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Bayesian networks for maritime traffic accident prevention: Benefits and challenges

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ABSTRACT

Bayesian networks are quantitative modeling tools whose applications to the maritime traffic safety context are becoming more popular. This paper discusses the utilization of Bayesian networks in maritime safety modeling. Based on literature and the author's own experiences, the paper studies what Bayesian networks can offer to maritime accident prevention and safety modeling and discusses a few challenges in their application to this context. It is argued that the capability of representing rather complex, not necessarily causal but uncertain relationships makes Bayesian networks an attractive modeling tool for the maritime safety and accidents. Furthermore, as the maritime accident and safety data is still rather scarce and has some quality problems, the possibility to combine data with expert knowledge and the easy way of updating the model after acquiring more evidence further enhance their feasibility. However, eliciting the probabilities from the maritime experts might be challenging and the model validation can be tricky. It is concluded that with the utilization of several data sources, Bayesian updating, dynamic modeling, and hidden nodes for latent variables, Bayesian networks are rather well-suited tools for the maritime safety management and decision-making.

1. Introduction

While Bayesian networks (BNs) have been around for a few decades, in the past few years the amount of literature on BN applications to maritime traffic safety modeling has been rapidly increasing. As an example, Fig. 1 shows the number of publications in the Scopus database[1] published between 2004 and 2013 with either "maritime traffic safety", "maritime safety", "marine traffic safety", or "ship safety" and "bayesian network", "bayesian belief network", or "bayes net" included in them. The percentages of documents containing the term "maritime traffic safety", "maritime safety", "marine traffic safety", or "ship safety" which also mention the aforementioned Bayesian network term(s) are presented in Fig. 2. Although in some of the publications, maritime safety had only been referred to and the paper had been focusing on another topic, the figures suggest that there is a growing interest in the maritime traffic BN modeling, especially in Europe and Asia (Table 1).

When considering the topics of Fig. 1 and some other published BN models, it can be summarized that they have covered various maritime traffic safety and risk matters such as the ship-ship collision or grounding occurrence (Friis-Hansen and Simonsen, 2002; Det Norske Veritas, 2003; Rambøll, 2006; Hänninen and Kujala, 2012; Hänninen et al., 2014a; Akhtar and Utne, 2014), accidents and their consequences (Antao et al., 2009; Hänninen et al., 2013; Kelangath et al., 2011; Li et al., 2014; Goerlandt and Montewka, 2014; Montewka et al., 2014; Konovessis et al., 2013; Zhang et al., 2013; Kristiansen, 2010), post-accident procedures and their costs (Eleye-Datubo et al., 2006; Montewka et al., 2013; Lehikoinen et al., 2013; Sarshar et al., 2013a; Norrington et al., 2008), human reliability analysis (Martins and Maturana, 2013) safety inspection findings (Hänninen and Kujala, 2014), safety management (Hänninen et al., 2014b) and other maritime organizational aspects (Trucco et al., 2008). The main purpose of the models has been either in characterizing the overall patterns between the model variables or performing inference on certain variables of interest.

While Bayesian networks offer several benefits over other modeling approaches, they have their limitations as well. The advantages and challenges of using BNs in the context of environmental modeling have been discussed earlier by Uusitalo (2007) and Aguilera et al. (2011). Weber et al. (2012) present some pros and cons in BN applications within dependability, risk analysis and

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[1] http://www.scopus.com/.

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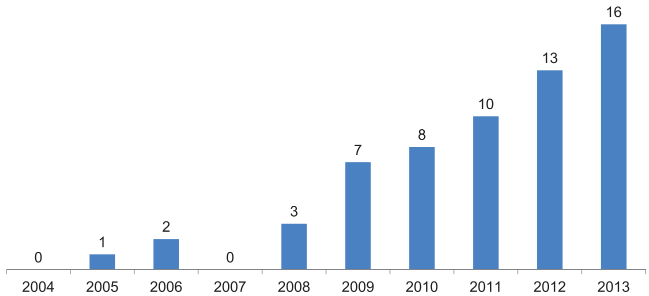

Fig. 1. The number of publications between 2004 and 2013 in Scopus given a search query `(ALL("maritime traffic safety" AND "bayesian network") OR ALL("maritime traffic safety" AND "bayesian belief network") OR ALL("maritime traffic safety" AND "bayes net") OR ALL("maritime safety" AND "bayesian network") OR ALL("maritime safety" AND "bayesian belief network") OR ALL("maritime safety" AND "bayes net") OR ALL("marine traffic safety" AND "bayesian network") OR ALL("marine traffic safety" AND "bayesian belief network") OR ALL("marine traffic safety" AND "bayes net") OR ALL("ship safety" AND "bayesian network") OR ALL("ship safety" AND "bayesian belief network") OR ALL("ship safety" AND "bayes net")).`

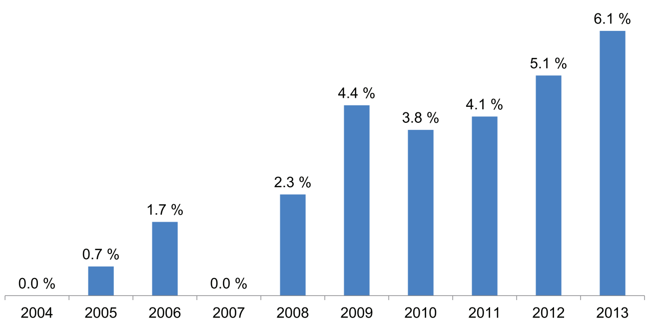

Fig. 2. The percentages of Scopus publications containing the term "maritime traffic safety", "maritime safety", "marine traffic safety", or "ship safety" which also include "bayesian network", "bayesian belief network", or "bayes net".

Table 1
The countries of Fig. 1 publications. Note that the total number is higher than the number of publications because the countries of all authors have been taken into account.

Country	No. of publications
United Kingdom	19
Finland	15
China	10
Singapore	5
Canada	3
Norway	3
South Korea	3
France	2
Hong Kong	2
Portugal	2
Brazil	1
Germany	1
Greece	1
India	1
Italy	1
Russian Federation	1
Sri Lanka	1
Turkey	1

maintenance areas. Although many of the characteristics described in those papers are universally relevant to any BN application area, the maritime traffic safety modeling features some specific matters to consider. This paper studies what BNs can offer to those matters and discusses a few challenges in the maritime traffic safety and accident prevention application. The evaluation is based on literature on BNs and their maritime traffic safety applications and the author's own experiences in constructing maritime safety BN models. The actual procedures of constructing BN models are not addressed, as many tutorials and guidebooks provide descriptions for those (e.g. Darwiche, 2009; Jensen and Nielsen, 2007; Heckerman, 1998; Daly et al., 2011; Chen and Pollino, 2012). Also, practical BN tools and software are not described in detail.

The rest of the paper is organized as follows. The next section gives a brief introduction to Bayesian networks. Section 3 focuses on applying BNs in the maritime accident prevention context; after discussing the main benefits in Section 3.1, some challenges and suggested ways to overcome them are presented in Section 3.2. Finally, Section 4 draws conclusions and provides suggestions for further studies.

2. Bayesian networks

Bayesian networks, also known as belief networks, Bayesian nets, and probabilistic directed acyclic graphs, are a technique for graphically representing a joint probability distribution of a selected set of variables (Pearl, 1988). The structure of a Bayesian network model is a directed graph, where the nodes represent the model variables and the links between the nodes the dependencies. The network is acyclic, i.e. from any node there must not be a way to loop back to the same node. Each network node consists of a finite number of mutually exclusive states. Each of these states has a probability of occurrence which depends on the current states of the variable's possible parent nodes, i.e. the variables with a direct link to the variable in question. The network structure, the graph, can be perceived as a qualitative part of the model, whereas the probability parameters add a quantitative dimension to the model (Darwiche, 2009).

Compared to other modeling techniques, BNs have been accredited for several factors such as their ability to combine data with expert knowledge, handle missing data, avoid overfitting, and present causal relationships while also providing a graphical representation which is easily understandable (e.g. Heckerman, 1998; Uusitalo, 2007). On the other hand, the relatively high number of probability parameters in already a rather simple model and the acyclicity and discrete (or discretized) variables have been stated as drawbacks of the BNs (Uusitalo, 2007; Chen and Pollino, 2012; Jensen and Nielsen, 2007). Although all of the general pros and cons apply to maritime accident prevention BN models as well, the ones which are especially relevant are discussed in the following section. Some of the addressed aspects are more related to BN properties, while some of the challenges rise from the application area, maritime traffic accidents and safety.

3. Bayesian networks in maritime accident prevention modeling

3.1. Benefits

3.1.1. Suitability for complex system modeling

The latest theoretical accident models for complex socio-technical systems state that accidents are a result of complex, at least partially unknown interactions in the system (see e.g. Dekker, 2002, 2011; Leveson, 2004; Hollnagel, 2009). Furthermore, they state that accidents cannot be described with linear cause-effect relationships, where removing one falsely component would prevent the accident occurrence (Leveson, 2004).

Bayesian networks enable presenting rather complex systems. For example, Trucco et al. (2008) included 71 nodes and 113 links in their maritime organizational effects BN, and the ship-ship collision causation model evaluated by the author in Hänninen and Kujala (2012) consisted of 100 nodes and 179 links. When