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Realising advanced risk-based port state control inspection using data-driven Bayesian networks

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ABSTRACT

In the past decades, maritime transportation not only contributes to economic prosperity, but also renders many threats to the industry, causing huge casualties and losses. As a result, various maritime safety measures have been developed, including Port State Control (PSC) inspections. In this paper, we propose a data-driven Bayesian Network (BN) based approach to analyse risk factors influencing PSC inspections, and predict the probability of vessel detention. To do so, inspection data of bulk carriers in seven major European countries from 2005 to 2008[1] in Paris MoU is collected to identify the relevant risk factors. Meanwhile, the network structure is constructed via TAN learning and subsequently validated by sensitivity analysis. The results reveal two conclusions: first, the key risk factors influencing PSC inspections include number of deficiencies, type of inspection, Recognised Organisation (RO) and vessel age. Second, the model exploits a novel way to predict the detention probabilities under different situations, which effectively help port authorities to rationalise their inspection regulations as well as allocation of the resources. Further effort will be made to conduct contrastive analysis between 'Pre-NIR' period and 'Post-NIR' period to test the impact of NIR started in 2008.

1. Introduction

The past decades witnessed an unprecedented growing rate on maritime transportation demand, which on one hand contributes to industrial prosperity, but on the other hand renders threats and risks to the maritime industry, including but not limited to ship collisions, stranding, fire, and oil spill causing large property losses, environmental pollution and casualties. For instance, the grounding of the Exxon Valdez, the capsizing of the Herald of Free Enterprise and the Estonia passenger ferry are well-known accidents in maritime transportation. These accidents attracted the attention of the world on maritime safety (Li et al., 2014a,b; Yang et al., 2013, 2014; John et al., 2016; Pristrom et al., 2016; Zhang et al., 2016) and Port State Control (PSC) inspections have been implemented as an administrative measure to reduce the occurrence of maritime accidents and ensure maritime safety (Viladrich-Grau, 2003; Li and Zheng, 2008).

PSC inspections, which render port authorities the ability to inspect vessels in their own ports, are set up in order to prevent illegal actions of ship owners and maritime accidents. The PSC officers select high-risk vessels for inspection according to the risk estimation mechanism suggested by the regional PSC organizations (Xu et al., 2007). If a vessel fails to pass the inspection, it will face a certain level of detention based on its safety status. Actually, PSC inspections are regarded as the last line of defence in coping with

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[1] In 2008, New Inspection Regime (NIR) was first introduced in Paris MoU port state control. Two sets of data, before and after 2008 are being collected for analysis of the effect of NIR. This paper, as the first phase study, analyses the detention probability before the implementation of NIR.

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substandard vessels that may cause maritime accidents. It is however well noted that although risk analysis approaches, qualitative or quantitative, have been widely used to enhance maritime safety in recent years, they have been insufficiently utilized in the PSC inspection area in the literature.

This study aims to develop a risk assessment model using Bayesian Networks (BNs) to reveal the importance degree of different risk factors influencing PSC inspection results, as well as predict the detention rate of individual vessels under different situations. In order to build the model, the bulk carrier data of seven major European countries from 2005 to 2008 is collected from Paris MoU online inspection database (www.parismou.org/inspection-search/inspection-search). Meanwhile, the risk factors related to PSC inspections are also identified from this database, including vessel flag, vessel age, Dead Weight Tonnage (DWT), recognized organization, type of inspection, port of inspection, number of deficiencies and inspection duration. The dependency among these factors and the causal relationships between them are simulated using qualitative diagram in BN while the quantitative configuration of such dependency (i.e. conditional probabilities) is obtained using a gradient descent approach based on the collected dataset (Jensen, 1999).

In this study, BN is constructed through a data-driven approach and it attempts, for the first time (up the authors best knowledge), to use BN in risk analysis and prediction on PSC. The network induced from a data-driven approach reduces the disturbance of experts' judgements on accuracy of the results. Additionally, incorporating BN to PSC inspections enables port authorities to predict the detention probability of vessels under different circumstances. The results of the study will provide important insights (1) for port authorities to ensure that optimal inspection actions are taken to improve safety at sea in a cost effective manner and (2) for ship owners to identify and address the potential deficiencies of their vessels in advance. Moreover, it is useful for both stakeholders to make decisions and check whether their actions are beneficial for inspections.

The remainder of this paper is organised as follows. Section 2 reviews the current literature relating to risk based PSC and use of BN in maritime risk assessment. Section 3 describes the methodologies and techniques applied in this study, which is followed by the risk based PSC model construction process and result analysis in Section 4. Finally, Section 5 concludes this study with reference to its contributions and implications.

2. Literature review

2.1. Risk studies on PSC inspection

Since PSC inspections play an increasingly important role in maritime safety, more and more researchers have conducted related studies in this area from both qualitative and quantitative perspectives. For example, the introduction and implementation of PSC inspection (Chiu et al., 2008), influence of PSC inspection (Cariou et al., 2008)and game analysis on optimal inspection policies (Li et al., 2015). However, use of quantitative risk approaches in PSC is limited to risk diagnosis, waiting new solutions on real time risk prediction to be explored.

Shen and Chen (2003) and Yang (2004) both proposed risk assessment PSC systems, which had been proved to have better performance than traditional PSC inspection mechanisms. Knowing that intense maritime traffic may cause significant navigational challenges in Istanbul Strait, Kara (2016) applied weighted points method to assess the risk level of each vessel experiencing the PSC inspection under Black Sea MoU. However, the weighting and scoring methods adopted in these studies are at large based on subjective expert judgements, which may cause arguments on the results.

To address this problem, Xu et al. (2007) presented a risk assessment system based on Support Vector Machine (SVM) to estimate the risk of candidate vessels according to historical data before conducting on-board inspections. Evaluations showed that the proposed system could improve the accuracy of risk assessment. Gao et al. (2008) combined SVM and K-nearest neighbour approaches to facilitate the risk assessment system capable of coping with noisy data. Consequently, this method significantly improved the accuracy of results. Although showing attractiveness, such methods still reveal problems in practical applications in terms of their capability of providing real time risk prediction (e.g. ship detention probability) in dynamic situations.

Based on 183,819 PSC inspection records, Knapp and Franses (2007a) applied binary logistic regression to measure the effect of inspections on the probability of casualties, especially for the very serious cases. Meanwhile, the model determined the magnitude of improvement areas for substandard vessels. Later in the same year (Knapp and Franses, 2007b) , they did a further econometric analysis about the influence on the detention probability of different risk factors, and the results indicated only vessel types and PSC regimes were influential elements.

2.2. Bayesian network in maritime risk analysis

Qualitative analysis was largely used to assess maritime safety. For instance, in a score method, the selected evaluation factors are scored according to subjective experience. It provides the basis of the target factor method employed by Paris MOU and Tokyo MOU. However, over the years researchers realized that it is hard to achieve the best risk assessment results by qualitative or quantitative analysis separately. Fuzzy comprehensive evaluation (Pillay and Wang, 2002; Akhtar and Utne, 2015), grey system theory evaluation (Wu and Xu, 2001), neutral network evaluation (Li et al., 2000) and some other approaches are gradually used to complement qualitative analysis in maritime safety studies. Meanwhile, risk analysis is moving away from accident investigation to the analysis of risk factors, resulting in the creation of advanced methods on risk diagnosis and prediction, such as BN (Eleye-Datubo et al., 2006; Eleye-Datubo et al., 2008; Ren et al., 2009).

Taking advance of causal inference, BN can be used to analyse the importance degree of risk factors and the relationships between