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Quantitative assessment of collision risk influence factors in the Tianjin port

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ABSTRACT

Collision between ships is one of the dominant types of accident in the approaches to Tianjin port, which accounts for 65% of all types of accidents. This paper presents a quantitative maritime risk assessment methodology by using Bayesian rules and least squares estimation method to identify the dominant factors that contribute to collision accidents. The approach relates accident data with traffic data by pairwise comparisons between the collision risks under different navigation conditions and different types of ships. The results indicate that small ships with lengths smaller than 100 m have a collision risk much higher than larger ships. The results also indicate that safety improvement of working ships and oil tankers is one of the most effective ways to reduce the overall collision risk. The collision probability of the ships without a pilot is about 9 times higher than those with a pilot. The analysis also shows that further steps should be undertaken to reduce risk during strong wind conditions to at least the same level of the normal conditions. The results obtained are useful for managers to support their decisions to control collision risk.

1. Introduction

Shipping is one of the most important modes of transportation, accounting for over 90% of international trade (Dabadgaonkar and Sen, 2015). However, the maritime transportation system (MTS) poses many risks. MTS is a large and complex system consisting of many elements related to humans, ships, the environment and management. As a result, MTS is subject to various types of hazards, many of which may result in accidents, including collisions, contacts, groundings, sinkings, and fires. Much research has been conducted on risk analysis and management in the maritime domain (Guedes Soares and Teixeira, 2001; Guedes Soares et al., 2010).

Tianjin port is one of the largest seaports in the north of China. In 2013, its throughput exceeded 500 million tons, and it has been the world's 4th largest port in terms of cargo volume. Fig. 1 presents the annual traffic volume from 2008 to 2013 in Tianjin port. It can be observed that the annual traffic measured in terms of the number of ships has remained at a high level over the years, approximately 80,000, although there was a reduction in 2012. On average, more than 200 ships enter or leave the port across the approach channel of the Tianjin port every day. However, maritime transportation in Tianjin port carries certain risks pertaining to accidents, such as collisions, groundings and contacts, which have the potential of resulting in environmental damages, economic losses as well as fatalities. Fig. 2 presents the distributions of accident types that occurred in Tianjin port during 2008–2013. It can be observed that collisions and groundings are the most common types of accidents. During the period, collisions between ships account for 65% of all accidents. Despite most of them (roughly 85%) have small consequences, some have resulted in serious consequences. For example, on June 20, 2009, a 100,000-ton Cambodian-registered general cargo ship collided with a 150,000-ton Panamanian-registered bulk carrier near the deep-water channel of Tianjin port. The collision caused serious damage to the bulk carrier, and the bow was flooded, resulting in the sinking of the ship. Another serious collision accident occurred on July 7, 2011, when an oil tanker collided with a general cargo ship outside Tianjin port. Two crew members fell off into the seawater but luckily they were rescued afterwards. There was no obvious environmental pollution. However, the accident resulted in the sinking of the general cargo ship and, consequently, in a large economic loss.

The navigational risk in Tianjin port have recently been studied by Zhang et al. (2016) using a Bayesian belief network (BBN) model. The objective was to estimate the consequences of all types of accidents and, further, to identify the indicators that have the greatest influence on consequences. The results of that study indicated that accidents are more sensitive to particular indicators such as the area where the ships are navigating, the time of day and ship length. The present paper aims at investigating the risk in more detail, focusing on the collision accidents. Despite the mechanisms of ship collisions being very complex, it is possible to identify the contributing risk factors from a statistical

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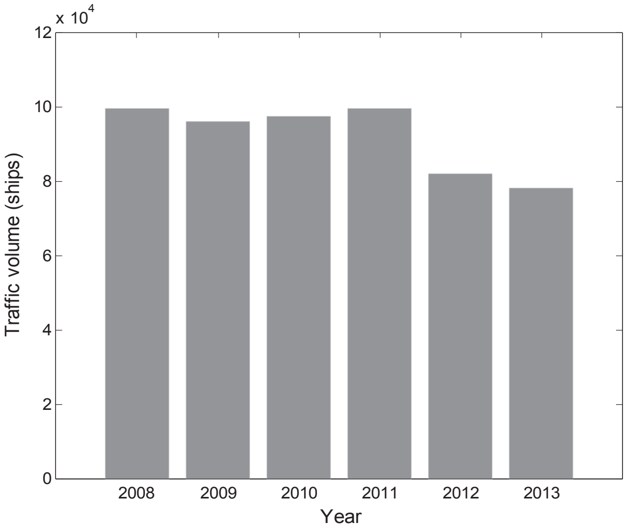

Fig. 1. Number of ships visiting Tianjin port from 2008 to 2013.

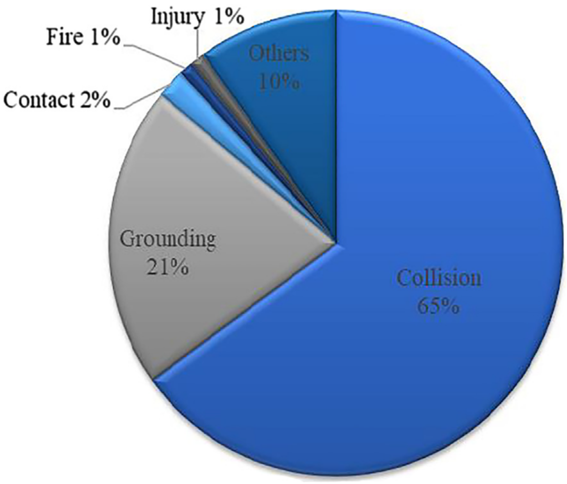

Fig. 2. Distribution of types of accidents in Tianjin port.

analysis of the historical data when enough accident data and traffic data are available. The main objective of the present paper is to analyse the importance of selected risk influence factors (RIFs) on collision accidents in the Tianjin port in a quantitative way based on historical data. Firstly, a Bayesian rule has been adopted to conduct pairwise comparisons of the collision probability under different states of each indicator. The least squares estimation method is then used to predict the regression coefficients, which can reflect the importance of the RIFs on the collision accidents.

The remainder of the paper is organized as follows. A literature review on maritime transportation risk assessment is presented in Section 2. In Section 3, the methodology that has been applied to risk assessment of Tianjin port is described in detail, including the Bayesian rules, the least squares estimation, and the uncertainty analysis. In Section 4, a quantitative assessment of risk influence factors is carried out using the proposed methodology. Finally, conclusions are presented in Section 5.

2. Literature review

The Formal Safety Assessment (FSA) methodology, proposed by the International Maritime Organization (IMO), has been recognized as a structured and systematic framework for risk assessment and control in maritime transportation-related industries. FSA is composed of five steps: hazard identification, risk assessment, development of risk control options (RCOs), cost-benefit analysis, and selection of the best RCOs (IMO, 2013). One of the objectives of FSA is to find the most cost-effective solution for risk reduction. FSA allows for the use of all possible data sources to conduct risk assessment in a qualitative or quantitative manner or a combination of the two. Although being widely utilized (e.g., Kontovas and Psaraftis, 2009; Psarros et al., 2010), some studies have shown that FSA still has some drawbacks, such as not being able to give an overall picture of risk (Montewka et al., 2014), not being able to measure the risk precisely (Merrick and Van Dorp, 2006), and its lack of reliability and validity (Goerlandt and Kujala, 2014), largely due to the use of subjective knowledge when historical data are not available (Guedes Soares and Teixeira, 2001).

To overcome such deficiencies, various novel ideas and methodologies have been proposed. These mainly include fault- and event-trees (Ronza et al., 2003; Antão and Guedes Soares, 2006), BBNs (Trucco et al., 2008; Antão et al., 2008; Yang et al., 2008; Zhang et al., 2013; Li et al., 2014), Belief Rule Base (BRB) (Zhang et al., 2014), and Markov Chain Monte Carlo (MCMC) (Faghih-Roohi et al., 2014). One common aspect of these methodologies is that they try to describe the maritime system quantitatively through the use of all possible data (Li et al., 2012). The data mainly include statistics on historical accident data (Psarros et al., 2010; Li et al., 2014), subjective data of expert knowledge (Szwed et al., 2006) and data from simulations on the maritime transportation system (Montewka et al., 2010), or the combinations of the above (Zhang et al., 2014, 2016). Although different, these data sources have good complementarity. For instance, a maritime accident is usually a rare event, and historical data usually lacks statistical features, especially for major accidents like the Sewol Disaster (Yoon and Cho, 2015). In this case, expert knowledge can be used together with historical data to conduct a more comprehensive risk analysis. As a result, Quantitative Risk Assessment (QRA) has received increased interest in maritime transportation risk assessment (Li et al., 2012; Wu et al., 2015). It is generally accepted that quantitative measures of the probability and consequences are critically significant for risk managers, particularly to identify cost-effective risk control options focusing on different aspects of safety management (Guedes Soares and Teixeira, 2001; Merrick and Van Dorp, 2006).

Typically, QRA can be divided into two types: absolute QRA and relative QRA, although they have some overlaps (Szwed et al., 2006; Li et al., 2014). “Absolute” QRA means that the purpose of the analysis is to calculate the values of the probabilities or the severities of accidents, or the combination of the two, to evaluate whether the risk is As Low As Reasonable Practical (ALARP) (Aven and Vinnem, 2005). For instance, the probability of collision is defined as the probability that a vessel is involved in a collision situation multiplied by the probability that the actions fail to avoid collision (Pedersen, 1995). The former can be calculated based on the geometric distribution of the traffic flow of ships in the waterway (Montewka et al., 2010; Goerlandt and Kujala, 2011; Silveira et al., 2013) and the indicators of ship traffic flow, such as the speed distribution, degree of acceleration or deceleration, and ship domain violations, among others (Qu et al., 2011). The latter is typically analyzed by human reliability analysis (HRA) (Bolt et al., 2010; Martins and Maturana, 2013) or by historical data on ship collisions that occurred in particular areas. By doing the above, the expected number of collisions in the waterway over a period can be calculated.

The focus of relative QRA is on the assessment of the relative importance of different factors to the accident. This is also useful to support managers when they are making decisions on measures to enhance the safety level of a maritime transportation system. In practice, relative and absolute QRAs can be utilized in analyses of different levels of detail. If sufficient data and models are not available to develop absolute QRAs, the relative QRA can be performed to find the best way to control the risks, which is also the focus of this paper.

The Analytical Hierarchy Process (AHP) is one of the most popular