Collision Avoidance Evaluation for Vessels Navigating in the Straits of Malacca

M. Rajali Jalal[1], Adi Maimun[1], Rahimuddin[3] and Istaz Nusyirwan[2]

[1]*Marine Technology Centre,* Faculty of Mechanical Engineering, *Universiti Teknologi Malaysia*
[2]*Department of Aeronautics, Automotive & Ocean Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia*
[3]*Universitas Hasanuddin, Makassar, Indonesia*

*Corresponding author: adi@mail.fkm.utm.my

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ABSTRACT

This paper presents the collision avoidance assessments for ships passing through the Straits of Malacca. The data of the ships traffic in Strait of Malacca were obtained from automatic identification system (AIS) receiver installed at the Marine Technology Centre, Universiti Teknologi Malaysia (UTM). A MATLAB program was developed firstly to retrieve the data for assessing the collision risks and secondly, for evaluating collision avoidances by using fuzzy logic for a specified ships traffic area and period of time. The fuzzy membership function for collision risk assessment that have been considered for analysis, were distance to the Closest Point Approach (DCPA) and Time to the Closest Point Approach (TCPA). While fuzzy membership function for collision avoidance decision making were collision risk and collision condition. The decision making was formulated in accordance with the International Maritime Organization Convention on the International Regulations for Preventing Collisions at Sea (COLREGs), 1972, to avoid conflicts that might occur during sea navigation in the strait. Three critical collision conditions were evaluated for collision avoidance decision making, namely, head on situation, crossing situation, and overtaking situation. The results showed that the recommended decision makings from the developed fuzzy logic program follow well the COLREGS.

KEY WORDS: *Straits of Malacca, AIS, Fuzzy Logic, collision avoidance*

NOMENCLATURE

AIS	Automatic Identification System
DCPA	Distance to Closest Point Approach
TCPA	Time to Closest Point Approach
MMSI	Maritime Mobile Service Identification
IMO	International Maritime Organization
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea
FIS	Fuzzy Inference System
SOG	Speed Over Ground
COG	Course Over Ground
δV	Speed Changes
$\delta\psi$	Course Changes

1.0 INTRODUCTION

The Straits of Malacca is one of the world's busiest shipping routes. It has long been main shipping channel between the Pacific Ocean and the Indian Ocean, linking major Asian trading countries such as China, South Korea, India and Japan. Annually, over five thousand ships passing through the straits, carrying about one-quarter of the global traded goods including Indonesian coffee, Chinese manufactures and oil. Nevertheless, the many ships moving back and forth the straits face the risk of colliding with each other.

On 21st September 1992, as reported in The Star News, A Japanese Oil Tanker (ninety five thousand ton Nagasaki Spirit) and a Hong Kong Container Ship (twenty thousand six hundred ton Ocean Blessing) collided in the congested Malacca Straits. Both burst into flames, and at least one crewman died while twenty five others were rescued. The safety issue was immediately discussed in the meeting that week.

Another case on 19th August 2009, Bloomberg reported collision between a 73,207-dwt Ostende Max (built 1998) and a 70,426-dwt Formosa product Brick (built 2005), which caught fire about 20 nautical miles off Port Dickson. Two died while nine others crewmen went missing in the incident.

The incidents highlight the risk that the more than ninety thousand ships face through every year when navigating the increasingly crowded straits between Malaysia and the Indonesian island of Sumatra, as well as the straits of Singapore. The straits of Malacca with 965 kilometres channel is almost six times busier than Suez Canal due to the 33 percent of global seaborne crude oil passing through it.

Many researchers are trying to develop more effective decision making system for the moving ships at sea. The system could help to increase the safety of navigation and prevent accident. The decision making system is similar to the human brain; able to calculate the collision risk between ships. In consequence, it will define the best decision in critical situation to prevent vessel collision, and send earlier warning and avoidance message to mariner.

An overview of the Autonomous Guidance and Navigation (AGN) systems was made by Perera et al. (2009), with respect to the collision avoidance in ocean navigation. In accordance with International Maritime Organization (IMO) Convention on the International Regulations for Preventing Collisions at Sea (COLREGS), they conducted a case study of a fuzzy logic based decision making process.

Ant colony algorithm, which was introduced by Dorigo et al. (1982), has successfully been used by Ming-Cheng Tsou et al. (2010) to solve a number of real-life problems, such as travelling salesman problem (TSP). As a whole, the ant colony algorithm has a unified framework model, which embodies positive feedback, robust, and has distributed computing characteristics. Therefore, for collision avoidance, the ant colony algorithm is indeed well suited.

Microsoft Visual Studio was used by Chien-Min Su et al. (2012) to establish a knowledge base of international regulations to prevent collision at sea. Thus, based on analyzing the situation when encountering other ships, using a fuzzy monitoring system, the knowledge base suggests an appropriate avoidance technique. It then proposes a novel collision danger domain that forbids entering for give-way ship.

Therefore, this study is done to develop a more intelligent decision making system that is able to not only detect the collision risk but also make the right decision to prevent marine accidents. This system calculates the collision risk in current time and also predicts the collision risk of next time. If the collision risk of next time step is higher than current time, the system will take action in advance and prevent the collision accident.

2.0 METHODOLOGY

2.1 AIS Data Collection

As reported by Maimun et al. (2013) and Koto et al. (2014), AIS data receiver at the Marine Technology Centre, UTM was used to collect the data along the Straits of Malacca and Singapore. The raw collected data was in .csv format and including several information about the ships data such as vessel structural data, speed, course and position. In addition, the data also provided static information such as type of ship, Call Sign and Name, IMO number, Maritime Mobile Service Identity (MMSI), beam, length, and position/location of communication antenna.

2.2 Fuzzy Logic Collision Risk Assessment

Ship collision risk was the first part to be evaluated in this research. The input variables selected for the fuzzy logic collision risk assessment were Distance of Closest Point Approach (DCPA) and Time of Closest Point Approach (TCPA) as per introduced by Shu Chen (2013).

Fuzzy logic inference system is developed from calculating the input linguistic variable, and is the core of a fuzzy logic control system. The Mamdani FIS is being considered for this paper. Mamdani and Assilian (1999) discussed the details of the Mamdani FIS, and stated that there are five kinds of defuzzification processes: smallest of maximum, largest of maximum, centroid of the area, mean of maximum and bisector of the area. The basic rules of the inference module consists of if a = maximum and b = maximum, then c = maximum, which is called Maximum-Criterion method. In this method, a random value is selected from the set of maximum elements. The fuzzy linguistic rules with linguistic variables are used to build the linguistic fuzzy model of Mamdani. The system has multi-input multi-output system type, since the antecedents and consequences of rules are expressed in several linguistic variables. This kind of system includes set of rules having the following form:

IF x is A_1 and y is B_1 THEN z is C_1
IF x is A_2 and y is B_2 THEN z is C_2
...
IF x is A_n and y is B_n THEN z is C_n

where x and y are the input variables, z is the output variable, A_n, B_n and C_n are linguistic values of the linguistic variables x, y and z in the universes of discourse U, V and W, respectively. Here, the DCPA and TCPA are input of fuzzy logic and output the collision risk.

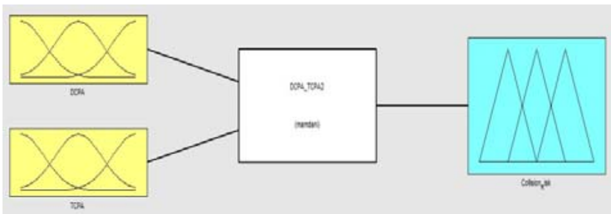

Figure 1. Two input – one output System

Figure 1 shows the two input – one input fuzzy linguistics rules. this linguistics expression has been used to develop Fuzzy Membership Functions.

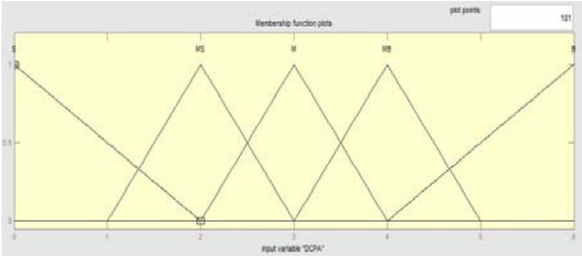

Figure 2. Fuzzy Membership Function for DCPA input

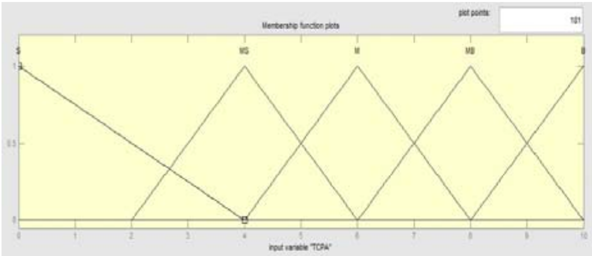

Figure 3. Fuzzy Member ship Function for TCPA input

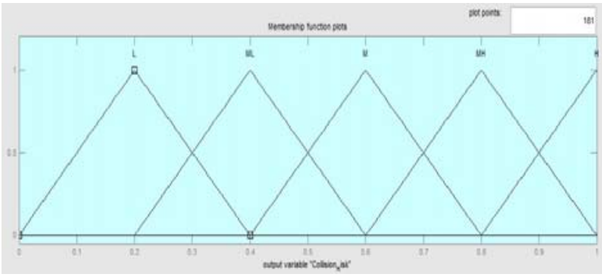

Figure 4. Fuzzy Membership Function for Collision Risk output

Figure 2 and Figure 3 indicate the fuzzy membership function for the two input variables; DCPA and TCPA respectively. Meanwhile, the fuzzy membership fuzzy for ship collision risk is indicated in Figure 4. DCPA and TCPA were noted as the process state variables, and CR was the control variable.

2.3. Fuzzy Collision Avoidance Decision Making Assessment

Similar with previous section, collision avoidance decision making was also determined by fuzzy logic system. The output variable, Collision Risk was used as the input variable, together with the Collision Situation. The collision situation is divided into three part which are; Head On, Crossing and Over Taking. Crossing situation occurs at three different angles, as shown in Figure 5.

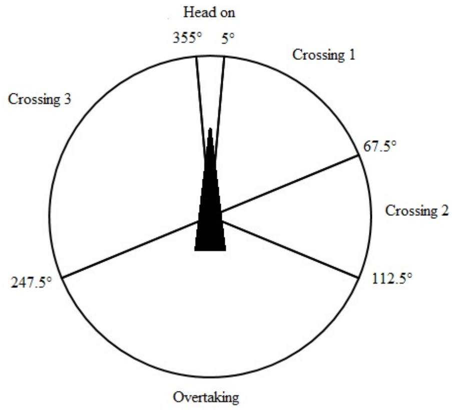

Figure 5. Ship Collision Situation

The decision making parameter in fuzzy logic was referred to the research by L.P Perera et al (2011) which are speed changes and course changes. They put the interval for the speed changes between -10 to 10 weightage value; the negative value is for slow down decision. Meanwhile, for course changes, they put the intervals between -40 to 40 weightage value. Negative and positive values mean that the own ship should turn to port side and starboard side, respectively.

The reasoning can be expressed in linguistic rules of two-input-two-output system, as shown in Figure 6. The Fuzzy Membership Functions for this study were developed from this linguistics expression.

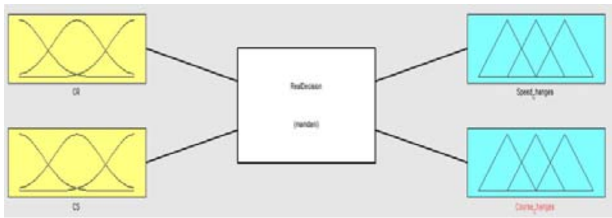

Figure 6. Two input- Two Output System

At this stage, the input linguistic variables are Collision Risk and Collision Situation as mentioned before. While, the output linguistic variables are Speed Changes and Course Changes. Collision Situation is represented by the relative angles for the Target Ship with respect to the Own Ship.

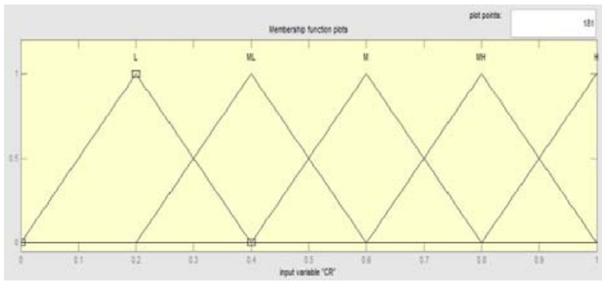

Figure 7. Fuzzy Membership Function for Collision Risk Input

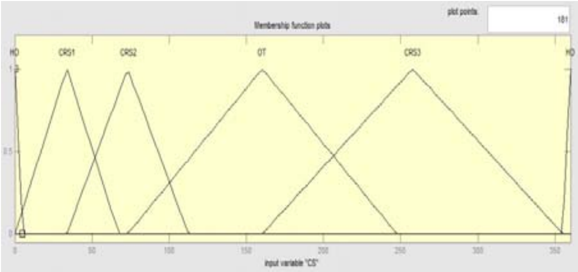

Figure 8. Fuzzy Membership Function for Collision Situation Input

Figure 7 and Figure 8 indicate the fuzzy membership function for two input variables, Collision Risk and Collision Situation, respectively.

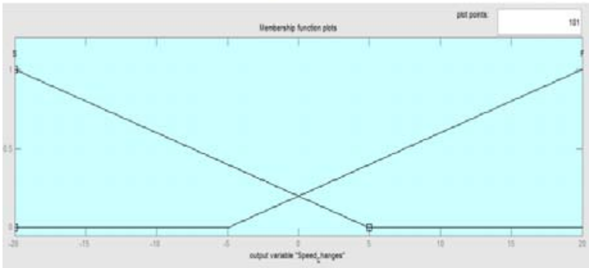

Figure 9. Fuzzy Membership for Speed Changes Output

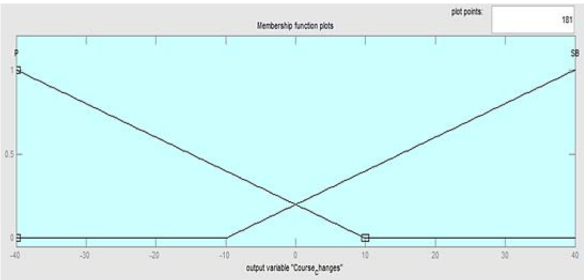

Figure 10. Fuzzy Membership for Course Changes Output

Meanwhile, for fuzzy membership fuzzy for two outputs variables for collision avoidance decision making, the speed changes and course changes are indicated in Figure 9 and Figure 10.

2.4. Simulation Process

A virtual Own Ship has been determined in the area of study. The speed and the heading of the Own Ship is set to 10 Knots. Two areas were selected for this evaluation, which was the region 1, the evaluation of the Own Sip was starting at 1.234° latitude and 103.387° longitude, and region 2, starting at 1.177° latitude and 103.832° longitude. The heading of the Own Ship at region 1 and 2 is 120° and 63° respectively.

Region 2 is located almost to the Straits of Singapore due to its heavy density. Also, the position of the ships along the Region 2 is nearer one to another compared with those in the Region 1. The data collected from the AIS data is being pre processed to calculated the DCPA, TCPA and Relative Angle of the Target Ship with respect to the Own Ship.

The simulation was conducted using Fuzzy Logic program in the MATLAB programming software. After both fuzzy logic programs had been developed, a MATLAB programming script was written in the M file format. The purpose of writing the programming script was to integrate both fuzzy logic programs into one simulation process. In fact, the data loading became easier compared to manual key-in in the developed fuzzy logic programs. The data had been compiled into Microsoft Excel format files.

3.0. RESULT AND DISCUSSION

3.1. One Hour Duration Collision Risk Assessment

Collision risk assessment was done in one hour at Straits of Malacca (Region 1) and Straits of Singapore (Region 2) on 1st May 2010 starting from 12.00 a.m. As mentioned in previous section, the data was obtained from AIS installed in UTM. The results of the Collision Risk Assessment by using the fuzzy logic program are shown in Figure 11 below.

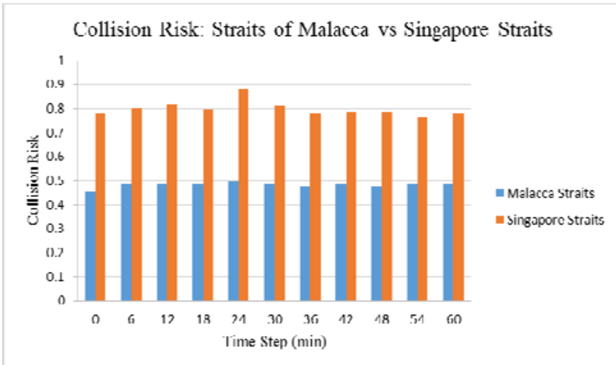

Figure 11. Collision Risk Value for Straits of Malacca vs Straits of Singapore

Collision risk assessment is a continuous assessment which has to be done all the time. It is because a ship faces different risk while sailing at the sea at different times and positions. In normal practice, when a ship is sailing at the sea, the condition of the ship is monitored every 6-minute time step as stated by AMSA (2008). Therefore, in this research, the risk of the ships was assessed in a 6-minute time step in duration of one hour. By using the developed fuzzy logic program for Collision Risk Assessment, the collision risk value of the Own Ship moving in Straits of Malacca was found from 0.45 to 0.49. It shows that the risk of the Own Ship moving along the Straits of Malacca in that particular duration is averagely in the medium risk. Meanwhile, for Own Ship moving along the Straits of Singapore, the value CRA was from 0.76 to 0.88. It shows that the risk of the Own Ship moving along the Straits of Singapore at particular date and time is averagely in medium high risk.

The risk reached high value at 24th minutes for both Straits of Malacca and Straits of Singapore, with averagely 0.499 and 0.8796, respectively. This was due to one or more target ships having lower value of DCPA and TCPA at that particular time. The risk value of the moving ships along the Straits of Singapore is averagely 50% higher than the Straits of Malacca.

3.2. Head to head Collision Risk Assessment.

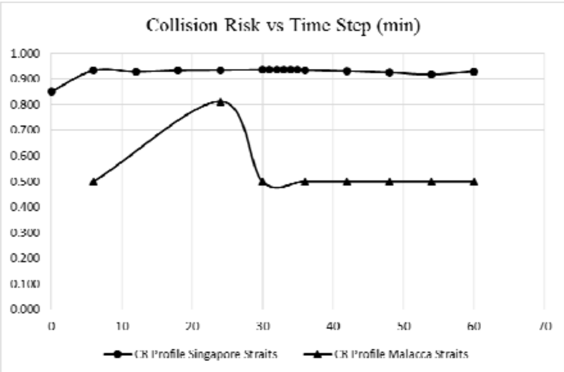

Figure 12. Head to head Collision Risk Profile in Malacca and Straits of Singapore.

One target ship was selected for the head to head collision risk assessment at the Straits of Malacca and Straits of Singapore. The target ships MMSI numbers were 563009210 and 636013706, respectively. The collision risks were plotted with respect to time in 1 hour duration, as shown in Figure 12. The collision risk value of moving Own ship in Straits of Singapore was consistently at high risk within the 1 hour duration assessment. Meanwhile, along the Straits of Malacca, the collision risk was mostly at 0.5, except at 24th minutes, with 0.8126. The data was captured at 6th minute, and then jumped to 24th minute. The explanation on the higher risk occurring while proceeding to 24th minute could be ignored due to the absence of data between 6th to 24th minute.

No.	Ship ID	Relative Angle θ_r	DCPA (Nm)	TCPA (hr)	Collision Risk (CR)
1	220565000	2.75	1.42	0.21	0.8000
2	220565000	9.75	0.57	0.08	0.9318
3	440661000	150	0.21	0.08	0.9311

3.3. Collision Avoidance Decision Making Assessment

Table 1. Selected Result of Collision Avoidance Decision Making

Speed Change δV	Course Change $\delta\psi$	Collision Condition
-10.142	20.285	Head On
-9.304	18.609	Crossing 1
11.037	-22.074	Overtaking

Table 1 shows the result of collision avoidance decision making from the developed fuzzy logic program. The tabulated result is only the selected result data that shows the action of the Own Ship when facing critical collision condition. The collision condition includes head on, crossing and overtaking situation. The result values from the δV and $\delta\psi$ do not represent the value of speed needed to be changed or the angle of course to be turned. They only represent the weightage value of the action to be taken by the Own Ship. For speed changes, any positive numbers would mean the Own Ship is suggested to increase the speed to take action, and vice versa. Meanwhile, for course change, any positive numbers would mean the Own Ship is suggested to turn the ship to the starboard side, and negative numbers to port side. The zeros value would mean the ship should not take any action but retain the speed and course. The selected result data can be visualized as in the figures below.

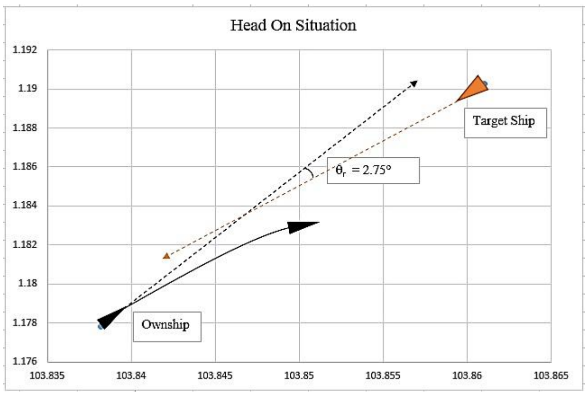

Figure 13. Result of the Head On situation

Figure 13 shows a graph on head on situation between Own Ship and Target Ship. In this situation, the Target ship is in the ‘‘Give way’’ situation and the Own ship is in the ‘‘Stand on’’ situation. However, in the simulation, the Target Ship did not take any appropriate actions to avoid the collision situations. Therefore, the Own Ship changed its velocity and course to avoid the collision situation. The weightage value of speed change and course change of the ship were -10.142 and 20.285, respectively. It means that the Own Ship decreased the speed and turned her course to starboard side to avoid collision.

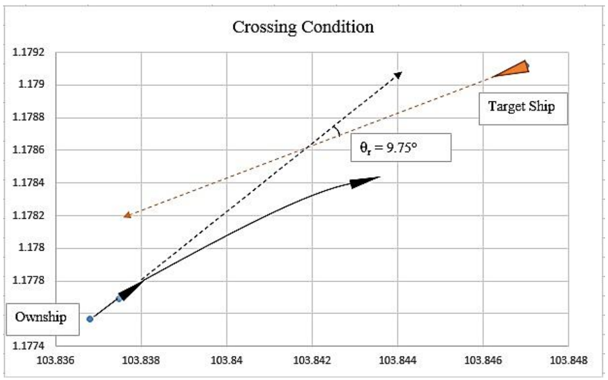

Figure 14. Result of the Crossing Situation

Figure 14 shows the crossing situation between Own Ship and Target Ship. In this situations, the Target Ship is in the ‘‘Give way’’ situation and the Own Ship is in the ‘‘Stand on’’ situation. However, in the simulation, the Target Ship did not take any appropriate actions to avoid the collision situations. Therefore the Own Ship changed its velocity and course to avoid the collision situation. The weightage value of speed change and course change of the ship were -9.30 and 18.61, respectively. It means that the Own Ship decreased the speed and turned her course to starboard side to avoid collision.

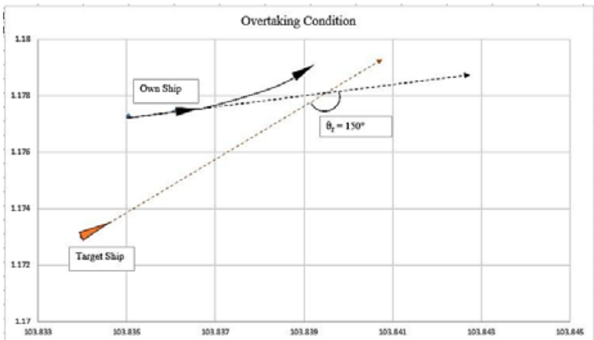

Figure 15. Result of the Overtaking Situation

Figure 15 shows the Overtaking situation between Own Ship and Target Ship. In this situations, the Target Ship is in the ‘‘Give way’’ situation and the Own Ship is in the ‘‘Stand on’’ situation. However, in the simulation, the Target Ship did not take any appropriate actions to avoid the collision situations. Therefore, the Own Ship changed its velocity and course to avoid the collision situation. The weightage value of speed change and course change of the ship were 11.037 and -22.074, respectively. It means that the Own Ship increased the speed and turned her course to port side to avoid collision.

3.4. Head to Head Collision Avoidance Decision Making Assessment

One Target Ship was selected for head to head collision avoidance decision making assessment. The assessment only focused at Straits of Singapore due to no critical collision condition found at Straits of Malacca.

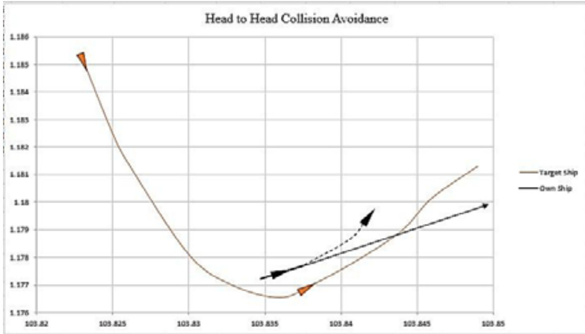

Figure 16. Result of Head to Head Collision Avoidance Assessment

The selected Target Ship MMSI number was 636013706. The dynamic AIS data of the ship was captured in every time step. Hence, the route of the ship was plotted along with the Own Ship. As shown in Figure 16, the Target Ship moved from behind the Own Ship until at one point to make a turn to the port side. In this situation, the target overtakes the Own Ship. However, in the simulation, the Target Ship did not take any appropriate actions to avoid the collision situations. Therefore, the Own Ship changed its velocity and course to avoid the collision situation.

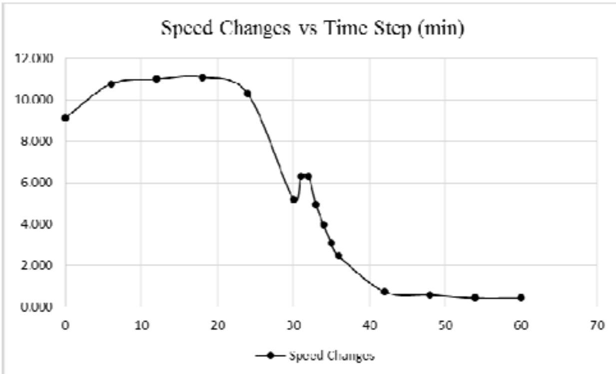

Figure 17. Speed Change weightage values at every time step

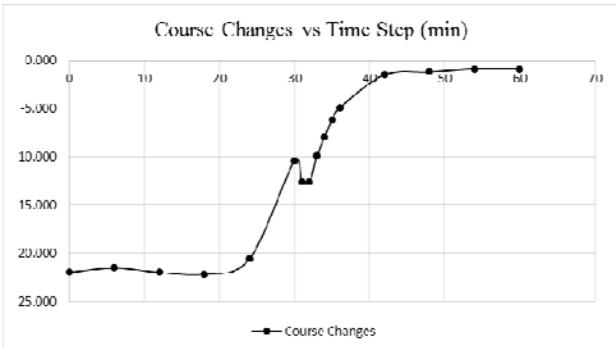

Figure 18. Course Change weightage values at every time step

The actions recommended to be taken are displayed in Figure 17 and Figure 18 for δV and $\delta\psi$, respectively. All values of δV are positive numbers. It means that the ship is recommended to increase the speed from the beginning to avoid the collision.

Meanwhile, all values of δψ are negative numbers. It means that the ship is recommended to change the course to the port side to avoid collision. The action to be taken by the Own Ship is illustrated in the figure above. All the values remaining at zeros towards the end means that the ship is recommended not to take any action due to no critical collision condition existing at that particular time. The figure shows the simulated result from the captured data. However, in real time, if this situation occurs, the pilot should take possible action earlier to avoid collision because he could not expect what might happen in the next few hours or even minutes.

4.0. CONCLUSION

A fuzzy logic simulation program able to assess the collision risk and collision avoidance of a moving ship has been successfully developed. The fuzzy logic is separated into two parts, which are collision risk assessment and collision avoidance decision making. The input linguistics variable of collision risk assessment are DCPA and TCPA. Meanwhile, the input linguistic variable for collision avoidance decision making are collision risk and collision condition, with reference to relative distance of the ships. A program in the M file of MATLAB has been written to simulate the program from the AIS data. The collision risk assessment has been conducted by using the developed fuzzy logic program. It is divided into two parts of assessment according to two areas, the Straits of Malacca and Straits of Singapore. The first part is a 1-hour assessment at selected date and time. The selected date and time is May, 1st 2010 and 0000 hrs, respectively. The assessment has been conducted in 6-minute time step. It is found that collision risk along Straits of Singapore is 50% higher than Straits of Malacca. The second part constitutes the head to head collision risk assessment between Own Ship and Target Ship. The result shows that the collision risk between two ships at Straits of Malacca is almost at 0.5 at every time step, which means that the ship is in medium risk. Meanwhile, the assessment on the Straits of Singapore shows that the value of the risk ranges from 0.8 to 0.93 at every time step, which means Own Ship is in high risk condition. Three critical collision conditions have been evaluated for collision avoidance decision making, which are head on situation, crossing situation, and overtaking situation. The results show that the recommended decision makings from the developed fuzzy logic program indeed follow the COLREGS. Head to head collision avoidance decision making also gives a good result and the recommended decision at every time step follows the COLREGS.

Although successful computational results have been obtained under critical collision conditions, it is assumed that more complex collision conditions in multi-vessel situations may possibly occur, and unexpected actions of the Target vessels may be experienced. Hence, higher capabilities must be formulated into the decision making system to overcome such unexpected situations. The input linguistics variable could be extended to some other inputs such as the collision region, relative distance, relative speed, collision angle, size of the ship, etc., since more input variables being considered makes the assessment become more realistic. As for the action of speed changes and course changes, one or more algorithms could be derived as they can help link the recommended action by the fuzzy logic program to the propulsion and manoeuvring system. The recommended action can estimate how much speed needs to be changed, or how much angle of degree that the ship should be turned. The development of the real time assessment can provide more valuable data to the controller and the pilot.

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