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Minireview

Marine traffic model based on cellular automaton: Considering the change of the ship's velocity under the influence of the weather and sea

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HIGHLIGHTS

- Characteristics of ship's velocity impacted by the weather and sea are found.
- Characteristics of ship's velocity change are taken into account in the model.
- Regular and random components of ship's acceleration are extracted.
- Ship's acceleration is regenerated accurately in the simulations.
- This model has a strong universality in terms of marine traffic simulation.

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ABSTRACT

It was found that the ships' velocity change, which is impacted by the weather and sea, e.g., wind, sea wave, sea current, tide, etc., is significant and must be considered in the marine traffic model. Therefore, a new marine traffic model based on cellular automaton (CA) was proposed in this paper. The characteristics of the ship's velocity change are taken into account in the model. First, the acceleration of a ship was divided into two components: regular component and random component. Second, the mathematical functions and statistical distribution parameters of the two components were confirmed by spectral analysis, curve fitting and auto-correlation analysis methods. Third, by combining the two components, the acceleration was regenerated in the update rules for ships' movement. To test the performance of the model, the ship traffic flows in the Dover Strait, the Changshan Channel and the Qiongzhou Strait were studied and simulated. The results show that the characteristics of ships' velocities in the simulations are consistent with the measured data by Automatic Identification System (AIS). Although the characteristics of the traffic flow in different areas are different, the velocities of ships can be simulated correctly. It proves that the velocities of ships under the influence of weather and sea can be simulated successfully using the proposed model.

Contents

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1. Introduction

Generally, different from a vehicle, a train or an airplane, the velocity of a ship is always slow. It always takes a long time for a ship to finish its trip. A ship may spend several hours to sail through a fairway. In a marine traffic study, the duration of a ship's movement is always longer than that of a vehicle, a bicycle, or a pedestrian in a road traffic study. Therefore, the impacts of the weather and sea on ships' velocities accumulate over time, which make the changes of ships' velocities significant and impossible to ignore. Fig. 1 shows the velocity-time curves of ships that sailed southwestward in the Dover Strait for 3 days.

Recently, in some marine traffic models based on cellular automaton (CA), the velocity change under the influence of weather and sea was not considered [1]. In some other models, the velocity change was considered as a random event, i.e., the impacts of tide, sea current, and wind are formulated by random variables. And normal distributions are used to represent the impact of these parameters on speed [2,3]. This approach is similar to the randomization probability in vehicle traffic models that is essential in simulating realistic traffic flow [4]. Using the randomization probability, the natural velocity fluctuations caused by human behavior or due to varying external conditions were taken into account in the vehicle traffic simulation. For a CA-based model, the randomization probability can reflect the likelihood of a driver speeding up or slowing down. Therefore, the randomization probability is always used to describe the stochastic driver acceleration–deceleration behavior [5–13].

By importing the idea of randomization probability in marine traffic model, the random fluctuation of a ship's velocity can be simulated. In addition, the model can be used to simulate the marine traffic flow when the duration time is short and the accuracy requirement of ships velocities is not very strict. However, besides the random change of velocity, there are obviously regular changes of velocities in the marine traffic, as shown in Fig. 1, which is different from the vehicle traffic. Therefore, to build a model that can be used to simulate the marine traffic with high velocity accuracy in a long duration of time, the characteristics of the regular change of velocity caused by the impacts of weather and sea cannot be ignored [14–21]. Some studies indicated that the changes of ships' velocities caused by the impacts of the natural condition may follow other rules and require a detailed study [3].

In the vehicle traffic study, the main impact of the weather on the traffic flow is the decrease of vehicles' velocities and traffic capacity in poor weather conditions, e.g., rainfall and snow. In rainfall conditions, because of the wet and slippery roads, a driver tends to slow down for safety. The study results show that the heavier the rain is, the slower the vehicles move. Under ice and snowfall conditions, not only do the vehicles' velocities decrease but also the start-up time is delayed [22–27]. First, compared with marine traffic, the impacts of weather on road traffic flow are not always significant and only occur under specific conditions. In contrast, in marine traffic, the velocity of a ship is impacted by the weather and sea all the time during the travel. Second, the characteristics of the velocity change caused by the impacts of weather are different between a vehicle and a ship. For the vehicle traffic, the research focus is on the decrease of the velocity, the delay of the start-up time, etc., which are negative factors for traffic efficiency. In contrast, for marine traffic, the ship velocity can decrease or increase, depending on the weather and sea conditions. Therefore, a new model is required that considers the unique characteristics of the changes of ships velocities under the influence of weather and sea.

As shown in Fig. 1, the changes of ships' velocities exhibit regular changes and random fluctuations. Thus, the accelerations of the ships can be considered to be composed of a regular component and a random component. First, the regular component must be analyzed according to the spectral analysis method. The purpose of the spectral analysis is to determine the characteristics of the macro regularity of the velocity change, not the local features or outliers. In addition, the movement information of ships, achieved by the Automatic Identification System (AIS), is discrete [28–31]. Therefore, the fast Fourier transform (FFT) method is referenced to study the regular component and confirm the form of the function for regular component [32–36]. Second, for the random component, the randomness of the acceleration must be estimated according to the auto-correlation function (ACF), and using the statistical method, the distribution of the random component can be determined [37–40]. Third, as the form, data and distribution of the two components are known, the coefficient of the functions for these components can be achieved by the curve fitting methods. To meet the requirements of the two components' characteristics above, the curve fitting method is improved. The curve fitting residual of the regular component, which is the random component, must be random sequence. This residual is added to the curve fitting method as a constraint condition. Last, the two components are combined to regenerate the acceleration, which is added to the ship's velocity in the update rules. In summary, based on the analysis of the velocity change characteristics and a comparison of different models, a CA-based model for marine traffic that considers the velocity change impacted by the weather and sea is proposed. In the simulations, based on this model, the accuracy of ships' velocities is improved.