applied to mitigate the involved risks in the system before actually implementing them (IMO, 2002). In this respect, what is truly important for the risk managers as decision makers to know is "how accurately the model can mimic the system's behavior, and how trustworthy the results of the model could be". In this respect, clearly communicating the level of background knowledge (BK) (see Section 4) that is used to build a model and the uncertainty attached to that knowledge is valuable and actually recommended (IMO, 2012; Aven, 2013a; Mazaheri et al., 2014; Montewka et al., 2014b). Evidence-based risk modeling (Fig. 1) is developed to fulfill such need for more realistic models that are based on real-life scenarios and also to communicate the BK that is used to construct the models (Mazaheri et al., 2015b).

Since, unfortunately, the ship-grounding accidents are not so rare in the maritime world, for the review of accidents in the Baltic Sea there is enough evidence at hand to learn from and to use in risk modeling; see for example Kujala et al. (2009) and Sormunen et al. (2015b). Due to the seriousness of its consequences and relatively frequent occurrence, these types of accidents are attracting a lot of attention in the academia, industry, and also among maritime authorities. A number of approaches trying to describe and model ship-grounding accidents are presented in the scientific literature. For the latest review, the reader is referred to Li et al. (2012), Özbaş (2013), and Mazaheri et al. (2014). One finding from reviewing the existing models is that there exists a large variation in the level of usefulness of the models for decision making, having a risk paradigm in mind. This means that there is a need for research on models that mimic

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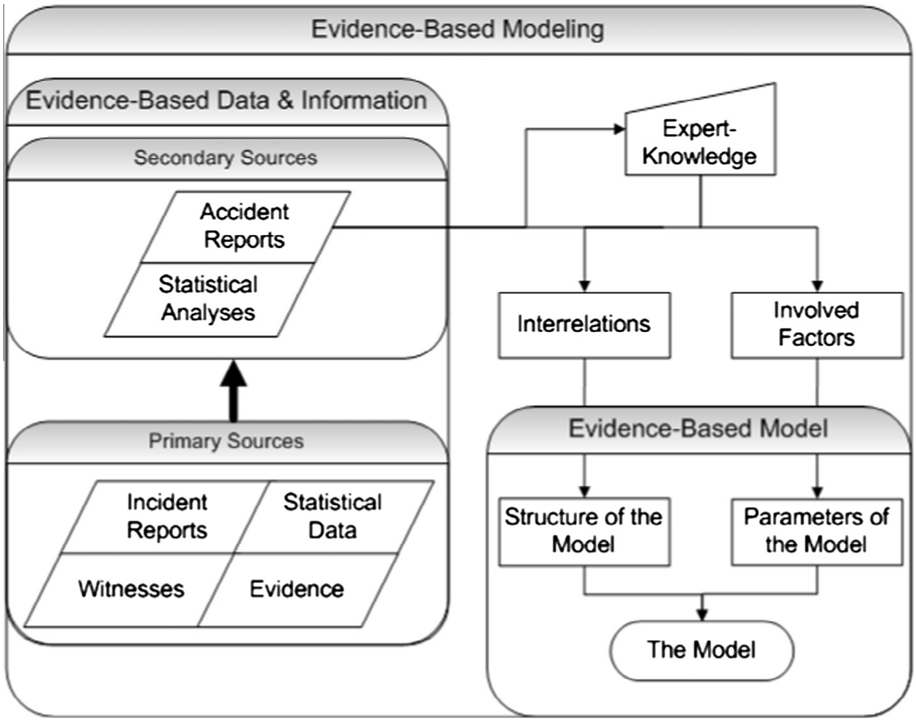

Fig. 1. Framework for evidence-based modeling (replicated from Mazaheri et al. (2015b)).

the relevant elements of a real system in such a way that interventions are possible and their effects on the outcome (i.e. the probability of a grounding of a ship) can be assessed. Second, the use of models that discover causal relations existing in the modeled system and allow two-way reasoning (i.e. from the cause to the effect and vice versa) may be beneficial. Third, the involved uncertainty in all sources of data should be clearly addressed, visualized and presented in the final results. The latter is specifically important as the issue related to the uncertainty assessment is not much discussed in the literature of maritime risk analysis (Goerlandt and Montewka, 2015b; Sormunen et al., 2015a).

As a response to these needs, an evidence-based probabilistic casual model of ship-grounding accidents is proposed here. Contrary to the models that are based purely on expert opinion and thus merely on the intuition of the developers, evidence-based models are supported by real-life scenarios; and the presented BK in such models is assumed stronger (Kristiansen, 2010, Mazaheri et al., 2014). A root cause analysis of the marine accidents in the Arctic region using real accident/incident cases by Kum and Sahin (2015), and quite the same approach for the Shenzhen estuarine waters by Chen et al. (2015) are also recent examples of the response to the need for using real scenarios to mimic the behavior of real systems in modeling. However, an important part of modeling is visualization and communication of the strength of the BK (Goerlandt and Reniers, 2016). This is essential when a risk model is used for decision making and the BK level is weak, thus the uncertainty is high. Such situation may result in risk estimates that falls in the acceptable level, whereas the associated uncertainty may be larger than the margin between risk level and acceptance boundaries, finally resulting in a situation where the risk shall not be deemed acceptable (Montewka et al., 2014b; Aven, 2015). Additionally, the strength of BK is important when assessing the effectiveness of risk control options (RCOs) and the residual risk in the system after implementing the RCOs. Thus, this issue is an additional feature also covered here of the evidence-based modeling.

The objective of this paper is twofold. First, to demonstrate how the collected evidence from the real-life scenarios as accident and incident reports can be used to construct an evidential, probabilistic causal risk model for assessing the probability and contributing factors of such an undesirable phenomena as ship grounding accident. Second, to evaluate the strength of the BK used to develop the model and to communicate it effectively to the end-users to make risk-informed decisions.

To reach the above goal, the remainder of this paper is organized as follow: the grounding model and the methodology that is used to develop it are presented in Section 2. The model validation process is explained in Section 3. A method evaluating the strength of the BK is proposed in Section 4. The model and its results are discussed in Section 5. Section 6 concludes the paper.

2. The model and its development methodology

Considering maritime transportation as a system, a well-defined approach by Haimes (2009) and Aven (2011) can be followed for defining the risk of the system. In that approach, the risk of the system can be defined as $R = \{S, L, C\}$, where S is the scenario for a mishap to occur, L is the likelihood of that specific scenario to occur, and C is the consequence of that specific scenario if it occurs. However, since our knowledge of the system is never complete, the system can never be characterized exactly (Aven and Zio, 2011). Therefore, what we will describe as the risk for a given system, at the end will be formulated merely based on our best knowledge about the system. This incompleteness, which is rooted in our lack of BK on the given system, should always be recognized and communicated. Therefore, the amount of available BK about the system should additionally be considered in the definition of risk. As the result, the description of risk perspective for the given system can yield $R \sim \{S, L, C|BK\}$ (Mazaheri et al., 2014).

Probabilistic causal modeling is known as one of the most suitable methods for modeling the risk of complex systems with high uncertainty like maritime transportation system (Goerlandt and