Ocean Engineering 124 (2016) 141–156

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

An advanced method for detecting possible near miss ship collisions from AIS data

Weibin Zhang [a], Floris Goerlandt [b], Pentti Kujala [b], Yinhai Wang [a,*]

[a] University of Washington, Department of Civil and Environmental Engineering, Smart Transportation Applications and Research Laboratory, Seattle, WA, 98195 USA

[b] Aalto University, School of Engineering, Department of Applied Mechanics, Marine Technology, Research Group on Maritime Risk and Safety, P.O. Box 12200, Aalto, FI-00076 Finland

ARTICLE INFO

Article history:
Received 31 December 2015
Received in revised form
7 June 2016
Accepted 26 July 2016
Available online 3 August 2016

Keywords:
Near miss
Ship-ship collision
AIS data
Traffic conflict
Maritime safety

ABSTRACT

Maritime accidents have the potential to cause significant financial loss, injury, and damage to the environment. One approach to investigating maritime safety is to focus on near misses, that is, situations which did not lead to an accident but where an accident was narrowly avoided. Based on the principles of the traffic conflict technique, which ranks traffic encounters through a conflict severity hierarchy, this paper proposes a novel model for screening maritime traffic data for near miss ship-ship encounters, particularly for open sea and coastal restricted sea areas. Compared to previous methods, the proposed method has a greater specificity, leaving fewer possible near miss cases to be assessed by navigational experts in a contextualised traffic setting. This is achieved by including the effect of ship size through a ship domain, and by better accounting for the criticality of the encounter direction through the Minimum Distance To Collision concept compared to earlier proposed models. The factors included in the model and their relation are based on expert judgments and using knowledge from previous studies. Model parameters are derived from AIS data points from a reference encounter situation dataset. The developed model has been applied to traffic data from the Northern Baltic Sea. The model is subjected to a number of validity tests, the results of which suggest that the model is adequate for ranking and prioritizing encounters for further assessment in an expert judgment phase to identify near misses. Thus, it establishes a method to enable subsequent research into the validity of near miss information to make statements of maritime safety in relation to collision accidents.

1. Introduction

Marine transport is crucial to economic development around the world, but represents significant financial and safety risk. Though maritime accidents are relatively infrequent, the personal, economic, and environmental costs of accidents can be huge (Heij et al., 2011). Groundings, collisions, and fires are the most frequent maritime accident types globally (Soares and Teixeira, 2001). Specially, ship-ship collisions are one of the most frequently occurring accident types in some locations with high traffic intensities, including the Gulf of Finland and the Singapore Strait (Kujala et al., 2009; Qu et al., 2012). It is therefore of crucial importance for maritime authorities, response authorities, and other stakeholders to have effective tools for analyzing the risks associated with these accidents and for gaining insight in the safety of maritime transportation in different areas.

Many risk analysis models and methodologies have been proposed for analyzing accident risk in general (Ferreira and Couto, 2015) and maritime transportation in particular. For an overview of current research, see Li et al. (2012) and Özbaş (2013) . Additionally, Debnath and Chin (2010) and Goerlandt and Montewka (2015a) describe some recent frameworks for analyzing maritime risk.

Other work does not focus on the accidents per se, but starts from non-accident information to obtain insight in the safety of maritime transportation. Such methods consider the occurrence of certain non-accident events in the traffic system as safety performance indicators. This basic data source for such methods is the data from the Automatic Identification System (AIS), which is a system for information exchange between vessels and between vessels and shore facilities. Focusing here on ship collisions, this approach is followed by Berglund and Huttunen (2009), van Iperen (2012, 2015), Qu et al. (2011), Goerlandt et al. (2012), Wen et al.

Abbreviations: VTS, vessel traffic service; AIS, automatic identification system; TCT, traffic conflict technique; DCPA, distance to closest point of approach; TCPA, time to closest point of approach; BCR, bow crossing range; VCRO, vessel conflict ranking operator

* Corresponding author.
E-mail address: yinhai@uw.edu (Y. Wang).

http://dx.doi.org/10.1016/j.oceaneng.2016.07.059

(2015a), Zhang et al. (2015), van Westrenen and Ellerbroek (2015) and Wu et al. (2016).

The work presented in this paper is an extension and improvement on the approach presented by Zhang et al. (2015). These authors propose a model to rank the severity of an encounter between two vessels based on three factors: the distance between the two ships, their relative speed, and the difference between their headings. While this model has been found to be adequate for ranking encounters as a basis for detecting near misses, one challenge with the existing model is that it is not very specific. In other words, the model will result in rather many ship-ship encounters needing to be further manually investigated by re-contextualizing the traffic context (other maritime traffic, environmental conditions, etc.). Such expert judgments can be rather time-consuming, which may impede the practical usefulness of the model.

Considering the above, the specificity of the model proposed by Zhang et al. (2015) is improved in this paper by incorporating the vessel size in the model through accounting for a ship domain. A further improvement is the inclusion of the Minimum Distance to Collision (MDTC) concept, which allows a better distinction of the risk levels at various encounter angles.

The rest of this paper is organized as follows. Section 2 outlines the conceptual basis for analysing the safety performance of vessels in a maritime transportation environment, to give the reader an understanding of the wider context and purpose of the proposed method. Section 3 presents the mathematical method for detecting and ranking potential near miss collisions from AIS data. In Section 4, the method is applied to shipping traffic in the Northern Baltic Sea area, and model evaluation tests are performed to assess the model's performance. Sections 5 and 6 provide some discussion and concluding remarks.

2. Conceptual basis

2.1. AIS data in maritime transportation research

AIS data is increasingly applied as a valuable source of information about ship traffic in maritime traffic engineering and in research addressing the safety of maritime transportation. AIS identifies each vessel equipped with an AIS transmitter, and transmits static and quasi-static data about the vessel (call sign, IMO number, destination, cargo, etc.), as well as frequent updates about the vessel position, speed and course. Such data is stored in shore facilities, from which the maritime traffic in a certain area can be reconstructed and further studied. In recent years, AIS data quality has been improved significantly (Felski et al., 2015; Sang et al., 2015), and further improvements are also possible with proper antenna installation (Last et al., 2015).

AIS data has been adopted in diverse purposes such as studying collision avoidance manoeuvers (Mou et al., 2010), ship trajectory analysis (Xiao et al., 2015), ship speed optimization (Psaraftis and Kontovas, 2014), ship domain analysis (Hansen et al., 2013; Rawson et al., 2014; Wang and Chin, 2015), accident investigation (Wang et al., 2013), and maritime risk models (Mazaheri et al., 2015; Goerlandt and Kujala, 2014; Silveira et al., 2013; Zhang et al., 2013).

It has been identified as one research direction using AIS data to detect possible near miss collisions. Goerlandt et al. (2012) applied the elliptical ship domain proposed by Fujii and Shiobara (1971) as criterion, while van Iperen (2012, 2015) applies a combination of proximity indicators and empirical ship domains to separate near misses from normal encounters. Qu et al. (2011) use fuzzy quaternion ship domains as a basis for counting vessel conflicts in a waterway. Wu et al. (2016) apply different conflict detection mechanisms in a waterway in Texas, including the VCRO method by Zhang et al. (2015).

Zhang et al. (2015) proposes a novel model for near miss ship collisions detection based on AIS data by considering three major factors, distance, relative speed and phase. Unlike the previously mentioned methods, these authors propose an operator which ranks the encounters in terms of their conflict severity, using a continuous ordinal ranking similar to the risk analysis method presented by Debnath and Chin (2010), and Debnath et al. (2011).

2.2. Near miss collisions in the context of traffic conflict research

The detection of near miss collisions has only relatively recently become in focus in maritime transportation research, with early work by Berglund and Huttunen (2009) and a first more elaborate treatment through the nautical traffic conflict technique (NTCT) by Debnath and Chin (2010). This focus on near misses and traffic conflicts has a longer tradition in road safety research, where the traffic conflict technique (TCT) is one of the mainstays, with work by Hydén (1987), Chin and Quek (1997), Svensson (1998) laying early foundations, which have been operationalized and extended also more recently, see Laureshyn et al. (2010) and Zou et al. (2014).

Both the TCT and the NTCT start from the idea that apart from accidents, also other traffic conflicts provide indications and insight into the safety level of the transport system. Such conflicts are situations in which traffic system users encounter one another with the possibility of an accident occurrence, without this accident actually materializing. The underlying reasoning is that conflicts representing a different severity have different safety margin towards an accident occurrence. The hierarchy of different conflict severities includes undisturbed passages, conflicts of various severities, near misses, and actual accidents. This hierarchy has been visually presented as a pyramid (Hydén, 1987) or a diamond (Svensson, 1998). The most significant benefit of the TCT is that vessel conflicts of lower severity levels occur more frequently than collision accidents, so that more can be said about the safety of the transportation system in shorter time periods (Debnath and Chin, 2010). A weakness however is that the exact relation between such vessel conflicts and accident occurrences is not actually very well established yet. Work by Hänninen and Kujala (2014) suggests that there indeed is a relation between near misses (as reported by VTS centres) and accident occurrence, but more evidences and research into this link is desirable. The contribution made in this paper should not be understood to mean that sea areas with more near misses necessarily represent areas of higher collision risk. Instead, the purpose is to define a method to assist experts to judge which encounters qualify as near misses. Those cases then be further linked to relevant accident databases, and other relevant shipping information sources to investigate the relationship between near misses and accidents.

Conflict measures are necessary for the definition of TCT, which are derived from the observable system states at a given time. These states are time-dependent, which corresponds to the intuition that traffic safety dynamically varies as the transportation system evolves over space and time. The conflict measures are used to rank the severity of the vessel encounters on a qualitative ordinal scale, then more serious conflicts can be identified and these can be further connected to the overall traffic safety by ranking the different encounters (Zhang et al., 2015). In almost all traffic conflict methods in maritime traffic, the conflict measures concentrate pairwise encounters between vessels, due to the enormous complexity in accounting for the spatio-temporal relations of multiple interacting traffic users (Laureshyn et al., 2010). An exception is the work by Wen et al. (2015b), who focus on the traffic complexity by explicitly accounting for the density of ships

Please cite this article as: Zhang, W., et al., An advanced method for detecting possible near miss ship collisions from AIS data. Ocean Eng. (2016), http://dx.doi.org/10.1016/j.oceaneng.2016.07.059