PREDICTION OF SHIP COLLISION RISK ON SINGAPORE STRAIT USING AIS DATA

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ABSTRACT

Straits of Singapore are one of the most congregate seaways in the world. These seaways are the main connection for the ships travelling between the western part and the eastern part of the world. From the statistical record, approximately 1,500 vessels were passing through the straits of Singapore daily. Ship to ship collision occurs frequently in these areas due to a large amount of ships movement. To assess the risk of ship collision on the Straits of Singapore, an AIS receiver station was set up by local researchers with the fund and support from Ocean and Aerospace Research Institute, Indonesia (OCARI). Computer software is also developed to decode the AIS signal received and to assess the risk profile of the traffic using Pedersen Method (1995). This self-developed decoder and analysis software is built under the assistance and guidance of Centre of Marine Technology and Engineering, Portugal (CENTEC). To obtain the risk of collision between ships, the software serves to calculate the number of collision candidates by considering the ship movement pattern, average ships speed in each course, ship course, the distance between ships and principal dimensions of the ships which use the Straits of Singapore. Due to the complicated traffic flow in this region, this paper only focuses in discuss the expected number of collisions for the head-on traffic and crossing traffic. To predict the expected number of collisions, the value of causation probability obtained from literature are used. Finally, this paper also presented the traffic pattern and predicted a risk of collisions in the Straits of Singapore based on the AIS data received between September 2019 to October 2019. It is found that cross-traffic collisions may happen every 3.8 years while head-to-head collisions may happen every 3.4 years.

KEYWORDS

Ship Collision Risk; straits of Singapore; AIS data

INTRODUCTION

1.1 Geographical Location of Singapore Straits

Singapore Strait is a channel connecting Malacca Straits and the South China Sea with a total length reaching 105 km (65 miles). The strait is 16 km (10 miles) wide and lies between Singapore Island on the north and Riau Islands in the south, part of Indonesia (Leinbach et al., 2021) Singapore strait is also surrounded by a lot of small islands. Besides, Singapore is also one of the world's busiest commercial routes (Leinbach et al., 2021).

1.2 Ship Collision Analysis

Ship collision analysis is a study of a collision for a ship and it can be done using various methods. Ship collision risk is addressed by different governing standards that include regulatory standards, classification society standards or guidelines. (Zhang et al., 2019). Ship collision is considered an important field as it is used to ensure that serious ship accidents can be reduced and service disruptions are low. International Maritime Organizations (IMO) Maritime Safety Committee (2013) established a procedure for Formal Safety Assessment (FSA) as a proactive approach to evaluating the risk associated with the different hazards.

This study is focused on ship head-to-head collision and cross collision in the Singapore Strait. The collision type is different by considering how the ship meets each other. When the heading angle between two ships is between -10^0 to 10^0, it is assumed that both the ships can involve in head to head collision. In opposite, if the ship meets each other at 10^0 to 170^0 then it is assumed that the ship has the possibility of a cross collision.

2.0 COLLECTING OF SHIP MOVEMENT DATA AND SHIPS DIMENSIONS

2.1 Using of AIS for Ship movement information

An Automatic Identification System (AIS) is a tracking system working automatically, to help the ship's pilot identify another ship in the vicinity. AIS is mandatory equipment that must be installed in every ship registered under IMO. SOLAS (2002) stated that AIS is intended to enhance the safety of life at sea, the safety and efficiency of navigation, and the protection of the marine environment.

AIS system transmitted two kinds of information, which is static and voyage related information. This kind of information was set up by a crew of the vessel and it is transmitted every six minutes. The next information is related to the dynamic information, which will be automatically transmitted depending on the vessel's speed and course underway every 2 to 10 seconds.

AIS data packet consists of several payload interpretations in form of data type. A total of 27 different data types, each of them carrying a different type of information can be sent by the AIS data transmitter. To obtain the ship movements and ship dimension data, only data type 1,2,3,18,19 and 24 will be used.

To receive the AIS signal, one AIS station was set up at Balai Cerapan, Universiti Teknologi Malaysia as shown in Figure 1. Balai Cerapan, UTM is around 145 meters above sea level, and it is the second-highest point in the Johor Bahru district. This advantage will allow the AIS station to receive a high number of AIS signals for the ship travel in this region. Based on the signal process it was found that this AIS station was able to receive the signal from a ship located as far as 100 kilometres from the station. Where the receiver can detect the ship located nearby Batu Pahat and Mersing from North to Batam Island from South. The signal received by the AIS receiver is transferred to Microprocessor, Raspberry Pi and then save as a text file. After that, the data text file is uploaded to the server and the local computer will automatically collect the data from the server and then decode it in the local computer.

Figure 1: AIS receiver station at Balai Cerapan, Universiti Teknologi Malaysia.

2.2 Collecting of Ships Dimensions Information

In collecting data for ship dimension, field 6 in AIVDM data packet will decode first to determine which type of data that particular sentence carries. After decoding, the first 6 length bit field of the decoded sentence is analyzed to determine which data type that carried. To obtain information about the dimension of the ship, the AIS sentence type 5 is required to further decode.

Data type 5 carries static and voyage related data, which this data packet usually consist of 424 bits carried b 2 different AIVDM data sentence. To obtain the ship dimension, fields numbered 240 until 269 were analyzed. From field number 240 to 248, it will use to obtain the dimension to bow and for dimension to stern, field numbered 249 to 257 will be used. For dimension to port and dimension to starboard, filed numbered 258 to 263 and 264 to 269 will be used respectively.

Besides, the data collection system is also designed to automatically search the ship dimension data from marine traffic websites if the static related data for the ship is unable to identify from the AIS signal. The automatic system also will compare the ship dimension extract from the AIS signal with the website to minimize the wrong information.

The information of the ship dimension then will be added according to each type of the ship and the average of each ship class will be calculated before applying it into Pedersen's method (1995).

3.0 CHARACTERIZATION OF MARITIME TRAFFIC OFF SINGAPORE STRAITS

3.1 Traffic Separation Schemes

A traffic separation scheme is a maritime traffic-management route system managed by the International Maritime Organization (IMO). The practice to follow predetermined ship routing is invented in 1898 and it is widely used in the shipping industry nowadays for the reasons of safety and smoothness of the traffic. Traffic separation schemes and other ship routing systems have now been established in the most major congested shipping areas of the world and had dramatically reduced the number of collisions and groundings in these areas (IMO, 2020).

As stated in SOLAS chapter V, IMO is recognized as the only international body for establishing such traffic separation schemes and ship routing systems (IMO, 2020).

IMO (2020) stated that any government that intends to establish a new routing system or improve the existing one, must send the proposed new ship routing system to IMO's Sub-Committee on Navigation, Communication and Search and Rescue NCSR. The proposal then will be evaluated and suggesting recommendations regarding the proposal. For the way to operate traffic separation scheme, it can be seen in rule 10 made by COLREG. The traffic separation scheme in Singapore Strait is shown in Figure 2.

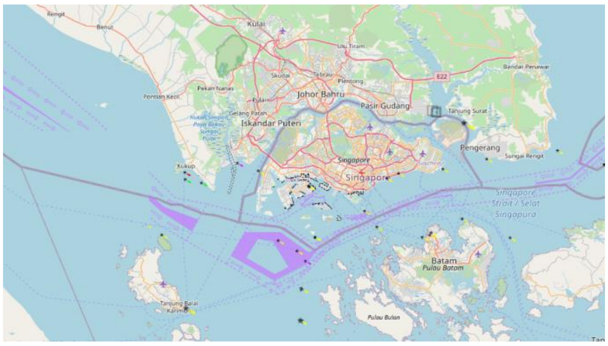

Figure 2. Traffic Separation Scheme at Singapore Straits

3.2 Statistical Data of Marine Traffic

From the statistical data, on average there were around 100,000 ships pass through the 105 km-long Singapore straits each year. In this paper, the data of ship movement between September 2019 to October 2019 was collected. By processing the data for this month, it is obtained that 7541 ships are moving in the Singapore Straits where some of the ships are visiting the straits more than once. Besides, some of the recorded ships are operated in the Singapore straits to shift the cargo and passengers between Malaysia, Singapore and Indonesia.

As shown in Figure 3, there are 44 % of ships in Singapore straits are Cargo ships which included bulk carriers, container ships etc. Besides, the second-largest percentage of ships detected are tanker ships which have a percentage of around 29%. Both the cargo ship and tanker ship contribute 73% of the total ship in the Singapore straits. The reason for this large amount of these two ship types in this area is because this is the shortest sea route to connect the Indian Ocean to the Pacific Ocean therefore most of the cargo shipments between eastern and western countries are passing through this sea route.

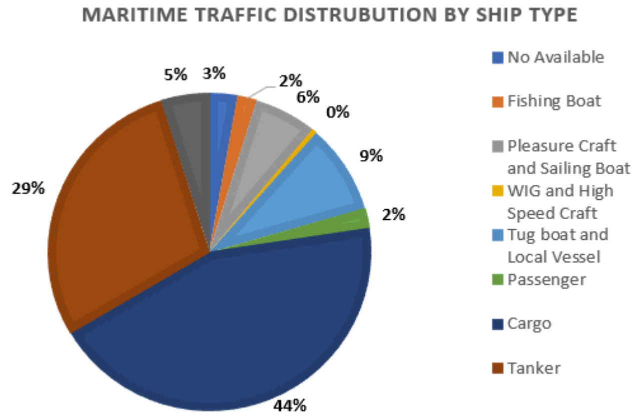

Figure 3: Ship using Singapore straits according to ship type

By categories the ships according to the overall range as s shown in Figure 4, it shows that vessel range from 1 to 50 meters is the highest number of ships that moving in Singapore Strait. The strait is a seaway surrounded by three different countries, which are Malaysia, Indonesia and Singapore. Most of the small vessels that use this seaway is a ferry connecting thus three countries. Other than small passenger vessels, tugboats are also the main contributor in the small vessel number against the number of ships. Tugboats use in the berthing and anchoring process of a ship by either pushing or towing the ship to the port. Around Singapore Strait, there are two main ports, which is Port of Singapore, Singapore and Port of Tanjung Pelepas, Malaysia, so there is a lot of tugboats operating around the Singapore Strait to assist all those big vessels.

By studying Figure 4 in more detail, it shows that most ships travelling in Singapore Straits have a length over 100 meters. Where these big size ships are either cargo vessels or tanker ships. Hence, the collision risk in the Singapore Straits also increases due to the large average size of the ships transit in the region. This is because the Singapore straits is a narrow and busy seaway and the long ship normally need a larger turning circle and longer time to stop.

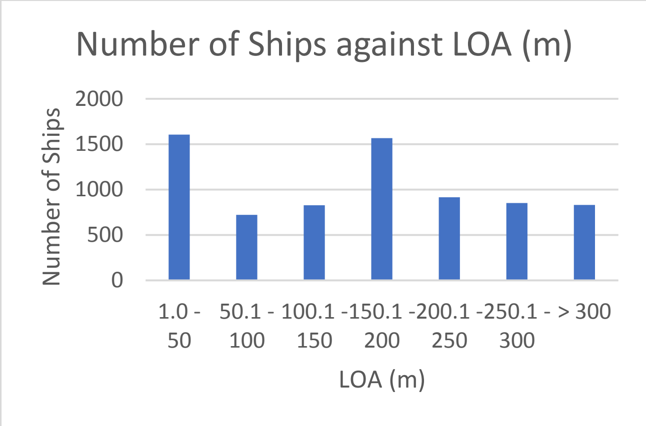

Figure 4: Number of ships against the LOA (m).

Figure 5 shows that the ship using the Singapore Straits can come from Melaka Straits, the South China Sea or travel crossing the Singapore Straits to transport products or passengers between Singapore, Malaysia and Indonesia. From the AIS data, there are some amounts of the ships that anchor berth at Singapore Port and Port of Tanjung Pelepas but some of them will only pass through the straits without berthing. The large size ships that sail through Singapore Straits are mostly moving in deep water locations as according to the Traffic Separation Scheme.

From the AIS signal, it is also shown that some of the ships using the TSS in Singapore Straits are over the speed limit which is 12 knots. This observation was also reported by Qu et.al (2011) where they reported that around 25% of the ships sail at the straits are over the speed limit. Based on the data collected in this paper, the location of ship sail with a speed over the limit in Singapore Straits are shown in Figure 6. Figure 6 shows the ships that do not follow the speed limit are available along the straits. From a more detailed study, it is found that the ships which do not follow the speed limit are Passenger ships, Pilot Vessel, Pleasure Craft and other types of ship which do not classify in AIS messages and the ships where the information are unavailable in this system.

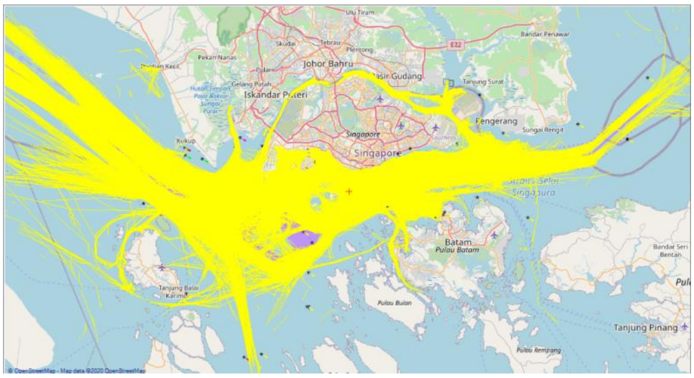

Figure 5: Ship route at Straits of Singapore

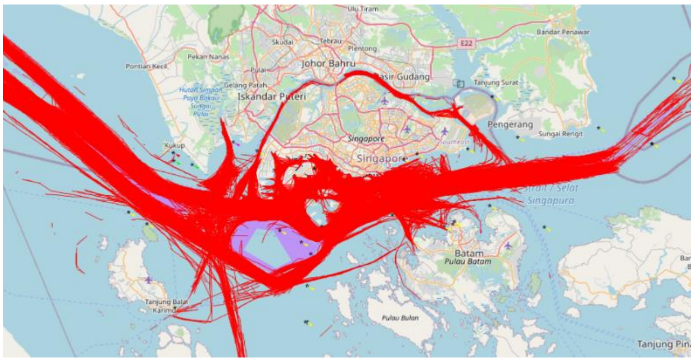

Figure 6. Location of detected overspeed ships in Singapore Straits

4.0 TRAFFIC CHARACTERISATION ON SELECTED ROUTES

From the AIS message obtain, part of the ships that sail in Singapore straits are only moving in a certain region of the straits. Also, some ships only sail within the region. In this study, the number of collision candidates is considered for the ship which sails in the TSS region. The TSS region at Singapore straits is shown in Figure 2. To better observe the ship movement in the straits, several locations are selected in this study to quantify the number of ships that pass through each segment of Singapore straits and the ship moving direction. The locations selected as the checkpoint to count the number of ships that pass through the segment are presented in Figure 7.

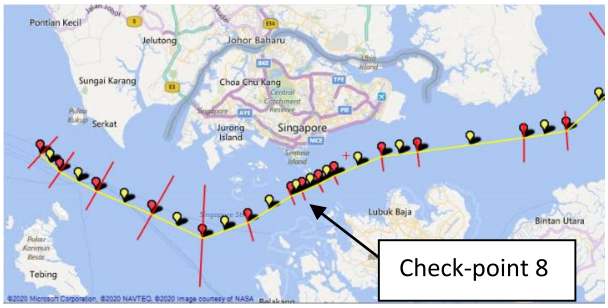

Figure 7: Selected check-point use to calculate the number of ships that pass through each segment in Singapore Straits.

From the gate set up in this experiment, the distribution of the ship across all the gates were identified. The gate that has been set up along the traffic separation scheme, which was implemented at Singapore Strait. From the data from September 05, 2019, until October 04, 2019, checkpoint number 8 shows the highest traffic flow and the distribution shown in Figure 8. In this distribution chart, the y-axis of the chart is representing the length of the gate in kilometres while the x-axis shows the number of ships. The distribution shows that most of the ships were following the traffic separation scheme and only a few of it not following. Most probably, the ship that does not follow the traffic separation scheme come from the small vessel group that will not bring critical impact to the probability of the collision. From Figure 8, the distance between the busiest ways for the ship that moving to the west and the busiest way for the ship that moving to the east is around 13km. This observation also shows that the TSS would help to reduce the risk of head to head collision of ships especially in this narrow and busy seaway.

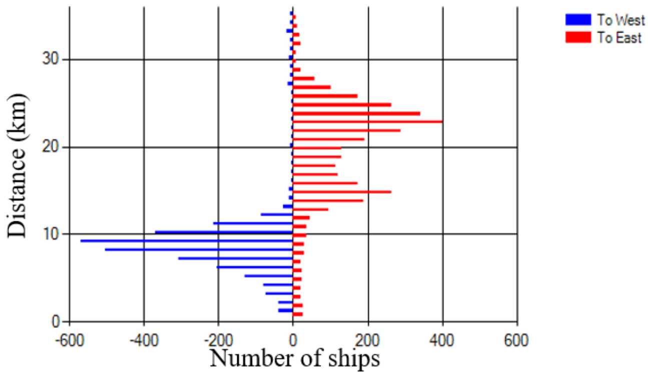

Figure 8: Ship distribution across check-point number 8

5.0 RISK OF SHIP TO SHIP COLLISION OFF SINGAPORE STRAITS

In this paper, the risk of a head-on collision is calculated using the method proposed by Pedersen (1995). 12 ship types were selected, which the type of ships are cargo ship, tanker ship, passenger ship, high-speed craft, tugboat, pleasure craft, pilot craft, fishing craft and unspecified ship type (unknown). The iteration for the 'i' and 'j' using the equation by Pedersen (1995) was based on the ship type that has been mentioned. All the ships passing by the Singapore Strait in the study period are sorted according to the ship types and all particulars for respective ship types will be added and calculate the average of the value of the particular. The equations to calculate collision candidate is shown in equation (1) and equation (2). Where equation (1) is applied to estimate the collision candidates in cross-traffic conditions while equation (2) is applied to estimate the collision candidate in head-on conditions. The sample of input data for calculation of collision candidates in perpendicular direction for an unspecified ship with the unspecified ship is shown in Table 1.

$$N_a = \sum_i \sum_j \frac{Q_{1i} \cdot Q_{2j}}{V_i^{(1)} \cdot V_j^{(2)}} \cdot \left[L_i^{(1)} \cdot V_j^{(2)} + L_j^{(2)} \cdot V_i^{(1)} + B_j^{(2)} \cdot V_j^{(2)} + B_i^{(1)} \cdot V_i^{(1)} \right] \Delta t \quad (1)$$

$$N_a = \frac{\sqrt{\pi}}{2} L_w \sum_i \sum_j \frac{Q_{1i} \cdot Q_{2j}}{V_i^{(1)} \cdot V_j^{(2)}} \cdot \left(V_i^{(1)} + V_j^{(2)}\right) \cdot \left(B_i^{(1)} + B_j^{(2)}\right) \cdot \frac{1}{\sigma_1} exp(-\mu^2/4\sigma_1^2)\Delta t$$
(2)

Where in equations (1) and (2)
N_a= Collision candidates
Q_{1i} , Q_{2j} = number of passages per time unit for each ship type and size in direction 1 and direction 2
$V_i^{(1)}$, $V_j^{(2)}$= speed for each ship type and size in direction 1 and direction 2
$L_i^{(1)}$, $L_j^{(2)}$= length of ship i and j respectively
$L_i^{(1)}$, $L_j^{(2)}$= breadth of ship i and j respectively
L_w= Length of waterway
σ_1=standard deviation of traffic distribution in perpendicular to waterway
μ= width of waterway

Table 1 Sample of data for perpendicular collision between unspecified ship with the unspecified ship.

Item	Value
Vi	2.761
Vj	3.167
Vij	5.928
Bi	16.281
Bj	17.205
Bij	16.74
µij	850.396
σij	1067.98
Lw	105

By using, the decoded AIS data retrieved from the server starting from September 05, 2019, until October 04, 2019, the total number of ships using the Singapore Strait is around 7542 ships. By using the Pedersen (1995) method explained in **Error! Reference source not found.**, the value of possible event of a ship-ship collision for head-to-head, N_a is 5966.9642, while for the possible event of a ship-ship collision for cross-traffic situation, Na is 2166.6767. The value is then multiplied by the value of ship-ship causation probability.

Based on Fujii (1975), the value of the causation probability for head-to-head collision, Pc is approximate, 4.9 x 10^{-5} while for the causation probability of crossing ships, Pc is approximately 1.2 x 10^{-4}. The equation (3) to calculate the probability of ship collision is as in below:

$$F_{ship-ship} = P_c N_a \quad (3)$$

From Equation (3), the risk of crossing collision for the ship travel in Singapore Straits is 0.26. From the estimation, it is predicted that there is one cross collision that happened in Singapore Straits every 3.8 years. Using the same ships particulars data obtained from the cross collision, the risk of head-on collision for the ship travel in Singapore Straits is 0.2924. From the estimation, it is predicted that there is one cross collision that happened in Singapore Straits every 3.4 years.

Comparing the result with the previous study by Zaman et al (2015), the probability for a head-to-head collision based on AIS data at 0200 hrs is 0.207 which made the collision probably happen every 4.8 years and for ship crossing collision probability based on AIS data at 0200 is 6.521 which made the collision probably happen in every 0.15 year. The difference between these two results may come from the volume of AIS data, where Zaman et al (2015) only use AIS data received at time 0200 hrs. However, this study calculated the collision candidate in equations (1) and (2) is based on the one complete month's AIS data. The comparison between the AIS data used in analysis and the result obtained for both the current study and Zaman et al (2015) is shown in Table 2.

Table 2: Comparison for the data and result obtain between the previous and current study

	Current Study	Zaman et al (2015)
Selected AIS Data	5 Sept 2019 to 4 Oct 2019	2 am, 5 April 2010
Total duration of AIS Data Use in Analysis	1 month	1 hour
Location of Study	Singapore Straits	Singapore Straits

Causation factor, P_c for head-to-head collision	4.9×10^{-5}	1.5×10^{-5}
Causation factor, P_c for cross traffic collision	1.2×10^{-4}	1.5×10^{-5}
Number of head-to-head collisions per year	0.294	0.207
Number of cross traffic collision per year	0.263	6.521

CONCLUSION

The marine traffic condition in Singapore Straits was studied using recorded AIS data in September 2019. From the recorded data, it is found that 7542 ships had operated in the straits for the study period. Based on the processes AIS data, the majority of the ships moving in the straits are cargo ships and tanker ships with a length above 150 meters. Besides, the assessment of the ship collision risk was conducted using Pedersen's method (1995), which Pedersen also adopted value of causation probability by Fujii (1983). Two different types of collision were calculated in this study, which is cross-traffic collision and head-to-head collision. For the cross-traffic collision, the ship-ship collision may happen every 3.8 years. For the head-to-head collision, the ship-ship collision may happen every 3.4 years.

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