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Traffic Safety Assessment in Water Area

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Abstract. The paper deals with the navigational safety of marine traffic. It examines the problem of determining the degree of danger of traffic scheme employed in a certain water area. The most important factor determining the safety of traffic in the water area is frequency of dangerous approaches. Metric of this or that sections of the water area is suggested to be introduced as one of possible variations based on a number and localization of closest points of approach. Specialized Internet resources of free access are used as a source of trajectory data. Your attention is called to traffic modeling technique based on reducing global geographical coordinates to local rectangular and piecewise-linear interpolation. It is shown that despite inaccuracy of initial navigational data and frequency limitation of received information, there is a possibility to create a stable picture(image) of dangerous sections of dangerous sections of water areas. The work is accompanied with the results of the study made on location. Estimation analysis of danger to traffic in the waters of the Inner Sea of Japan has been presented.

1. Introduction

The volume of marine transportation has been growing from year to year which leads to the increase of traffic in waters areas of sea ports and their approaches. For example, there can be up to 3,500 vessels which motion is in different directions and of different density in the water areas adjacent to the large ports of Asia (e.g. Hong Kong, Singapore).

In the conditions of high density of traffic control of safety of navigation with the help of existing techniques may be efficient only together with preliminary estimation and planning of a safe traffic scheme in the water area.

Observance of a certain traffic scheme depending on the geography of the area and special features of its traffic is prescribed by the regulations of navigation. A choice of this or that version of the scheme is made after considering the necessity of ensuring maximum safety control and comfort for navigators.

Despite the rich arsenal of mathematical techniques for solving the problem of traffic control for various types of transport (optimization techniques, genetic algorithms, game theory techniques and others [1-4]), generation of a real traffic schemes for a specific water area on the basis of formal mathematical presentation of the problem is almost impossible. The cause of it is a large number of



informal locations(positions/statements) used in navigational practice [5], which are formed due to professional experience. That is why a traffic scheme is determined as a rule based on analysis of experts. It requires development of mathematical apparatus which allows to estimate the degree of safety of existing traffic schemes and ensures support in taking decisions in the process of their planning. It seems that without such optimization of traffic schemes further growth of traffic in heavy traffic areas will finally result in increase of dangerous situations.

The purpose of this work is to study mathematical models and traffic danger estimation techniques which are aimed to be implemented in forward-looking intellectual traffic control systems. Scientific novelty of this work is introduction of metric (criteria) reflecting an aspect of the concept 'dangerous situation' and development of a traffic danger estimation technique based on it. The obtained information on degree of danger in this or that section of the water area serves as a basis for supporting a decision on keeping or changing (optimization of) safe traffic schemes actual traffic of the sea water areas serves as initial data.

2. Basis modeling conceptions

When modeling navigational safety of traffic schemes the following metrics can be used:

1. Metric based on traffic density [6];
2. Metric based on analysis of location of closest points of approach (CPA) [7];
3. Metric based on identification of dangerous approach risk [8];
4. Metric based on the model 'room-of-maneuver' by Mitrofanov [9] and Degre, Lefevre [10].

The present work studies potentials and specific features of application of the second metric. The most important index of the safe traffic scheme quality is frequency of dangerous situations. Forward-looking approach to its estimation is application of Automatic Identification System (AIS) data taken from free Internet resources. Such data has limited accuracy in determining vessels navigational parameters and frequency of information received. When calculating the second metric this fact does not allow points of closest approach to be determined directly and requires implementation of interpolation procedures.

Traffic data accessible from free Internet resources of such type [11] look like a lot of records such as:

$$\{ShipID, Lon, Lat, Speed, Course, Time\} \quad (1)$$

where *Ship ID* is vessel's identifier, *Lon*, *Lat* are geographical longitude and latitude, *Speed*, *Course* are vessel's speed and course, *Time* is the time of data receipt. Information on every vessel: its type, flag, port of destination etc is also available. The data are updated once every 60 seconds (discreteness of parameters *Time*), though it can occur much more seldom. For example, for vessels maneuvering intensively in the water area of sea ports such data are updated once every 1-3 minutes, for those moving rectilinearly and evenly along sea routes the period of data updating may last several hours.

When modeling the traffic in the water area which size does not usually exceed hundreds of kilometres, it is advisable to come from geographical coordinates to local rectangular ones by conversing-them according to the rule:

$$\begin{aligned} x &= R \cos(Lat) \sin(Lon - Lon^*), \\ y &= R \sin(Lat - Lat^*), \end{aligned}$$

where *R* is mean radius of the Earth, *Lon** and *Lat** are longitude and latitude of the point which is considered to be the origin of the local rectangular coordinate system.

Keeping in mind a piecewise-linear interpolation of trajectory, we will have the following equations of motion for a pair of vessels.

$$\begin{aligned}
x_1(t) &= x_1(t_1^0) + Speed_1 \sin(Course_1)(t - t_1^0), \\
y_1(t) &= y_1(t_1^0) + Speed_1 \cos(Course_1)(t - t_1^0), \\
x_2(t) &= x_2(t_2^0) + Speed_2 \sin(Course_2)(t - t_2^0), \\
y_2(t) &= y_2(t_2^0) + Speed_2 \cos(Course_2)(t - t_2^0),
\end{aligned}$$

where $x_1(t)$, $y_1(t)$, $x_2(t)$, $y_2(t)$ are coordinates of the first and second vessels of the moment of time t , while t_1^0 , t_2^0 are the moments of time corresponding to available actual data of each vessel, so $t_i^0 = Time_i$. With such conception a square of distance between the vessels at the moment of time t will be equal to

$$r^2(t) = (x_1(t) - x_2(t))^2 + (y_1(t) - y_2(t))^2$$

When solving the equation $dr^2(t)/dt = 0$ with regard to t we will have the time of closest point of approach t_{CPA} , corresponding to it value of the closest distance between the vessels $r_{CPA} = r(t_{CPA})$ and coordinates of both vessels in the point of closest approach $x_1(t_{CPA})$, $y_1(t_{CPA})$, $x_2(t_{CPA})$, $y_2(t_{CPA})$.

Data concerning the value r_{CPA} characterize degree of danger in the situation 'vessel-vessel' at the time of their closest approach, while the value t_{CPA} and appropriate coordinates of the vessels show the time and place of expected situation. When working with a mass of information on traffic (actual or retrospective) covering long periods of time (days, weeks, months) you may imagine frequency of dangerous situations and localization of points of closest approach in space and time. Although the data supplied by such resources [11] is not quite correct and rarefied, when solving the given problem of frequency estimation of dangerous situation, their large number in free form can give a stable pattern of the phenomenon. The statement is proved by the carried-out experiments.

3. Results of full-scale experiments

The traffic data received from the resources [11] with the help of specially made program system [12] were used to conduct the research. The study was made in several interesting water areas with dense traffic. The results for one of the water areas of Inner Sea of Japan characterized by its uncontrolled heavy traffic mainly in the open water are presented here.

Figure 1 show closest points of approach for vessels moving in the Harima Sea and the Osaka Bay which were estimated with the help of the described technique. The traffic scheme is built based on the data collected within one day in the summer of 2016. There were about 1,600 vessels in the observed zone and the processed amount of data exceeded 1 million of records (1).

Red colorcast indicates positions of vessels approached up to the distance of less than two lengths of their hulls, while yellow dots show positions of vessels approached each other up to the distance of less than five lengths of their hulls. You can clearly see the fairways with regard to the dense traffic found 'North-East' and 'South-North' which is made conditional on geographical features of the water area. You can also note that the greatest number of dangerous approaches is seen in narrow places of the fairways and in the port waters (the ports of Kobe and Osaka).

Figure 2 presents average frequencies of 'red' dangerous situations (corresponding to the data of figure 1).

Frequency of dangerous approaches is much lower than two situations an hour in a larger section of the water area. In straits westward of the Harima Sea where traffic density is highest, the frequency of dangerous approaches reaches four or five an hour.

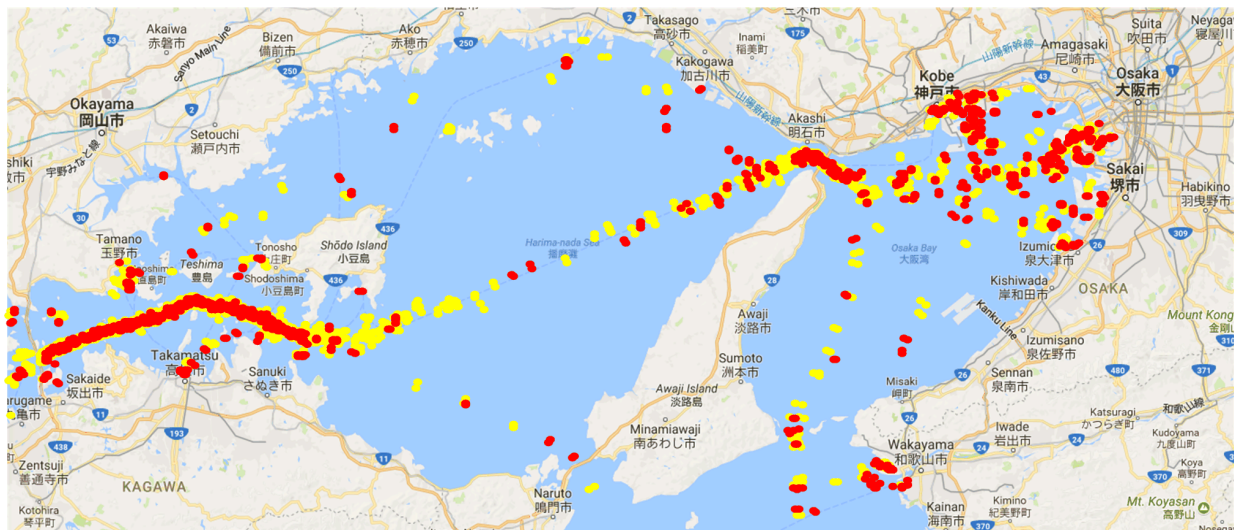


Figure 1. Closest points of approach.

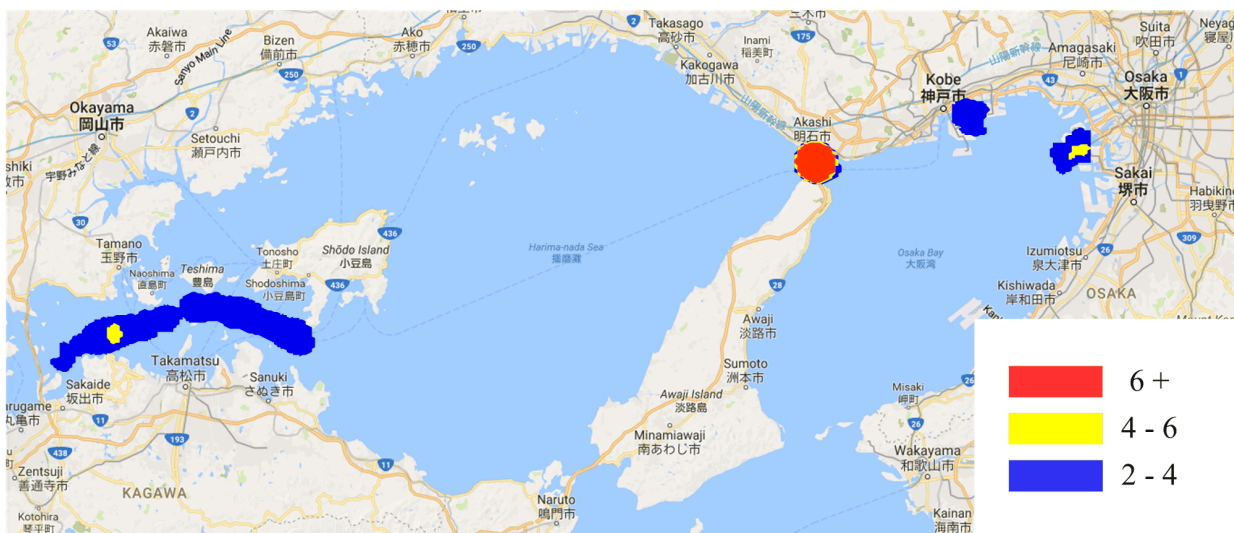


Figure 2. Average frequency of dangerous approaches of vessels (situations an hour).

The ports of Kobe and Osaka are characterized by a comparatively small number of dangerous close approaches for such places, what shows a well-thought and optimized traffic scheme in their waters. Rather large number of dangerous approaches is seen in the strait nearby the town of Akashi, where their medium frequency reaches 7-8 situations an hour though it can be higher. Navigators sailing in that area must pay special attention to the circumstances around and be always on alert as such a high number of dangerous approaches occurs in the area with heavy traffic, which makes navigation rather difficult, and can lead to incorrect operational decisions.

In the areas like the presented one there must be very high level of traffic control from shore-based vessel traffic systems. The developed picture serves as a signal for services whose duty is to ensure safety of navigation to start working at changing traffic schemes in the water area to make them less dangerous.

4. Conclusion

Estimated of traffic safety in water areas in an important stage of traffic schemes planning. One of the probable indicators of navigational safety in water areas is frequency of dangerous situations a forward-looking way to estimation of this indicator of this indicator is application of AIS retrospective data supplied by free Internet resources. Despite the relative incorrectness of such data, they contain enough information to have a clear idea of traffic type in a water area and it is possible to build a stable picture of dangerous sections in water areas on their basis. The data are of interest for vessel traffic systems, demonstrate forward-looking potentials for danger degree estimation of traffic scheme to be implemented in the water areas and for working out recommendations how to change them to have less dangerous configurations.

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