IOP Conference Series: Materials Science and Engineering

Emotional Load on Navigators Under Heavy Ship Traffic

To cite this article: V M Grinyak *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1079** 062061

Emotional Load on Navigators Under Heavy Ship Traffic

V M Grinyak[1,2,3], **A S Devyatisilnyi**[2], **A V Shulenina**[3]

[1]Department of Information Systems and Technologies, Vladivostok State University of Economics and Service, Gogolya, 41, Vladivostok, 690014, Russia
[2]Department of Navigation and Control, Institute of Automation and Control Processes FEBRAS Radio, 5, Vladivostok, 690041, Russian Federation
[3]Department of Applied Mathematics, Mechanics, Control and Software, Far Eastern Federal University, Sukhanova, 8, Vladivostok, 690091, Russian Federation

E-mail: victor.grinyak@gmail.com

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. In addition to technical and natural factors, the nature of the psychological and emotional stress on navigators should also be taken into account when assessing the risk of a traffic pattern, which is especially important in high traffic density. Metric is suggested to be introduced as one of possible variations based the model “room-of-maneuver”. The purpose of this work is to study mathematical models and traffic danger estimation techniques which are dimed to be implemented in forward-looking intellectual traffic control systems. The measure of the emotional load is the degree and nature of the filling of the “room-of-maneuver” chart, the ratio of dangerous and safe values of the speed and course of the vessel in conditions of intensity traffic. The characteristic values of this metric for a specific marine area are an important and informative indicator that determines the navigational safety. A promising way to estimate metrics is to use data from the Automatic Identification System. The paper presents a model of traffic data available on open Internet resources, a way to bring them to a form suitable for analysis. The work is accompanied with the results of the study made on location. Estimation analysis of danger to traffic in the waters of the Tsugaru Strait and Inner Sea of Japan has been presented.

1. Introduction

Ensuring navigational safety of ship traffic is the main task that must be solved during the operation of water transport routes [1]. It is provided with a whole range of tools and instruments: coastal vessel traffic management systems (VTS), airborne navigation systems, and rules of navigation. The rules of navigation are based on the International rules for preventing collisions at sea (COLREGS -72) [2]). When determining the rules of navigation for a certain water area, the General principles of the COLREGS are supplemented by local provisions determined by the specifics of this water area.

The results of well-known studies [3] show that in conditions of intense traffic, vessel traffic safety can only be ensured if these vessels follow a certain traffic scheme, depending on the geography of the water area. The choice of a specific variant of such a scheme from a variety of possible options is carried out taking into account the maximum traffic safety and practical aspects of navigation.

There are many well-developed mathematical models and methods for solving the problems of organizing the movement of various types of transport. At the same time, navigation includes many informal provisions related to personal and collective professional experience in various conditions [4] (weather, time of day, crew qualifications, mentality of traffic participants, etc.). Therefore, it is hardly possible to develop a scheme of vessel traffic based on a purely mathematical approach. The traffic scheme in a particular water area can be determined on the basis of a comprehensive expert analysis of various information about the water area, taking into account the prevailing navigation practice [5]. Among the factors that determine navigation safety in the water area, the following can be identified [6]: traffic intensity (number) of vessels and the distance between them (density) in a particular section; the characteristic speed and size of ships, the intensity of their maneuvering; hydrographic and weather conditions in the water area (currents, shallows, wind, waves, visibility); the degree of provision of water with navigational aids (the presence of lighthouses, buoys, VTS class).

In addition to technical and natural factors, the nature of the psychological and emotional stress on navigators should also be taken into account when assessing the risk of a traffic pattern. The emotional load on the navigator is also due to the complexity of the surrounding navigation environment and managerial decision-making. A possible approach to formalizing such complexity is to evaluate the set of dangerous and safe values of speed and heading of a controlled vessel in conditions of collective movement [7, 8].

In this paper, we consider a model for assessing the emotional load on navigators, based on the classical idea of the “room-of-maneuver” by Degre and Lefevre [9]. The metric (measure) of the load is the degree and nature of filling the corresponding diagram “speed-rate”. In the simplest version, the metric is represented as a fraction of the dangerous values of the speeds and courses of movement of the vessel. Determining the characteristic values of the metric at a certain point in the water area makes it possible to assess the degree of danger of the traffic pattern and give recommendations on how to change it to a less dangerous configuration.

2. Method and materials

Remaining within the tradition, we will consider the model of the danger of collective movement in the water area as a set of dangerous situations “ship-to-ship” for each pair of vessels. Consider two ships with coordinates $x^{(1)}$, $y^{(1)}$ and $x^{(2)}$, $y^{(2)}$, and components of the velocity vector $v_x^{(1)}$, $v_y^{(1)}$ and $v_x^{(2)}$, $v_y^{(2)}$. Let's describe the relative motion of ships by a set of values s=(r_x, r_y, v, η_v), where v – speed of relative movement of vessels, r_x, r_y , - components of the vector of the relative position of the vessels r, η_v – direction of the vector v of the speed of the relative movement of the vessels (figure 1).

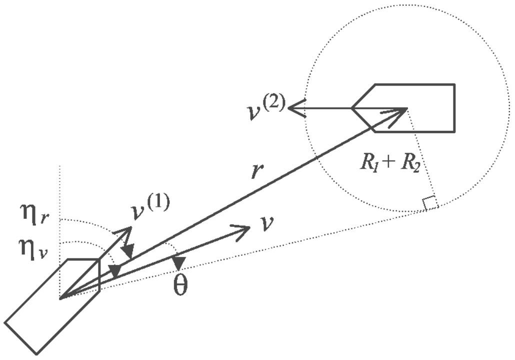

Figure 1. Model of relative movement of two vessels.

Traditionally, it is considered that for safe movement of vessels must comply with the navigation safety zone of the vessel (also called “room-of-maneuver”) [9, 10]. In this paper, the navigation safety zone is rigidly connected to the vessel n and is defined by a circle of radius R. Figure 1 shows the following values describing the ship-to-ship navigation situation: θ – the angle determined by the distance between the ships and the size of the domains (it is assumed that in a safe state, the ship's domains should not "invade" each other); η_r – the azimuth of the vector r.

We introduce the following values: T – the time remaining until the maximum approach of vessels (TCPA) T* - the threshold value of time T. We formalize the dangerous approach of the two vessels as follows:

$$|\eta_v - \eta_r| < \theta \tag{1}$$

$$0 < T < T_* \tag{2}$$

Condition (1) corresponds to the situation when, with uniform and straight-line traffic of vessels. The point of their shortest approach will be inside the navigation safety zone of at least one of the vessels (that is, the vessels are approaching dangerously). Condition (2) selects from the general set those vessels whose time to approach is less than the threshold. We will represent the dangerous and safe values of the ship's movement parameters with the well-known "speed-course" diagram ("room-of-maneuver" according to Degre and Lefevre [9]). It is constructed as follows. Let the first ship be controlled (own ship), and the second is considered a target ship. We define the set of "dangerous" values of the vector v according to geometric representations (1) and (2). Moving from the relative motion of the vessels to the absolute, the corresponding set of "dangerous" values of the velocity vector of the first vessel will be obtained by parallel transfer of the sector of "dangerous" values of the vector v to the vector (Figure 2, shaded part). Moving from the relative movement of vessels to the absolute, the corresponding set of "dangerous" values of the speed vector of the first vessel v^1 is obtained by parallel transfer of the sector of "dangerous" values of the vector v to the vector v^2 (figure 2, shaded part). The circle of radius r shows the maximum possible speed of the first vessel (figure 2). Such a clear visual representation of dangerous and safe parameters of the movement of the controlled vessel allows navigators to effectively make decisions to prevent dangerous approaches.

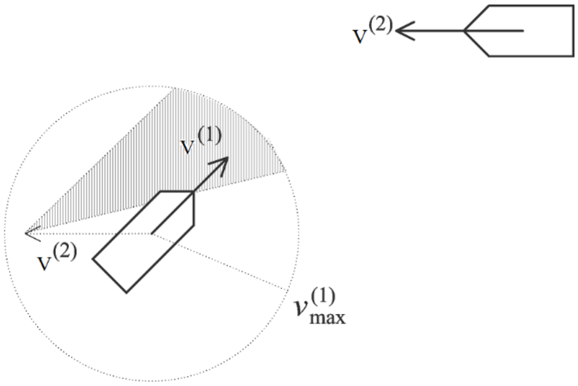

Figure 2. The "speed – course" diagram construction principle.

The degree and nature of filling in the "speed-course" diagram gives an idea of the complexity of decision-making by the shipmaster in the current navigation situation. Thus, the metric of emotional stress on shipmaster can be considered, for example, the share of dangerous values of ship speeds and courses.

The characteristic values of this metric for a specific sea area are an important and informative indicator that determines the navigation safety of traffic. Its high value serves as a signal for a thorough study of the existing traffic pattern and, possibly, the development of a new scheme that provides safer traffic

Ship traffic data available on open Internet resources like [11] are a multitude of tuples of the form

$$\{SID, LAT, LON, V, K, TIME, AGE\} \tag{3}$$

where SID is the vessel identifier; LAT – geographical latitude; LON – longitude; V – movement speed; K – course; $TIME$ – data arrival time; AGE is the age of the data that determines the actual point in time to which they correspond. In addition, additional information is available about each ship: type, flag, port of destination, etc.

In the event that it is required to carry out modelling of ship movement over a specific local water area, the characteristic dimensions of which usually do not exceed hundreds of kilometres, it is advisable to move from the geographical coordinates of the vessel to local rectangular ones, transforming them according to the rule:

$$x = R\cos(LAT)\sin(LON - LON^*);$$
$$y = R\sin(LAT - LAT^*),$$

where R is the average radius of the Earth when represented by its sphere; LAT^* and LON^* – respectively, the latitude and longitude of the point, taken as the beginning of the local rectangular coordinate system. We will have the following equations of motion for each vessel located in the water area:

$$x(t) = x(t_0) + SPEED\sin(COURSE)(t - t_0),$$
$$y(t) = y(t_0) + SPEED\cos(COURSE)(t - t_0).$$

where $x(t)$, $y(t)$ are the coordinates of the ship at time t, t_0 is the time corresponding to the age of the data. In practice, from the set of data (3) for each ship, the data with the lowest AGE should be selected as the most reliable.

Having many records (3), it is possible according to the described methodology to determine the percentage of dangerous values of speeds and courses of movement of each vessel at each moment in time. Dividing the waters into sections and calculating the values of the specified metric for passing on them ships, we can estimate a characteristic (for example, average) values of metrics for each section of the area.

3. Results

These metrics were calculated on real traffic data of several marine areas. This paper presents the results for the Tsugaru Strait and Osaka Bay. Figures 3 and 4 show the average percentages of dangerous speeds and courses of vessels moving in the Tsugaru Strait (figure 3) and in the Harima Sea (figure 4).

The water area is divided into square sections with a side of 1000 meters, the radius of the navigation safety zone was set equal to the length of the vessel's hull.

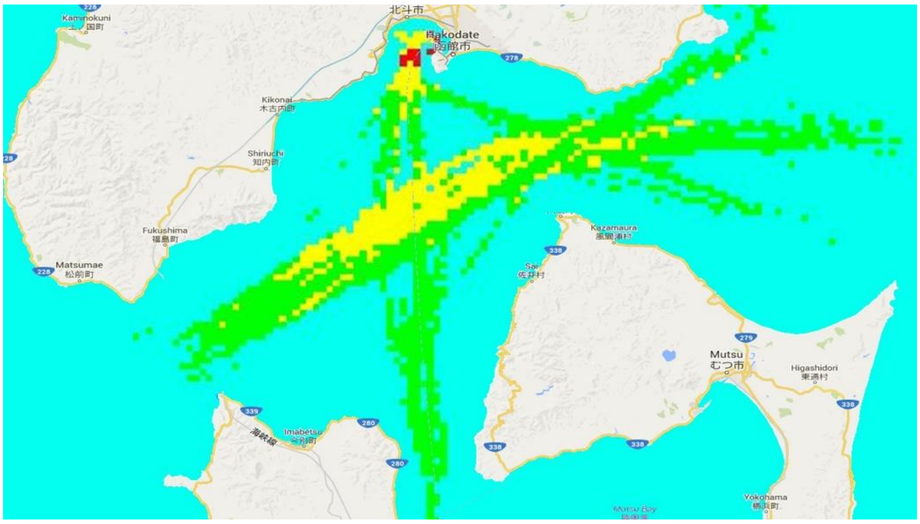

Figure 3. The average values of the fraction of dangerous speeds and courses in Tsugaru Strait.

The red colour indicates the sectors of the water area with the highest degree of decision-making complexity (more than 80% of courses and speeds are dangerous), green colour – with the least degree (dangerous courses and speeds up to 50%), yellow colour – with an average (from 50-80% of dangerous courses and speeds). It can be considered that on the green sections it is easy for the shipmaster to make a decision, on the yellow sections it requires increased attention. Orange and red sections are characterized by a complex navigation situation and suggest a high concentration and emotional tension of the shipmasters.

Figure 3 shows that only the central part of the Tsugaru Strait, located at the intersection of the “North-South” and “West-East ship” flows, and the waters adjacent to the port of Hakodate, are loaded. A significant change in the traffic pattern in the strait is not necessary.

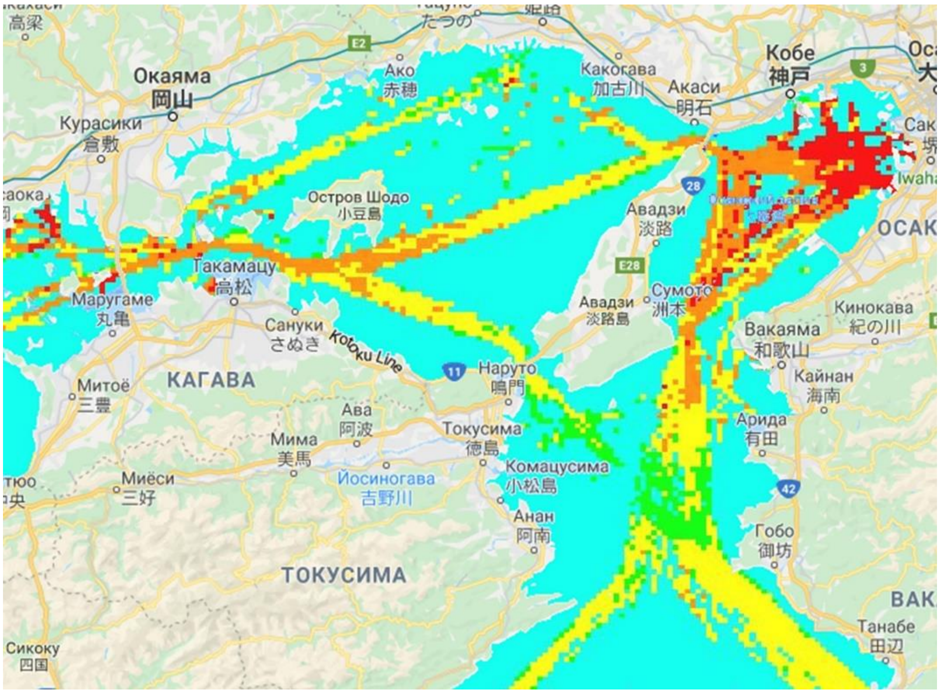

Figure 4. The average values of the fraction of dangerous speeds and courses in Harima Sea and Osaka Bay.

The Inland sea of Japan is a highly loaded water area with complex hydrography. Figure 4 shows that the main fairways in the Harima Sea require increased attention. Osaka Bay is also quite complex, with ships constantly moving around each other, especially in the Eastern part. This means that shipmasters need to plan their work taking into account the increased load and rapid fatigue, for example, to put the most experienced crew members on the bridge with understudies, to resort to the services of a pilot. For regulatory services, this may signal the need to change traffic rules in this part of the water area.

4. Conclusion

The approach presented in this paper allows us to assess the complexity of decision-making by navigators working both “on board” (the ship's captain) and “on shore” (the operator of coastal VTS) – taking into account the specifics of collective movement. The method identifies potential, hidden and “unrealized” traffic hazards, which can result in real dangerous situations in the event of an unfavorable combination of circumstances (reduced visibility, failures in navigation equipment, incorrect dispatcher commands, etc.). The proposed metric is an attempt to formalize the psychological and emotional load on the participants of the movement. Representation of the navigation situation in the form of speed-course diagrams and their analysis allows you to develop recommendations for reducing the share of dangerous values of speeds and courses. This is one of the advantages of the studied approach. Although only other vessels were considered as obstacles in this article, the proposed metric can easily be supplemented by taking into account the characteristics of fairways, shorelines, prohibited areas, etc.

Analysis of traffic data using various intensity and hazard metrics allows for a comprehensive assessment of marine traffic. Comparison of the results of traffic hazard assessment in the water area by the methods listed above can be represented as a hierarchy with the following order of decreasing importance of hazard factors:

1. geographical and hydrographic factors;
2. typical frequency of dangerous situations;
3. the characteristic percentage of dangerous values of speeds and traffic courses (the proposed method);
4. traffic intensity.

Thus, the approach proposed in the article can harmoniously complement the existing set of methods for assessing the danger of movement in the water area, revealing another aspect of the multi-faceted concept of “dangerous situation”.

As a measure of the load on navigators, the paper considers the average values of the percentage of dangerous speeds and courses of vessels. Along with this, you can use other characteristics of the “speed-course” diagram: the degree of occupancy; modes; numbers, distributions, and “area” of connectivity areas, etc. The question of the relationship of various parameters of the “speed-course” diagram with emotional stress and formal uncertainty in decision-making requires additional research.

5. References

[1] Gagarskiy E A Kozlov S G and Kirichenko S A 2018 *Transport: science, equipment, management* **1** 14-18.
[2] Gutsulyak V N 2015 *Int. Regulations for Preventing Collisions at Sea 1972 (COLREGs-72) with Comments* (Moscow: Centre For Maritime Law) p 224
[3] Grinyak V M Devyatisilnyi A S and Ivanenko Y S 2019 *IOP Conf. Series: Earth and Environmental Science* **272** 022017
[4] Tam Ch K, Bucknall R and Greig 2009 *J. of Navigation* **62(3)** 455–476.
[5] Lobanov A A Yu V Rumyantsev 2013 *Navigation and Hydrography* **35** 29–38
[6] Wu L Xu Y Wang Q Wang F, and Xu Zh 2016 *J. of Navigation* **70(1)** 67–81
[7] Grinyak V M Devyatisilnyi A S and M A Trofimov 2016 *Marine intellectual technologies* **1** 269-273
[8] Grinyak V M 2016 *Vestnik Gosudarstvennogo universiteta morskogo i rechnogo flota imeni admirala S.O. Makarova* **4** 51–61
[9] Degre T and Lefevre X 1981 *J. of Navigation* **34(2)** 294–302
[10] Vaskov A S and M A Garashchenko 2017 *Ekspluataciya morskogo transporta* **4** 38-44
[11] MarineTraffic. Web. 1 Jul. 2019 <http://www.marinetraffic.com>

Acknowledgments

The reported study was funded by RFBR, project number 20-38-90018.