Real-time Bayesian risk modeling of ship pilotage: an approach for automatic and dynamic risk estimation and monitoring

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Introduction

Maritime transportation, facilitating over 80% of global trade, requires stringent risk analysis and monitoring due to its complex and safety-critical nature. Furthermore, the advancements in maritime industry such as Remote pilotage and autonomous ships, escalating system complexity and systemic interactions, necessitate innovative risk analysis approaches. Bayesian Network (BN), utilized for risk model development in the maritime domain, offers numerous advantages, such as effective management of common cause failures and easy integration of heterogeneous datasets. Despite the potential of BN, developing a risk model is resource-intensive and time-consuming. Furthermore, there is a lack of studies that aim to automate the development of real-time BN models using an incident database. Hence, automating the BN model development using incident database for real-time risk monitoring should be explored.

Materials and methods

Employing Python, we automate Bayesian Network (BN) model development and inferential risk monitoring. Initially, risk variables (losses, accidents, hazards, causal factors) are extracted from 169 incidents within a pilotage database and processed using the Pandas package. Using this data, prior risk event probabilities are calculated. Subsequently, a BN model structure, integrating extracted variables, is developed and updated with prior probabilities utilizing the Smile Engine package. Post completion, the model runs via Smile Engine, generating inferences - the posterior occurrence probabilities of risk variables. These inferences are visually represented in a Graphical User Interface, developed using Tkinter. The encompassing Python code, inclusive of data extraction, processing, BN modeling, inference, and visualization, runs at specified intervals for real-time risk monitoring, facilitated by the Windows Task Scheduler.

Results

The BN model developed using the python script resulted in a model with 33 risk variables. These variables included 2 types of losses (e.g., damage to ship or fairway object), 4 types of accidents (e.g., collision or contact), 7 types of system-level hazards (e.g., disruption of ship maneuverability), and 20 causal factors (e.g., ECDIS failure). Figure 1 shows a section of the resulting BN model for ship pilotage operation consisting of the risk variables from 169 pilotage incidents. The BN model indicates that the critical factors with higher occurrence probability are the disruption of ship maneuverability, delay in operation, and lack of requisites for operation. Concerning losses, it suggests a probability of damage to other ships or fairway objects during pilotage and damage to the own ship. Similarly, for accidents and incidents, the critical factors include collision or contact and blackout. The result shows that the developed python tool is capable to automatically develop/update the BN and provide real-time occurrence probability of risk variables for risk monitoring given new observations in the incident database.

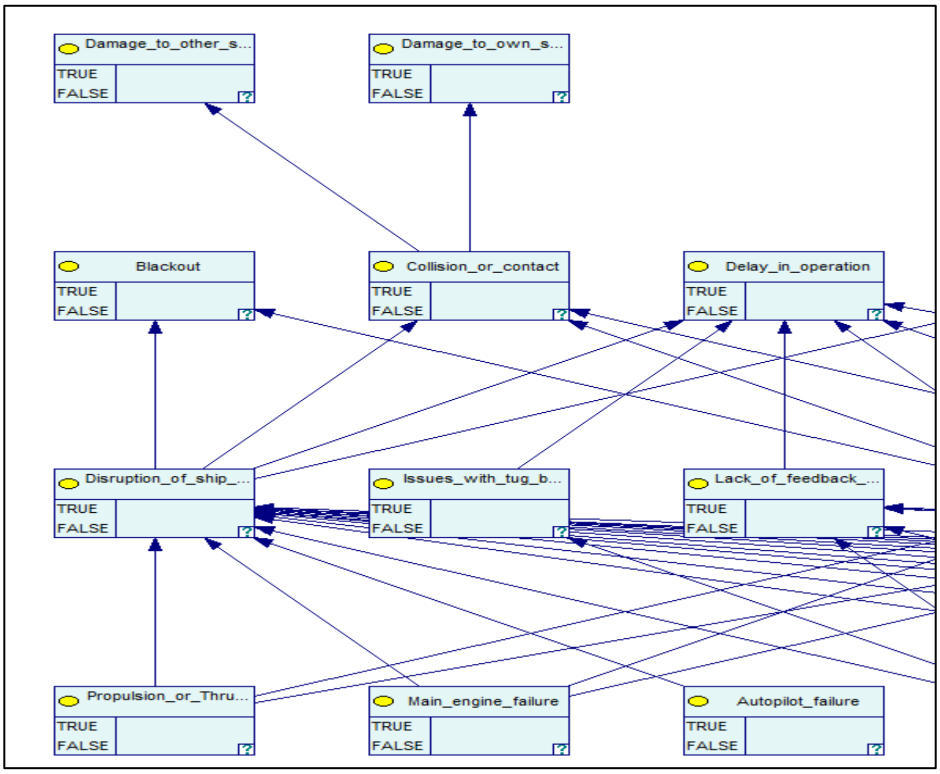

Figure 1: A section of the BN risk model for ship pilotage resulting from the python code

Implications on sustainable maritime operation

In conclusion, advances in technology have made it easier to use computers to do manual tasks, especially in managing and overseeing maritime systems and actions. This study introduces a python tool that providing real-time risk monitoring capabilities using BN. Using existing information from the incident database allows the model to provide important risk information to the pilotage decision-makers. The method was tested by making a risk monitoring tool for ship pilotage operations in Finnish waterways. The risk model should be a starting point for monitoring risks during ship pilotage and needs to be improved by adding incident data from several years. Furthermore, checking the model's usability and thoroughly evaluating its sensitivity and uncertainty are crucial next steps. Additionally, developing a general tool that is applicable to other maritime operations should be considered in the future.