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Review

Modelling of marine traffic flow complexity

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ABSTRACT

Recent increases in the number of high-speed, large-scale, and heavy-load vessels have made marine traffic more complex. Traffic situations are more difficult to manage as a result because of the rapid increase in the traffic density and the development of ship encounter situations. Here, we introduce a marine traffic complexity model to evaluate the status of traffic situation, use the complexity to investigate the degree of crowding and risk of collision, and support mariners and traffic controllers to get the traffic situation awareness. The traffic unit complexity model is constructed using pair-wise ship traffic characteristics such as the relative distance, relative speed, and intersecting trajectory. This model is extended to an area traffic complexity model through interpolation post-processing. We show that a higher complexity corresponds to more crowding and dangerous traffic in which the traffic situation should be carefully managed. Simulated data from the Shenzhen West Sea are employed to demonstrate the model and construct a map of the spatial distribution of the marine traffic complexity. The complexity model is shown to be effective in indicating different traffic situations.

Contents

1. Introduction

Situation Awareness (SA) is aware of the environmental situation by collecting and interpreting information (Van de Laar et al., 2013). Being aware of traffic situation is a prerequisite for mariners and traffic controllers to low accident probability, make informed decisions, and

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List of symbols

VC_{ij}	the basic traffic unit which is consisted of ships i and j
l_{upper}	the distance boundary of VC_{ij}
l_{lower}	the radius of a rounded ship domain in this paper
l_{middle}	the distance boundary which both ships take action to avoid a collision
den_{ij}	the complexity caused by the traffic density, also named as density complexity
ρ	a redefined density function
$\overrightarrow{P_i}$	position of ship i
$\left\|\overrightarrow{D_{ij}}\right\|$	the distance between ship i and j in VC_{ij}: $\left\|\overrightarrow{D_{ij}}\right\| = \left\|\overrightarrow{P_j} - \overrightarrow{P_i}\right\|$, (see in Fig. 3)
R_{ij}	the minimum safe distance between the two vessels in the VC_{ij}
α	a internal parameter for fitting the model to the different water areas
λ	a internal parameter for fitting the model to the different water areas
$conf_{ij}$	the complexity caused by the traffic situation, also named as the conflict complexity
θ	the track-crossing angle, also known as collision angle.
$\overrightarrow{v_{ij}}$	the relative velocity between ship i and j in VC_{ij}: $\overrightarrow{v_{ij}} = \overrightarrow{v_j} - \overrightarrow{v_i}$
$angle_{ij}$	the complexity caused by the track-crossing angle, also named as the angle complexity
$g1$	an adjustment function when $\left\|\overrightarrow{D_{ij}}\right\| \in (l_{lower}, l_{middle}]$
$g2$	an adjustment function when $\left\|\overrightarrow{D_{ij}}\right\| \in (l_{middle}, l_{upper}]$
$Conv_{ij}$	the complexity caused by the relative motion, also named as the convergence complexity
$Complexity_{ij}$	the total complexity in VC_{ij}
$C(i)$	the total complexity from ship i's view
N	the number of ships in the area
L	the length of the ship
B	the width of the ship

take appropriate actions. To get traffic situation awareness has three phases: perception of ships in the environment; comprehension of traffic situation; projection of future states of traffic situation.

As so far, various kinds of equipment/systems, such as: land- or ship-radar, Vessel Monitoring Systems (VMS) and Automatic Identification System (AIS), etc., have been engaged (Fefilatyev et al., 2012) and numerous traffic data, like: ships' location, size, type, and destination, can be collected to help the traffic controllers know about traffic. Which means it's easy for mariners and traffic controllers to get the perception of elements in that way.

However massive traffic data do not always help traffic controllers or mariners to understand the traffic situation. On the contrary, too many irrelative data may decrease the cognition of other important information. Therefore, how to draw useful massage from the massive data to describe traffic situation is becoming a hot topic. Looking into existing research, currently, there are three main methods to show traffic situation.

Traffic statistics is the most popular way to describe traffic situation. The average speed, quantity of traffic flow, traffic distribution, the types of ship and et al. are treated as the basic features of the traffic system. Some researchers focus on finding the relationship between them and traffic situation, and then exhibit the long-term traffic situation (Weng et al., 2012) (Balmata et al., 2009). Whereas, others built traffic simulation model (Goerlandt and Kujala, 2011; Goerlandt et al., 2012) based on the traffic statistics data and evaluate the marine traffic situation in the traffic simulation systems (Blokus-Roszkowska and Smolarek, 2014). These kinds of researches are usually used to evaluate the long-term traffic situation, but they cannot meet the demands to estimate the real-time traffic situation. Traffic controllers have to judge the current traffic situation on the basis of long-term ones by their experience.

Traffic flow theory has been widely used in road traffic field. Because of the similarities between road traffic and marine traffic, it is introduced to research marine traffic in recent years (Shao and Fang, 2002; Yip, 2013). In their researches, the macro traffic flow is treated as a continuum model. In road traffic field, scientists used the traffic statistics variables: flow rate, density, and speed to plot the traffic fundamental diagram which can indicate the traffic status: free flow, synchronized flow, and wide moving jam (Kerner, 2009). However, in marine traffic field, these features haven't been verified.

Recently, researchers tried to visualize the AIS trajectory and draw a traffic density map to show the traffic situation (Willems et al., 2013). In this way, mariners and traffic controllers can get a direct cognition of traffic. Whereas, traffic conflict is not considered in their research. As a consequence, the traffic situation information provided in their map is limited.

Above all, present researches rarely focus on quantitatively describing the real-time traffic situation, which is important to inform mariners and traffic controllers the comprehension of traffic situation. Hence we formulate a new method based on the research of air traffic complexity.

Over viewing the development of the air traffic complexity, it is developed to estimate traffic controllers' workload at beginning. With the research goes on, the traffic complexity is applied to describing traffic situation. The air traffic complexity researches contain three stages till now.

Initially, the density of aircraft is the only factor to indicate the traffic complexity (Hilburn, 2004), i.e. the more aircrafts in certain section, the more complex it is. It is the basic of the traffic management, especially in US and Europe, but scientists found it's not precise. Low traffic density can also lead to a seriously complex traffic situation and need to be paid more attention to Masalonis et al. (2003). To solve this issue, some researchers brought out the dynamic density (DD) to indicate the complexity. The DD is regarded as a multidimensional index that reflects the change in the complexity. It contains some measurable index extracted from traffic flow, such as: the numbers of flights, the head changing rate, the altitude changing rate and so on (Wang et al., 2013). With these indexes, Laudeman et al. (1998) constructed a linear DD model to calculate the complexity of a flight sector, and Chatterji and Sridhar (2001) later pointed out the limitations of the linear model and proposed a nonlinear method to analyse the relationship between complexity factors.

In recent decade, some researchers believe that workload and traffic situation are only related to traffic intrinsic features (like: location and motion) (Lee, 2008). They used aircrafts' location and motion as the basic index to build complexity model. Delahaye et al. (2000, 2002) have used two approaches to define the airspace complexity; the first described an air traffic complexity indicator based on the geometry of the traffic, while the second was based on dynamic systems theory and used the Kolmogorov entropy to measure the global disorder of the system as it evolves over time. Lee (2008) proposed a way to analyse the airspace when an intruder aircraft crosses a sector boundary and presented a complexity map to describe response in the airspace to a set of disturbances. Zhang et al. (2009) analysed the intrinsic relationship between the airspace and air traffic, established an air traffic complexity metric through