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A Bayesian inference and metaheuristics model for estimating maritime accidents: the case of Fernando de Noronha

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Toxic spills that arise from maritime accidents can lead to catastrophic environmental damage to animals. The numerous oil tankers that travel the planet raise the risk of potential oil spills that can affect sensitive ecosystems such as oceanic islands. To evaluate those risks, frequency estimation is an essential step. However, dealing with events with low frequency and high consequence poses a challenge, since classical statistical approaches strongly relies on data, which are scarce in this case. To overcome this shortcoming, a Bayesian population variability-based method is proposed to assess the accident rates considering accident data from various databases combined with the expertise of professionals such as academics, captains, pilots, and chief officers. As a real case application, we used this framework to estimate the frequency of accidents near Fernando de Noronha Archipelago. The results can support decision-making regarding measures to prevent accidents or reduce risks.

Keywords: Bayesian analysis, Maritime accidents, Frequency assessment, Quantitative risk assessment, Oil spills.

1. Introduction

The maritime traffic accentuates the risk of potential oil spills. Fernando de Noronha Archipelago (FNA), located in the Brazilian northeast region, is home to endemic species and it has a Conservation Unit's status to protect it. Since it constitutes a fragile ecosystem, the consequences of a spill can be even aggravated since FNA lacks infrastructure and mitigation plans for such accidents and it is located near maritime routes (Siqueira et al., 2023).

Assessing accidents such as oil spills is very challenging, due to data scarcity and to inconsistencies in the available databases (Siqueira et al., 2022). This drawback is circumvented here by using Bayesian-based methods to address the lack of specific data by complementing the information available with specific data, such as expert opinions. Therefore, this work aims to estimate the accident rates that lead to oil spills in FNA using a Bayesian–based method, the Bayesian Population Variability Analysis (BPVA) (Siqueira et al., 2022), to estimate maritime accident frequency occurrence from databases and expert opinions.

2. Methodology

We have an integrated framework to perform the BPVA (Fig, 1). First, we need to fit the data regarding the prior knowledge regarding accident rate λ to a continuous prior distribution. Next, we define the likelihood function according to parameters found via Particle Swarm Optimization to incorporate the specific data. Finally, we obtain the non-parametric posterior distributions.

We use exposure data, considering the number of events within a time, to formulate the likelihood estimation. The National Technical University of Athens Ship Design Laboratory database, the Annual Overview of Marine Casualties and Incidents 2020 and the Statistics of Marine Accidents of the Japan Transport Safety Board databases were considered (EMSA, 2020; JTSB, 2021). The expert opinion data was collected via questionnaires, answered by academics, pilots, ship authorities and other waterway professionals, assigning a weight according to the respondent category and navigation experience.

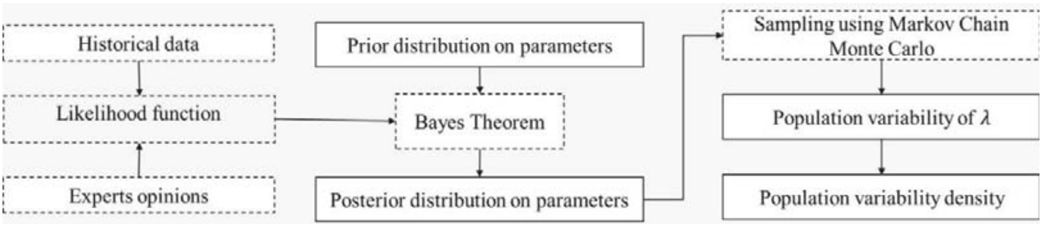

Figure 1. Methodology flowchart.

3. Results

Fig. 2 depicts the prior and posterior distribution of the accident rate. The prior (blue) is obtained via probability distribution over the model parameters, while the non-parametric posterior (green), is obtained via Markov Chain Monte Carlo methods. Note how the distribution shift to the right, moving away from the initial estimate and overestimating the rate.

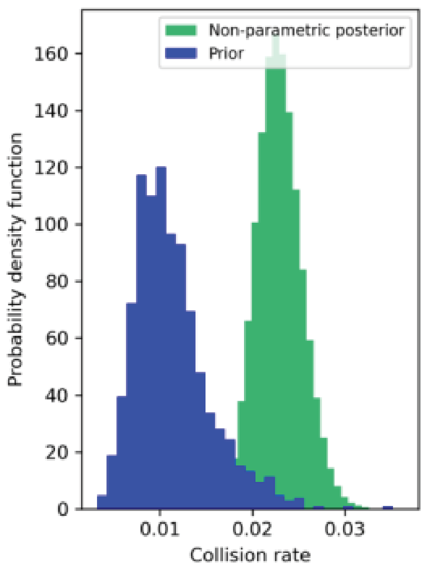

Figure 2. Population variability density for collision rate.

4.Conclusion

The main capability of our model is that it can incorporate different kinds of information in a context of data scarcity, as we did here in the oil spill context. We can also assess the underlying variability of the relevant data available to our problem (i.e., maritime accident databases). Thus, we can improve the robustness of our prior estimates. We suggest as a future step to include in our assessment the evaluation of the normalized root mean squared error, in which we simulate the accident data with these hyperparameters and compare the deviation from the real data. Moreover, the outcomes of this article can aid risk assessments, as it is a sophisticated tool to estimate the frequencies of infrequent accidents such as oil spills.

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