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Fuzzy Inference System for Determining Collision Risk of Ship in Madura Strait Using Automatic Identification System

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Abstract**—**Madura Strait is considered as one of the busiest shipping channels in Indonesia. High vessel traffic density in Madura Strait gives serious threat due to navigational safety in this area, i.e. ship collision. This study is necessary as an attempt to enhance the safety of marine traffic. Fuzzy inference system (FIS) is proposed to calculate risk collision of ships. Collision risk is evaluated based on ship domain, Distance to Closest Point of Approach (DCPA), and Time to Closest Point of Approach (TCPA). Data were collected by utilizing Automatic Identification System (AIS). This study considers several ships' domain models to give the characteristic of marine traffic in the waterways. Each encounter in the ship domain is analyzed to obtain the level of collision risk. Risk level of ships, as the result in this study, can be used as guidance to avoid the accident, providing brief description about safety traffic in Madura Strait and improving the navigational safety in the area.

Keywords**—**Automatic identification system, collision risk, DCPA, fuzzy inference system, TCPA.

I. Introduction

SURABAYA West Access Channel which is located in Madura Strait is one of the busiest shipping channels in Indonesia. Many ships that operate in Madura Strait are sailing toward several major ports such as Port of Tanjung Perak Surabaya and Port of Teluk Lamong Gresik. Fig. 1 shows statistic data about the number of vessels which operated in Madura strait from 2008 until 2013.

Fig. 1 represents a significant increase of the number of vessels in 2013. The growth of ships number tends to increase the number of ship accidents including ship collision. As stated by Zhu and Liu that the number of ship collision accidents is directly proportional to the quadratic of ship traffic density [1]. According to the report from Mahkamah Pelayaran, there have been 293 cases of accidents during 2005 until 2009 in Indonesia. It can be categorized into: Ship sinking (31%), ship grounding (25%), ship collisions (18.27%), ships fire (9.67%), and others (16.06%). Major causes of accidents are human error (78.45%) [2]. Other causes are technical error (9.67%), weather conditions (1.07%), and 10.75% due to a combination of weather and technical errors [2], [3]. Gong also presented statistical data on maritime accident that 30% maritime accidents are ship collisions and 90% of the accidents were caused by human error [4]. When the accident occurs, the risk of life, property, and marine environment immediately becomes higher [5]. Hence, it is necessary to ensure the safety of marine traffic in the area by evaluating the collision risk of ships. There are several methods to assess the risk, that have been done by many researchers. Previous methods in evaluating collision risk are based on traffic flow theory, ship domain, and the numerical models based on DCPA and TCPA. Risk calculation based on traffic flow theory is not commonly used now. Collision risk evaluation based on ship domain is far better than traffic flow theory. The other alternative risk collision calculation method is then introduced because there are many factors affecting the risk collision. The most important factors are the DCPA and TCPA [6].

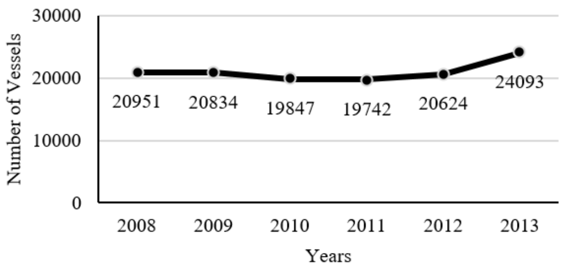

Fig. 1 Number of Vessels Operated in Madura Strait [7]

The concept of ship's domain was firstly introduced by Fujii and Tanaka [8]. The other most common definitions of the ship's domain have been given by Goodwin in 1975 and Coldwell in 1983 [9], [10]. The main concept of ship domain is an area around a ship where the navigator should maintain and keep clear of other objects or vessels to remain safe and comfortable [11], [12].

Ship domain concept makes an analysis of ship collision risk become easier. When a ship enters inside the boundary of domain, it is considered as potential dangerous encounter. To determine whether an action must be taken or not, collision risk then should be calculated based on DCPA and TCPA.

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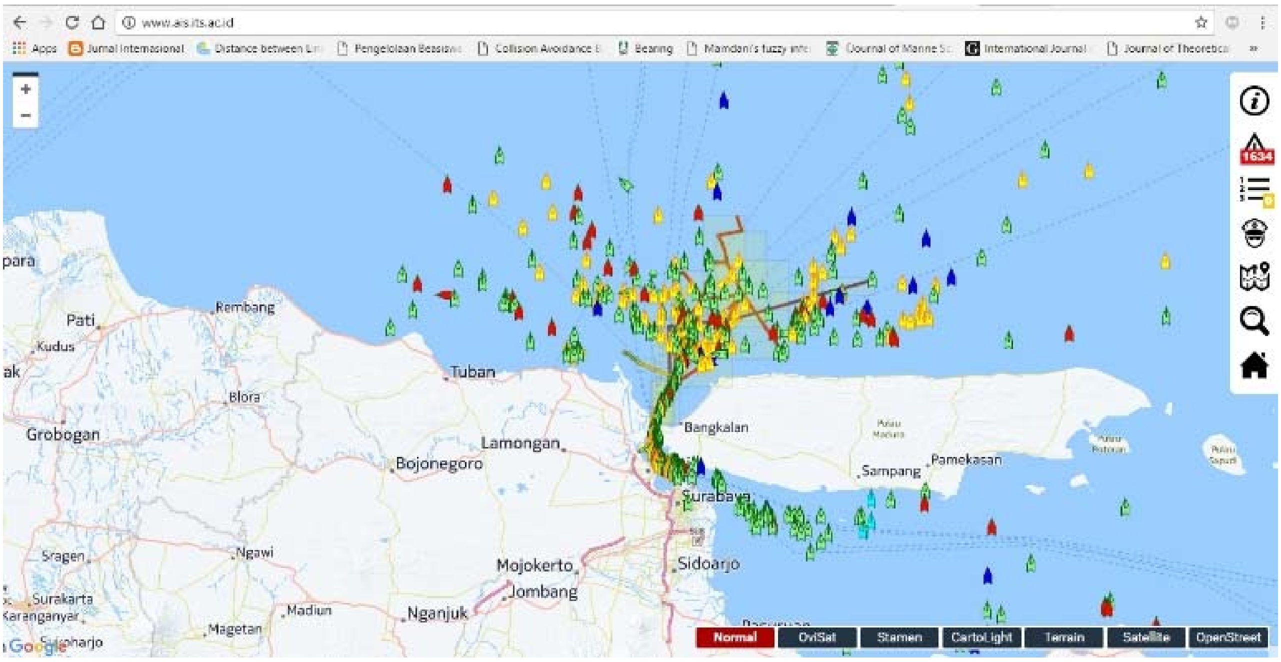

Fig. 2 AIS

Xu and Wang in 2014 and Bukhari et al. calculated the degree of collision risk based on FIS by inputting the parameters, such as DCPA, TCPA, bearing and variance of compass degree (VCD) [6], [13]. Chen et al. proposed the risk collision calculation method using combination of fuzzy and fuzzy comprehensive evaluation methods based on the membership functions of DCPA and TCPA, distance between ships (*d*) and navigation angle of the target ship [3].

This study presents collision risk calculation between ships at current time by utilizing AIS and fuzzy theory. Firstly, we identify ship encounter by using ship's domain. Secondly, we repeat a method for calculating DCPA and TCPA of each ship using ship's information data that are received from AIS. Lastly, the collision risk will be calculated based on FIS by inputting the DCPA and TCPA.

II. Automatic Identification System

AIS is a navigation device for providing information of ship and transmitting data to other nearby ships and AIS base stations automatically. AIS provides message of ships such as call sign, Maritime Mobile Services Identities (MMSI), tonnage, destination, position, course, and speed. Since 2004, IMO recommended new requirement for all vessels over 300 GT in international voyages, all cargo vessels over 500 GT and all passenger vessels to be equipped with AIS for providing information about the ship [16]. The data automatically exchange between ships and coastal using VHF radio waves. AIS receiver has been installed in Marine Reliability and Safety Laboratory, Institut Teknologi Sepuluh Nopember (ITS) which provide data about ships operating in Madura Strait. Visual monitoring provided by AIS in ITS can be shown in Fig. 2.

AIS has been widely used in many applications. Artana et al. combined AIS data and fuzzy clustering to measure danger score of ships. AIS data were also used to estimate the distribution of ship emission by combining with Geographic Identification System (GIS) [14]. Several research works utilized AIS data for ship evacuation assessment, hazard identification map, and vessel inspection [15], [16]. In 2012, collision alert system was developed by integrating VTS/AIS/marine geographic information system (MGIS) and applying fuzzy logic theory and analytical hierarchy process (AHP) to give an optimal decision for ship collision avoidance [17].

III. Risk of Ship-Ship Collision

A. DCPA and TCPA Calculation

This section shows the calculation of two important compositions of collision risk; DCPA and TCPA. DCPA is the shortest distance between two vessels which approaching each other. While, TCPA is the time needed to reach the point. Fig. 3 displays two vessels, named as ship *O* (own ship) and ship *T* (target ship). Both vessels move with different speed and course. DCPA between ship *O* and ship *T* is indicated by the space dash line [3].

Fig. 4 demonstrates the collision scenario between two vessels which maneuver and move with different speeds and courses. Firstly, DCPA and TCPA between vessel O and T can be found by calculating the relative speed to target ship measured from own ship refer to (1). DCPA can be seen in Fig. 4 as the distance between the parallel direction of target ship's position and the own ship's position.

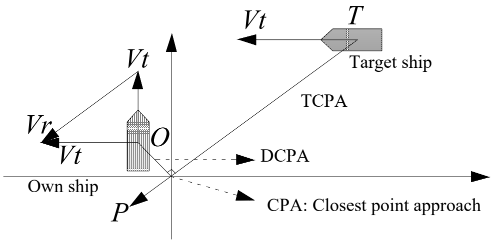

Fig. 3 DCPA and TCPA calculation [3]

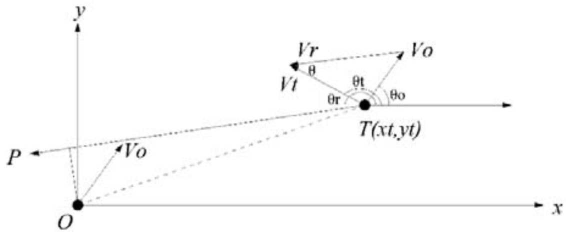

Fig. 4 Scenario for DCPA and TCPA calculation [3]

The relative speed of own ship to the target ship is calculated as (1):

$$V_r = \sqrt{V_O^2 + V_T^2 - 2|V_O \times V_T|\cos(\theta_T - \theta_O)} \quad (1)$$

DCPA and TCPA between two ships can be calculated by using (2) and (3):

$$DCPA = \frac{D|V_O \times \sin\alpha + V_t \sin\beta|}{\sqrt{V_O^2 + V_t^2 + 2\times V_O \times \cos(\alpha-\beta)}} \quad (2)$$

$$TCPA = \frac{D(V_O \times \sin\alpha + V_t \sin\beta)}{V_O^2 + V_t^2 + 2\times V_O \times \cos(\alpha-\beta)} \quad (3)$$

V_O = speed of own ship, V_T = speed of target ship, D = distance between own ship and target ship, α = relative bearing from own ship, β = relative bearing from target ship.

B. FIS

Fuzzy sets theory was firstly introduced by Zadeh in 1965 to deal with the uncertainty, ambiguous, and vagueness that may occur in many various problems [18], [19]. The process involves membership functions, fuzzy logic operators, and if-then rules. In this study, fuzzy system is used to determine the level of collision risk. Actually, there are many factors affecting collision risk including DCPA, TCPA, position of target ship, velocity ratio *K*, and collision angle. This study considered DCPA and TCPA as the most important factors to be inputted in fuzzy system [6].

Table I presents rule for DCPA, TCPA and Collision Risk (CR) that consists of five linguistic values [3].

Fig. 5 shows the membership function of CR. CR is defined by five linguistic variables using membership functions, which are defined between 0 and 1. Five linguistic variables in membership function of CR are adopted from previous research conducted by Chen et al. [3].

DCPA and TCPA are the input variables, while CR is the output variable. Rule for CR based on two input variables is shown in Table II.

TABLE I
RULES FOR DCPA, TCPA AND CR MEMBERSHIP FUNCTIONS

DCPA/m	Value	TCPA/s	Value	CR	Value
0-2	Small	0-4	Small	0-0.4	Low
1-3	Medium Small	2-6	Medium Small	0.2-0.6	Medium Low
2-4	Medium	4-8	Medium	0.4-0.8	Medium
3-5	Medium Big	6-10	Medium Big	0.6-1	Medium High
4-6	Big	8-10	Big	0.8-1	High

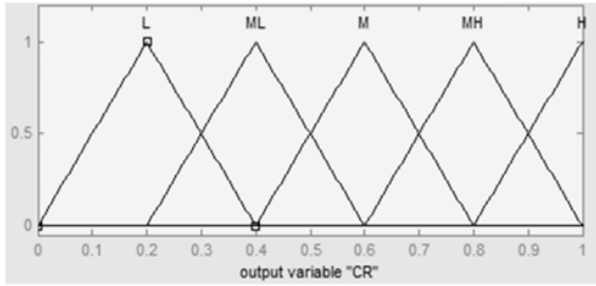

Fig. 5 Membership Function of CR

TABLE II
REASONING RULE OF DEGREE OF CR

CR		DCPA				
		S	M	MS	MB	B
TCPA	S	H	H	MH	MH	MH
	MS	H	MH	M	M	M
	MS	MH	M	M	ML	ML
	MB	MH	M	ML	ML	L
	B	MH	M	ML	L	L

IV. RESULT

A. Marine Traffic in Madura Strait

The AIS base stations used in this study are located in ITS Surabaya. Messages and data from ships are derived from AIS for a year in 2015.

Based on the data obtained from the AIS during 2015, it was shown that the highest traffic density occurred in April. In this study, the ship collision risk analysis is only conducted on April 8, 2015 at 3:00 am and 13:00 pm when the traffic reached its highest density. Fig. 6 shows the visualization of traffic patterns after decoding AIS messages.

Ship data obtained from AIS in that time are then analyzed and it can be concluded that there are two types of ship, passenger ship and general cargo, with a similar specification.

B. Ship's Domain in Madura Strait

Ship domain is one method to evaluate the collision risk in narrow channel. It is also used to show the characteristic of marine traffic in the specific area. Firstly, this paper compared two kinds of ship domain models proposed by Fujii [8] and Goodwin [9] for marine traffic in Madura Strait.

The author has analyzed the ship's domain in Madura Straits as a narrow fairway. Figs. 7 and 8 show ship domain model proposed by Fujii [8] for largest and smallest ship and Goodwin [9] that applied in Madura Strait. When both models are compared, it shows that area covered by Fujii's ship domain model is smaller than Goodwin's domain. It means that Fujii's domain gives more potential risk of ship collision because there are more ships entering the domain area.

From the concept of ship's domain, it can be concluded that marine traffic in Madura Straits is congested waterways since the ship enters into other ship's domain and the distance between ships is shorter than the length of domain. Therefore, all encounters are considered as dangerous encounter and need for a further risk collision evaluation.

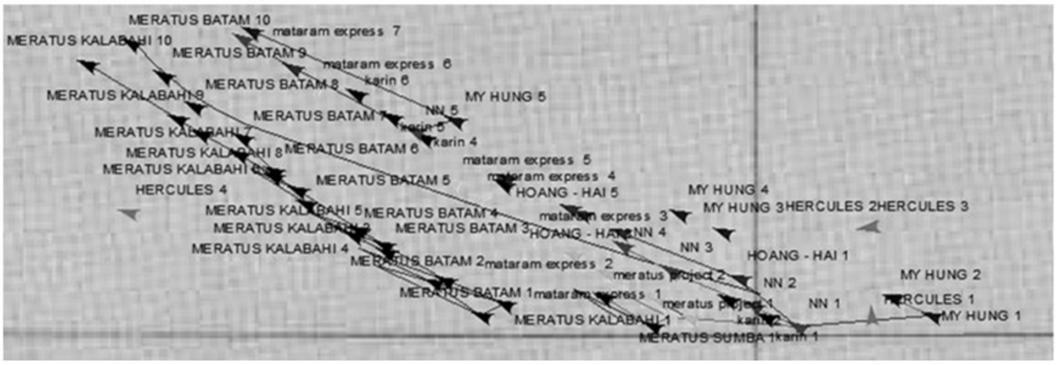

Fig. 6 The ships at Buoy 10 Surabaya West Access Channel, on 8 April 2015 at 3 am and 1 pm

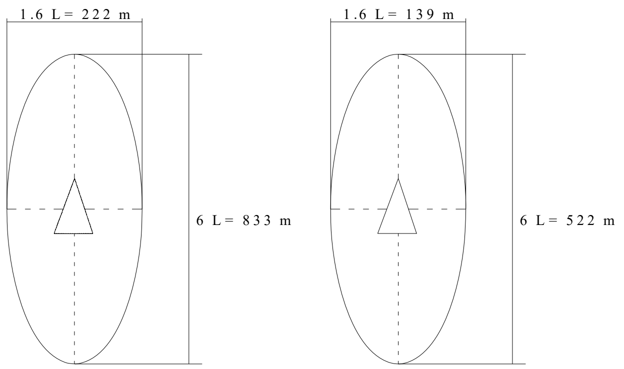

Fig. 7 Ship Domain by Fujii for Largest and Smallest Ship in Madura Strait

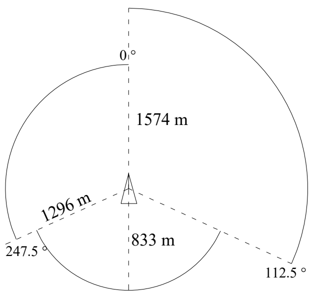

Fig. 8 Ship Domain Model by Goodwin [9]

C. Collision Risk Evaluation Using FIS

Collision risk of ships then calculated based on criterion of DCPA and TCPA as input of fuzzy system. From AIS data, there were seven ships which may give potential collision risk based on their encounter situation. All ships have been identified and it shows that there were seven encounters between ships in ship domain. The value of DCPA and TCPA are calculated using (2) and (3). They had been inserted in FIS as two input variables for resulting the risk collision as an output variable. Every value of risk collision is categorized into degree of CR which shows the collision risk level according to Table II. The calculation results of risk collision and their level for all encounters can be seen in Table III.

TABLE III
RESULT OF COLLISION RISK CALCULATION

Encounter	D (m)	α	β	Vr	DCPA (m)	TCPA (s)	CR	Level
Encounter 1	23	59	117	4.7	2.5	-4.8	0.74	MH
Encounter 2	158	28	152	6.0	96.3	-9.1	0.24	L
Encounter 3	152	19	156	6.9	7.2	23.3	0.23	L
Encounter 4	91	48	120	5.2	2.6	11.5	0.43	ML
Encounter 5	93	15	163	5.2	10.5	-3.0	0.43	ML
Encounter 6	80	41	135	9.5	28.7	-9.1	0.24	L
Encounter 7	26	26	154	4.1	11.2	-2.5	0.49	M

V. CONCLUSION

This study provides collision risk evaluation using ship's domain model and FIS based on DCPA and TCPA. Risk evaluation using ship domain model is not clearly enough because Madura Straits is a congested waterway with high traffic density. Collision risk is then calculated by FIS according to the two most important parameters, DCPA and TCPA, as input variables. From the analysis of risk of collision on April 8, 2015 at 3 pm and 13 pm at buoy 10, it is shown that there are some encounters or meeting vessels that have high collision risk of ships, namely 0.74. Based on rules, the value of 0.74 is included in the category of Medium High (MH). Higher value of collision risk could be caused by the position of both ships, so that the distance between the two vessels was relatively close. Moreover, heading angle of the ships toward to the closest point of approach makes the level of risk become higher. Based on the analysis performed in this study, the data received from the AIS can be used to assess the risk collision of ships. Collision risk produced by this paper is expected to be used as guidance to avoid the accident, providing brief description about safety traffic in Madura Strait and improving the navigational safety in the waterway.

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