TRANSNAV International Journal on Marine Navigation and Safety of Sea Transportation
Volume 4 Number 1 March 2010

Evaluation of Main Traffic Congestion Degree for Restricted Waters with AIS Reports

Q. Hu, J. Yong & C. Shi
Shanghai Maritime University, Shanghai, China
G. Chen
Shanghai Maritime Administration, Shanghai, China

ABSTRACT: Traditionally, marine traffic congestion degree in restricted waters is usually deduced from traffic volume or traffic density. Both of which, however, can not be easily and accurately determined and can not fully reflect the traffic congestion degree. This paper uses the concept of main traffic flow velocity, which varies with the main traffic congestion from a statistics view, to determine the main traffic congestion degree in restricted waters. Main traffic flow velocity can be calculated by averaging the speeds of all ships equipped with an AIS transponder if the percentage of these ships over all vessels in the main traffic is great enough and they are well-distributed, and a fuzzy relationship is established to determine the traffic congestion degree under varying main traffic flow velocity. The concept of main traffic flow velocity provides a more intuitive and accurate way to evaluate the main traffic congestion degree of restricted waters than traffic density and traffic volume in certain situations, and can be easily implement.

1 INTRODUCTION

In recent years, shipping is developing rapidly over the world to meet the growing economic demands. Ships are getting greater, speedier, and more professional, and the number of ships improves dramatically. These factors make ports and channels more and more crowded and complicated, and the resulted traffic congestion or jam may enhance the risk of collision and decrease the traffic efficiency in a great extent. So the traffic congestion degree is becoming a more and more important parameter for traffic monitoring and management.

The concept of marine traffic congestion degree and its calculation, however, have not been well developed like in the road transportation domain. One important reason is the difficulty of collecting marine traffic information. Fortunately, more and more vessels have been equipped with AIS (Automatic Identification System), which can frequently broadcast own-ship's position, name, speed, course, size, etc. and so can facilitate marine traffic information collecting very much(Zhaolin W.&Jun Z.2004).

With position reports of all ships in restricted waters, we can try to evaluate traffic congestion degree from the aspect of all ships. However, in restricted waters, there may be only partial vessels equipped with AIS while others may not for it's not compulsory for them according to the regulations. So in the context of this paper, we classify the ships into two category, one is the local small boat with or without AIS equipment, and the other is the general business ship of certain tonnage (for example, 500GT) or above, and ships belong to this category are usually equipped with AIS equipment. To ships of different category, the same traffic situation may mean different traffic congestion degree for they have different handling capacity and need different size of room for sailing. In this paper, we focus on the evaluation of main traffic congestion degree from the aspect of general business vessels by considering the existence of the small local boats.

This paper is organized as follows: Section 2 presents the features of marine traffic congestion, the traditional methods to determine it and their disadvantages. Section 3 proposes a fuzzy reasoning model to determine the main traffic congestion degree with main traffic flow velocity. Section 4 illuminates the method to calculate the main traffic flow velocity with AIS reports. Finally, main conclusion and discussion are offered in section 5.

2 MARRINE TRAFFIC CONGESTION FEATURES AND TRADITIONAL DESCRIPTION OF TRAFFIC CONGESTION DEGREE

At present, there is no definite definition of traffic congestion degree of restricted waters. In fact, marine traffic congestion always exists and can be manifested as:

1 With low sailing velocity and speeding up and down frequently.
2 With disorder navigation.
3 With too many vessels blocked in the restricted waters.

From the domestic and international research of marine traffic, it is found that marine traffic engineers prefer to use traffic density or traffic volume to determine traffic congestion degree (Yan L. et al.2007&Yansong G. & Zhaolin W.2001).

Traffic density is the instant average quantity of the vessels per unit area in the surveyed waters, while traffic volume is the number of vessels through a certain waters during a certain time period （Zhaolin W. & Jun Z.2004）. Both traffic density and traffic volume can not describe the above 1) and 2) features of marine traffic congestion. Besides that, there are two other major disadvantages when traffic density and volume are applied to determine the marine traffic congestion degree.

1 It is not convenient to get the source data for calculating traffic density or volume. Manual or semi-automatic traffic survey, radar observation and aerial photography are generally needed.
2 Ships of different sizes need to be unified when calculating traffic density or volume, and the unification can not be done accurately.

So traffic density or volume is not a perfect parameter to determine traffic congestion degree.

3 A FUZZY EVALUATION MODEL OF MAIN TRAFFIC CONGESTION DEGREE BASED ON MAIN TRAFFIC FLOW VELOCITY

It is well known that traffic congestion degree can be determined by average velocity on road, such as: smooth traffic means that the average velocity is more than 30 kilometers per hour, normal traffic means that the average is between 20 and 30 kilometers per hour, crowed traffic means that the average is between 10 and 20 kilometers per hour and blocking traffic means that the average velocity is not more than 10 kilometers per hour or maybe nearly zero (Huapu L. & Janwei W.2003).

Similar to road traffic, when the traffic in restricted waters is not congested, vessels can sail fast to the upper limit, while congested, vessels can only move slowly or even stop. Based on this similarity, this paper tries to propose a new evaluation method for marine main traffic congestion degree by using average velocity of vessels in the main traffic or main traffic flow velocity. Because the congestion is a fuzzy concept, a simple fuzzy inference system to calculate the congestion degree with traffic flow velocity as the input is designed（Khaled H. & Shinya K 2002）.

3.1 *Fuzzy inference system*

Fuzzy inference system, based on fuzzy set theory, fuzzy rule of If-then and fuzzy inference, contains three parts: 1) many fuzzy rules of If-then; 2) database for defining membership function; 3) inference engineering to get fuzzy results by input and fuzzy rules(JANG J S R. 1997). Figure 1 shows the general structure of a fuzzy inference system.

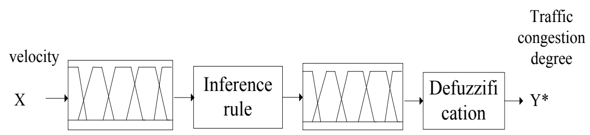

Figure 1. General structure of fuzzy inference system

3.2 *Building fuzzy sets of traffic flow velocity and traffic congestion degree and their membership function*

Considering people's evaluating scale, the fuzzy sets can be set as: traffic flow velocity= {"very fast", "fast", "middle", " slow", "very slow"}, traffic congestion degree= {"blocking", "crowed", "not steady", "normal ", "smooth"}

Figure 2 shows the membership function of the traffic flow velocity, where v_e is the ratio of the current traffic flow speed and the free speed and $v_e \in [0, 1]$, and V_m is the ratio of the designed speed or the recommended speed for prevailing weather condition and normal traffic and the free speed.

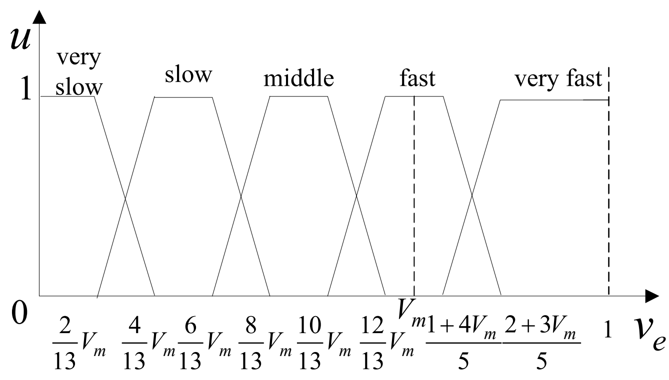

Figure 2. Membership function of traffic flow velocity

Given v_e and the membership function of traffic flow velocity, we can determine the linguistic value of v_e by finding the linguistic value on which v_e gets the max membership. For example, if $u_{very\ slow}(v_e)$ =0.6 and $u_{slow}(v_e)$=0.4, the linguistic value of v_e is *very slow*.

Figure 3 shows the membership of traffic congestion degree (TCD), which is quantified between 0 and 1, where 0 means traffic state is jam and 1 simplifies that it is very smooth in the waters.

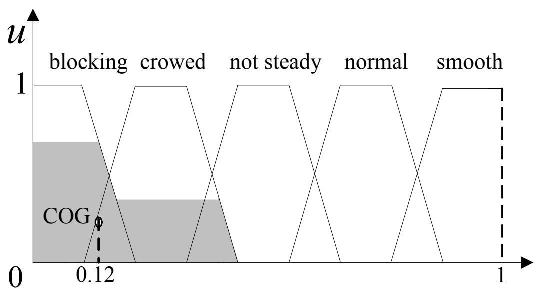

Figure 3. Membership function of traffic congestion degree

3.3 *Fuzzy inference rule of the evaluation*

Here the fuzzy inference rule between traffic flow velocity and traffic congestion degree should be:

- If traffic flow velocity is “very fast”, then traffic congestion degree is “smooth”, and given v_e, $u_{very\ fast}(v_e) = u_{smooth}(v_e)$.
- If traffic flow velocity is “fast”, then traffic congestion degree is “normal”, and given v_e, $u_{fast}(v_e) = u_{normal}(v_e)$.
- If traffic flow velocity is “middle”, then traffic congestion degree is “not steady”, and given v_e, $u_{middle}(v_e) = u_{not}$ steady(v_e).
- If traffic flow velocity is “slow”, then traffic congestion degree is “crowed”, and given v_e, $u_{fast}(v_e) = u_{crowed}(v_e)$.
- If traffic flow velocity is “very slow”, then traffic congestion degree is “blocking”, and given v_e, $u_{very\ slow}(v_e) = u_{blocking}(v_e)$.

Table 1 shows the mapping relationship between the fuzzy sets of traffic flow velocity and traffic congestion degree.

Here velocity has been divided into five grades and every grade is measured by designed speed Vm, which has considered influential factors of velocity, such as, visibility and can change a lot under different weather condition.

Table1. Fuzzy set mapping between traffic congestion degree and traffic flow velocity

Grade	Traffic congestion degree	Membership of traffic flow velocity
1	smooth	very fast
2	normal	fast
3	not steady	middle
4	crowed	slow
5	blocking	very slow

3.4 *Defuzzification*

As the output of fuzzy inference system is fuzzy, it is necessary to map the fuzzy congestion degree into a concrete value, which is called defuzzification. There are five defuzzification techniques and the most typical one is center of gravity (COG) (JANG J S R. 1997), which is used in the context of this research.

For example, if $u_{very\ slow}(v_e)$ =0.6 and $u_{slow}(v_e)$=0.4, then $u_{blocking}(v_e)$ =0.6 and $u_{crowed}(v_e)$=0.4, and finally the defuzzification value y* is 0.12 as figure 3 shows.

4 MAIN TRAFFIC FLOW VELOCITY CALCULATION WITH SPEED INFORMATION PROVIDED BY AIS REPORTS

Generally, traffic flow velocity can be calculated by equation (2), where n means the total number of ships in an investigated waters and v_i means the current speed of i-th ship.

$$\overline{v} = \frac{\sum_{i=1}^{n} v_i}{n} \tag{2}$$

When we use equation (2) to calculate the main traffic flow velocity with the information provided by AIS reports, we shall note that not all ships in an investigated waters is equipped with AIS transponder, so the total number of ships can not be acquired.

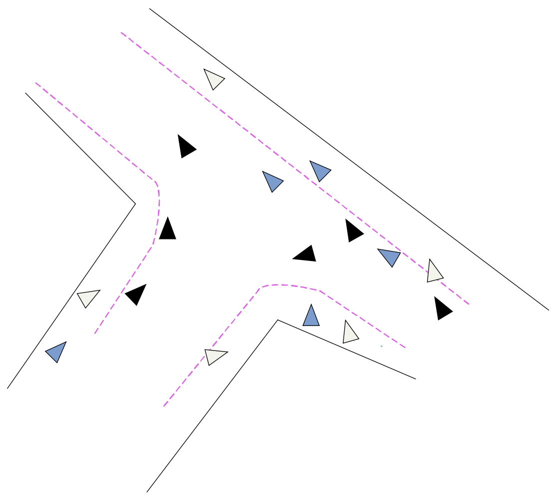

Figure 4. Schematic diagram of marine traffic, where black triangles stand for the ships equipped with AIS and in the main traffic, gray triangles present the ships without AIS, while white triangles signify local traffic ships with AIS

In this paper, we regard each ship with AIS transponder in the main traffic as a sampling sensor, so if the percentage of these ships over all ships in the main traffic is great enough and they are well-distributed, the average speed of these ships will be able to reflect the traffic congestion degree.

For example, in Figure 4, we regard the average speed of all black vessels as the main traffic flow velocity. All white vessels are ignored because they are not in main traffic, and their speeds are not closely related to the traffic congestion degree for they may at anchor, berthing, etc.

5 CONCLUSIONS AND DICUSSION

This paper proposed to apply the concept of main traffic flow velocity to determine the main traffic congestion degree in restricted waters. Main traffic flow velocity is calculated by averaging the speed of all ships equipped with AIS transponders in the main traffic. A fuzzy inference model was built to determine the main traffic congestion degree under varying main traffic flow velocity. Comparing to traffic volume or density, the concept of main traffic flow velocity provides a more intuitive and accurate way to evaluate the main traffic congestion degree of restricted waters in certain situation, and can be easily implement.

The more percentage of ships equipped with AIS transponders in the main traffic is, the more reasonable the evaluating result given by the method proposed in this paper is. For the restricted waters where the percentage is not determinable, there are two conditions shall be satisfied before applying the method proposed in this paper: (1) the percentage of vessels with AIS transponder over all ships in the main traffic is great enough, and (2) the ships are well-distributed. The lower limit of the percentage and how to determine whether the ships are well-distributed shall be further studied. Besides that, traffic volume or density may be combined with traffic flow velocity to make the evaluation. We also have plans to apply clustering method to determine the limits between congested waters and smooth waters, and to render the marine traffic congestion degree on the Web sea map to facilitate ship owners and marine safety authorities to monitor the traffic.

ACKNOWLEDGEMENTS

This work was supported by Shanghai Education Committee under grant No.08YZ107 and by Shanghai Leading Discipline Project under grant No. S30602

REFERENCES

Huapu L. & Janwei W. 2003.Analysis of Urban Traffic Congestion and Dynamic Distinction Method. Beijing: Peoples' Transportation Press

Jang J.S.R. 1997. Neuro-fuzzy and soft computing. USA: International Edition

Khaled H. & Shinya K. 2002. Developing a Measure of Traffic Congestion: Fuzzy Inference Approach .Transportation Research Record (1802): 77-85.

Yan L. et al. 2007. Analysis and evaluation of navigation safety influenced by navigation environment in port. Journal of Waterway and Harbor28 (5):342-347

Yansong G. & Zhaolin W. 2001. Analysis and evaluation on the danger degree of environment in the channel of Xiamen port. Journal of Dalian Maritime University 27 (1): 5-8

Zhaolin W. & Jun Z. 2004.Marine traffic engineering. Dalian: Dalian Marinetime University Press