Study on Probabilistic Risk Assessment Model for Crossing Situation in Sunda Strait

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Abstract. Sunda Strait is a busy channel where cargo vessels could probably have a crossing situation with roro ferries. Due to a very limited record of the actual crossing collisions in Sunda Strait, this study performs a Probabilistic Risk Assessment (PRA) of near miss crossing situations in Sunda Strait due to the Traffic Separation Scheme (TSS) that has been set since July 1st, 2020. The analysis is based on the Automatic Identification System (AIS) data during three time-intervals (TI), the first two TIs represented the condition before the TSS came into force, while the last TI was taken after the TSS has been set. The traffic in Sunda Strait was categorized to eight vessel courses, two conditions and seven crossing zones. We proposed a new perspective for the evaluating the TSS by looking at the crossing situation with three different bases, namely crossing zone basis, course basis, and vessel type basis. The probability of a crossing situation was calculated based on the hour basis for each time interval. The UK HSE standard for individual risk is utilized and it is found that the TSS effectively reduced the frequency level of crossing situation from unacceptable to ALARP in CZ 1, 2, and 4. While in CZ 3, the frequency is decreased dramatically from unacceptable to acceptable level.

1. Introduction

Collision accident has become a major problem in the maritime world, for example, as reported by the European Maritime Safety Agency in its annual report from 2014 until 2019 that the number of collision accidents always above 250 cases per year [1] and it is almost similar to the statistics of marine accident in Japan that shown the number of collision accidents also in 2014 until 2019 that never get below 200 cases annually [2]. The same phenomenon also occurs in Indonesia, a home to the three Indonesia Archipelagic Sea Lanes (IASL), where ocean going vessels can have their sailing route above these lanes. However, the accident reports and the statistics about any maritime accidents are not archived well and not easily accessible, so we could not have a clear vision about the real situation. The homepage of the National Transportation Safety Committee of Indonesia [3] only shows the accidents that have been investigated, which mostly are major accidents. Furthermore, the statistics of the marine accidents is not updated annually. The lack of collision accident data then becomes the background of doing the near miss analysis to get a picture on the marine traffic in Indonesia, besides we do never hope that an actual collision would happen just to enable us to make a calculation for the annual collision frequency.
This study is analyzing the near miss in Sunda Strait area with the help of Automatic Identification System (AIS). AIS is a broadcasting system that enable a vessel to be identified by other vessels and shore-based stations. It can be used for tracking the vessel movements as the data is continuously send by the AIS transponder onboard as presented in Figure 1. This device shall be installed onboard vessel with 300 GT or above that engaged in an international voyage and 500 GT or above that is engaged in a non-international voyage. While for the passenger vessel, the AIS transponder shall be installed onboard regardless the size [4]. The AIS transmits two categories of data; the static data, that stored any data that do not change with the movement of the vessel, and the dynamic data, which updated frequently along with the vessel movement. The static data include the maritime mobile service identity (MMSI), vessel name, type, callsign, gross tonnage, deadweight tonnage, dimension, flag, etc. On the other hand, the dynamic data is the one that provide the location (longitude and latitude), timestamp, and the feature of vessel movement (rate of turn, speed over ground, course over ground, and heading). Despite of its potentials, the AIS is still considered to have some limitations, for example, data redundancy, noise data, or even no data received at all by the AIS receiver [5]. This may lead to incomplete or unrealistic vessel tracks that could make the analysis that using AIS data becomes unreliable.

This paper focuses on the probability and annual frequency assessment of the near miss crossing situation in the Sunda Strait during three time-intervals (TI), October 8th-14th, 2018, April 13th-19th, 2019 and July 1st-7th, 2021. The first two TIs represented the condition before the TSS came into force, while the last TI was taken after the TSS has been set. The contents are organized as follows: the transformation of the AIS database becomes a vessel trip database, after that the marine traffic produced by AIS data is categorized to eight vessel courses, two conditions and seven crossing zones. The definition of crossing situation and how to determine the near miss is outlined before analyzing the probability and annual frequency based on three bases: crossing zone basis, course basis, and vessel type basis.

2. Transforming AIS Data to be A Vessel Trip Database
The traffic separation scheme in Sunda Strait was introduced on July 1st, 2020. The data collection is divided into two periods, before and after the introduction of TSS. Two sets of AIS data from October 8th, 2018, until October 21st, 2019, and April 6th until July 24th, 2021 are collected from the AISITS. It is a

![Figure 1. Illustration of AIS](image-url)
startup company that provides ship tracking as well as early warning system for subsea pipelines that may possess a danger due to passing vessels based on AIS data. However, not all data contains sufficient data. Hence, three weeks with the highest number of collected data are taken to model the traffic pattern. Each week is labelled as a different time interval (TI): October 8th-14th, 2018 as TI 1, April 13th-19th, 2019 as TI 2, and July 1st-7th, 2021 as TI 3. The data distribution of these TIs can be seen in Figure 2. The focus area for this study is a rectangle bounded by four points with coordinates of P1 (-5.78018, 105.631), P2 (-5.78018, 106.071), P3 (-6.07616, 106.071), and P4 (-6.07616, 105.631). The data distribution along 24 hours of TI 1, TI 2 and TI 3 are shown in Figure 2 (a), (b), and (c), respectively.

**Figure 2.** Distribution of AIS data in 24 hours basis.
The AIS data that have been collected is the basic to construct a vessel trip database because one AIS datum alone only represents one certain point at a certain time. Thus, it is necessary to group the vessel movements to make one continuous track. As an initial step, the AIS data are inserted to the software named IALA Waterway Risk Assessment Program (IWRAP) to make a density plot. The plot of TI 1 and TI 2 only represents the traffic characteristic of large vessels, because it only received the data from the Class A AIS transponder, which installed in the vessel above 300 GT. Smaller vessels like conventional fishing vessels do not transmit Class A AIS data to the base station, which make them undiscernible in these time intervals. However, during the TI 3, several fishing vessels and pleasure vessels are discoverable. As we can see in Figure 3, the marine traffic in Sunda Strait is dominated by ro-ro/passenger ferries then followed by oil products tankers and bulk carriers with 68, 64, and 42 vessels recorded during October 8th-14th, 2018; 65, 55, and 40 vessels for April 13th-19th, 2019; and 75, 80, and 78 vessels for July 1st-7th, 2021. The density plot can also give a visualization of the traffic around Sunda Strait, which then categorized into eight courses (C1 – C8) indicating unique tracks and two positions (at anchor (C9) and at port (C10)) as shown in Figure 4. This figure also contains all crossing zones formed by two or three courses that intersect each other in a certain crossing zone.

The traffic pattern, as shown in Figure 4, shows four different channels. The first one located in the IASL 1, that has northbound and southbound direction and named as Course 1 and 2, respectively. The next one is the most crowded channel in the Sunda Strait, made by the crossing ro-ro/passenger vessels having round trips from Merak to Bakauheni and coded as Course 3 and 4. Another northbound and southbound traffic are in the eastern of Sangiang Island and named as Course 5 and 6. Lastly, the Course 7 and 8 are made by vessels that make a shortcut from the Indian Ocean to the Java Sea. However, the one named as the Course 9 is not a track followed by a vessel, but it is an anchoring condition. Whilst the Course 10 is reserved for the vessel located on the port.

2.1. Vessel course

2.1.1. Course 1 and Course 2 (C1 and C2).

These courses represent the IASL 1 that has been set as the course for cargo vessels that are going to pass through Indonesian territory. These courses are dominated by vessels engaged in a trip from Australia, Europe, or West Asia going to East Asia (Vietnam, Japan, etc.) and most of them are general cargo and bulk carriers. Course 1 is going to northern direction, while Course 2 is the opposite. These courses are important passageways in Sunda Strait as big vessels are using both courses alternately.

![Figure 3. The number of vessels by type at TI 1, TI 2, and TI 3.](image-url)
2.1.2. Course 3 and Course 4 (C3 and C4).
The other important courses in Sunda Strait are Course 3 and 4, which crossed by roro/passenger ferries that sail from Port of Merak to Port of Bakauheni and vice versa. Based on the actual schedule published by the Port of Merak, there are 50 trips per day commenced from the Merak, which make the traffic in the Sunda Strait vicinity becomes very crowded. Course 3 is from Port of Merak going in western direction and Course 4 is on the opposite direction from Port of Bakauheni to the eastern direction.

2.1.3. Course 5 and 6 (C5 and C6)
These two courses are parallel with the Course 1 and Course 2, but a little denser and diverge traffic is observed in the eastern part of Sunda Strait. Similar with C1 and C2, these courses are dominated by merchant vessels. Most of the vessels are sailing in the domestic route, from the Java Sea to the industrial ports close to the Port of Merak, although several vessels also engaged in the international voyage similar to those in Course 1 or Course 2. The TSS implementation does not affect the traffic pattern in C5 and C6 as no routeing measure is set in this area.

2.1.4. Course 7 and 8 (C7 and C8).
These courses are dominated by domestic cargo vessels with smaller dimension sailing from the west part of Sumatera to the Java Island and return. Both courses are spanned diagonally and intersect with Course 1, Course 2, Course 3, and Course 4. Bulk carrier, tanker and general cargo are still found to be the most frequently passing vessel in these courses. Course 7 is going to the northeast direction, while Course 8 is going to the southwest direction.

2.2. Crossing zone
Along with the courses that have been identified above, seven crossing zones as shown in Figure 5 are designated as the intersection area between two or more courses. The features of seven crossing zones are explained as follows:

Figure 4. The traffic pattern in Sunda Strait before the implementation of TSS.
2.2.1. Crossing zone 1 (CZ 1), Crossing zone 2 (CZ 2), and Crossing zone 3 (CZ 3).
The CZ 1, CZ 2, and CZ 3 are in the west area of Sunda Strait. The CZ 1 is an intersection between the
course that follow IASL 1 (Course 1 and 2) with Course 7 and 8 which follow a diagonal course, and
with Course 3 and 4 which designated for roro/passenger ferries. It is expected that crossing zone 1
would have the highest number of crossing situation, due to this crossing zone is made by 6 courses that
intersect each other. The crossing zone 2 is the intersection between Course 1 and 2, the passage for
cargo vessels, and Course 3 and 4, the courses for roro/passenger ferries. Hence, crossing situation is
expected between ocean going cargo vessel and roro ferries. The crossing zone 3 (CZ 3) is located a
little bit to the east side of the CZ 2, which is the potential location of crossing situation made by Course
7 and 8, which dominated by domestic cargo vessels with Course 3 and 4 for roro/passenger ferries.

2.2.2. Crossing zone 4 (CZ 4) and Crossing zone 5 (CZ 5).
The CZ 4 and CZ 5 are crossing zones that involving Course 5 and 6 dominated by cargo vessels and
Course 3 and 4 for roro/ferries. Both locations are in the east area of Sunda Strait close to the Port of
Merak. The CZ 4 is made between Course 5 and 6 with Course 3, which accommodating the
oro/passenger ferries going from Port of Merak to the Port of Bakauheni. While the CZ 5 is also
involving Course 5 and 6 together with Course 4, which is the passage for crossing roro/passenger ferries
going from Port of Bakauheni to the Port of Merak.

2.2.3. Crossing zone 6 (CZ 6) and Crossing zone 7 (CZ 7).
These crossing zones are made due to the the extension of Course 5 and 6 that meet with Course Course
7 and 8. As the Course 7 and 8 are dominated by domestic cargo vessels that going to or from the eastern
part of Indonesia, so the vessel engaged in those courses might encounter a crossing situation in CZ 5
or CZ 6. The difference is, the vessel engaged in Course 7 and 8 would meet vessel engaged in Course
5 and 6 that sail to the north direction in CZ 6, whereas in CZ 7 the vessel sailing in Course 7 and 8
might encounter with vessel sailing in Course 5 and 6 that is going to the eastern direction.

This study is utilizing vessel trips as the basis for conducting the probability assessment, which make
the development of the trips database is important. The trips database is arranged to contain information
including timestamp, MMSI, vessel name, vessel type, length, width, trip count, course number, and
crossing zone. The IWRAP software not only automatically connects the adjacent coordinates of one
vessel to be considered as one trip, but also terminate the trip if the distance between one point to the
next one is too far. However, due to the missing AIS data in between, it makes sometimes the software
considers 1 trip as 2 or more trips. Hence, we need to conduct a visual observation to validate the trips
resulted from the IWRAP. Another reason to conduct the visual observation is the inconsistency of the
direction that we might find on some trips which make it hard to categorize the trip into the course
number. The example of trips resulted by the IWRAP is depicted by Figure 6. Figure 6(a) shows the trip
list of a vessel which consists of two trips. If we see the duration of both trips, the time gap between two
trips is less than 1 hour, but the IWRAP separated it to be two different trips as shown in Figure 6(b)
and (c). Thus, by doing the visual observation we conclude the trip count in the trip database for this
vessel is only one trip instead of two.

3. Crossing Situation in Sunda Strait

3.1. Traffic Situation in Sunda Strait
Sunda Strait, as seen in Figure 4, have become one major strait in Indonesia with a high density currently
because of the activities of roro/passenger ferries that serve Port of Merak and Port of Bakauheni. The
number of trips of each course taken from the trips database is shown in Figure 6. The figure gives a
brief information that during two different time intervals, Course 3 and Course 4 give a major
contribution to the traffic density with 27% and 35% of the total traffic for the Course 3, while for the
Course 4 the percentages are 28% and 35%, for TI 1 and TI 2 consecutively. The second highest traffic
occurs in the eastern side of the Sunda Strait where the Course 5 and 6 are located. Although Course 9
and 10 have higher numbers compared to Course 5 and 6, but these courses represent two positions of the vessel (at anchor and at port), therefore those courses are not considered here. Another way to see the characteristic of the traffic in Sunda Strait is by looking at the number of trips passing each crossing zone. Figure 7 depicts the number of trips in the designated crossing zone. The graph indicates that the 
CZ 4 is the crossing zone passed by the highest trips, either in TI 1 or TI 2. The second most populated crossing zone is the CZ 5 and it is located in the south of CZ 4. This crossing zone is also involving the roco/passenger ferries in Course 4 as well as cargo vessels navigating in Course 5 or 6. These facts are in a good agreement with the number of trips shown in Figure 6 which shows the Course 3 & 4 and Course 5 & 6 are having the highest traffic compared to others, as the CZ 4 is a crossing area where a vessel sailing the Course 3 could meet a vessel sailing the Course 5 or 6.

3.2. Closest Point of Approach (CPA)
A crossing situation occurs when two vessels are encountering each other with an angle between 5° to 112.5° or 247.5 to 355° looked from the own vessel as displayed on Figure 6. The closest point of approach (CPA) is an indicator to show that an own vessel is at its closest point to the target vessel. This indicator is divided into two features, the spatial or the distance to the CPA (DCPA) and the temporal or the time to the CPA (TCPA) [6]. Figure 7 shows an illustration about the CPA when t = t₁. During this period, the distance between the own vessel and the target vessel reaches the minimum and the time to reach that point is known as the TCPA. The concept of CPA is used in this paper to determine a vessel encounter to have a crossing situation or not.

The CPA approach is a good methodology to be used in a non-accident probabilistic risk assessment approach as no real accident is involved in the calculation. Many researchers have proposed the value of CPA in different conditions. A research conducted by Goodwin, for example, stated that the safe DCPA is 2.35 nautical miles (nm) for the open sea [7]. Meanwhile, Park in his research found that the DCPA is 0.15 nm and the TCPA is 3 minutes for Korean waters [8]. Furthermore, a research by Fukuto and Imazu proposed the value of safe DCPA as 1.0 nm and the safe TCPA is 5 minutes [9].

This study evaluates the DCPA of passing and crossing vessels in Sunda Strait over time during the time intervals previously mentioned. Among those DCAs that have been proposed by the previous research, an interview with a deck officer of a cargo ship was conducted to get the idea about what the crew feels about each DCPA. The result of this interview is that the DCPA from Fukuto and Imazu [9] with the distance of 1.0 nm is taken for categorizing the vessel encounter condition, considering the condition of Sunda Strait that has a passing and crossing traffic. If two vessels are encountering each other and the closest distance between each other is less than 1.0 nm, the encounter is categorized as a crossing situation. The general formula of the DCPA calculation is involving the position and speed of both own vessel and target vessel and the equation is [10]:

\[
D_{CPA} = \frac{|XV_{RY} - YV_{RX}|}{V_{T}}
\]

(1)

\[
V_{T} = \sqrt{V_{RX}^2 + V_{RY}^2}
\]

(2)

Where X, Y is the recent position of T, the AIS device installed in the target vessel, whereas V_{RX} and V_{RY} are the relative speeds component in the x and y axes of the target vessel as illustrated in Figure 1.

3.3. Crossing Situation Database
Crossing situation is mentioned in the International Regulations for Preventing Collisions at Sea (COLREG) Rule 15 by a condition when two power-driven vessels are crossing each other and it is involving a risk of collision, the vessel that has another vessel on her starboard side shall be the give-way vessel by reducing the speed or altering the course. The give-way vessel shall also avoid crossing ahead another vessel, if possible.
The DCPA calculation is conducted by means of the IWRAP. This software offers a great help in analyzing the traffic as it can perform a traffic simulation as well as CPA calculation as well. In addition to the DCPA calculation results, IWRAP also provides the sign for indicating encounters that have the DCPA value equals to or less than the setting value. The crossing situation analysis is performed in all crossing zones mentioned in the Chapter 2.2 by setting the value of the DCPA with the distance that has been chosen by the deck officer as 1.0 nm. Figure 8 and Figure 9 illustrate the crossing situation in Crossing Zone 1 and Crossing Zone 4 on July 7th, 2021 and July 3rd, 2021. The DCPA of the first situation is 0.53 nm and the second situation is 0.29 nm. All crossing situations are collected and assembled as a database that consist of information about the date, time, location, name of vessels, MMSI number, type of vessels, heading, course over ground, speed, course, and role of the vessel based on COLREG Rule 15. The example of the crossing situation database is shown in Table 1.

4. Probabilistic Risk Assessment

The implementation of the routeing measure in Sunda Strait, which TSS is one of the routeing measures, has four objectives as outlined in the Decree of the Minister of Transportation no. 130 Year 2020 and those are [11]:

1) reduce the number of head-on situations to increase the safety of navigation by separating opposing traffic streams in the area,
2) reduce the grounding accident by keeping all vessel away from the coral reef atolls of Terumbu Koliot,
3) reduce the collision risk between vessels by recommending one precautionary area (PA), and
4) ensure all vessels follow the routes that free from all dangers due to the coral reef atolls of Terumbu Koliot by AToN.
The routing measures in Sunda Strait is more focused on the head-on situations by setting the TSS with separation zone and separation line in the northern and southern part of Sunda Strait. However, the risk of crossing situation is present due to seven crossing zones explained in Chapter 2 and it also needs attention. Risk assessment for the maritime accident is determined by the commonly used risk concept as [12]:

\[ R = PC \]  

(3)

Where in the case of ship crossing collision \( R \) denotes the risk of collision, \( P \) is the probability of the crossing situation and \( C \) is the consequence of the crossing situation, that can be an event of oil spill, structural damages, number of injuries or deaths, or some economic loss. However, the term of frequency is usually used more frequently to replace the probability to represent the number of the event in a period of time (i.e. the number of crossing situations per year) [13].

Although Equation 3 is the broadly accepted formula in determining the risk, the probabilistic risk assessment has been discussed more than the consequences. The previous researches [14] [15] have widely discussed the collision frequency that is notated by:

\[ f = Np_c \]  

(4)

The frequency is affected by the number of vessels in conflict, \( N \) and the probability that the vessel cannot perform an evasive maneuver in a given time or known as the causation factor, \( p_c \). This paper proposed a new perspective to perform a probabilistic risk assessment that is used to evaluate the implementation of the routing measures, specifically the TSS and the precautionary area. The probability and the annual frequency of crossing situations are analyzed not only based on a time window, but also based on the number of trips in each crossing zone. The analysis is conducted on the hourly basis of each time interval: TI 1 has 106 hours, TI 2 has 150 hours, and TI 3 has 168 hours as shown in Figure 2.

The probability and frequency of crossing situations in this study are assessed by using three bases, namely crossing zone basis, course basis, and vessel type basis. The database, which has been constructed from the collection of crossing situation contains information about the crossing zone, course, as well as the vessel type, is processed to get the total number of crossing situation for each basis. The equation used for calculating the probability of each basis is explained as follows.

4.1. Probability of crossing situations

The importance of analyzing the crossing situations probability in this paper is because we want to understand the likelihood of a trip is involved in a crossing situation. As mentioned in the previous chapter, this probability assessment is performed under three point-of-views. A vessel must be engaged in a trip and belong to one vessel type to enable it to be analyzed. The detailed equations and explanations for the probability of crossing situations are outlined as follows:

4.1.1. Crossing zone basis. The probability of crossing situation in crossing zone \( CZ_i \) is:

\[ P_{CZ_i} = \frac{n_{CZ_i} \times 2}{t_{CZ_i}} \]  

(5)

Where \( n_{CZ_i} \) is the number of crossing situation in \( CZ_i \) and \( t_{CZ_i} \) is the number of trips in \( CZ_i \). The number of \( n_{CZ_i} \) is multiplied by 2, because one crossing situation in a crossing zone is made by two trips of two vessels. Hence, to calculate the probability of it, the number of crossing situation is doubled.
The definition of the crossing situation probability in the crossing zone basis or $P_{CZ_i}$ is how likely a trip that crosses $CZ_i$ would experience a crossing situation.

4.1.2. Course basis. The probability of crossing situation in course $C_i$ is:

$$P_{C_i} = \frac{n_{C_i}}{t_{C_i}}$$

(6)

Where $n_{C_i}$ is the number of crossing situation in course $C_i$ and $t_{C_i}$ is the number of trips in course $C_i$. The probability calculation with course basis does not need to be multiplied by 2, because each trip is already counted as 2 trips in a crossing situation. The crossing situation probability under the course basis or $P_{C_i}$, can be defined as the likelihood of a trip in course $C_i$ to have a crossing situation in that course.

4.1.3. Vessel type basis. The probability of crossing situation in crossing zone $V_i$ is:

$$P_{V_i} = \frac{n_{V_i}}{t_{V_i}}$$

(7)

Where, $n_{V_i}$ is the number of crossing situation of vessel type $V_i$ and $t_{V_i}$ is the number of trips of vessel type $V_i$. Similar to the calculation of the course basis, the calculation does not require a multiplication by 2 for the $n_{V_i}$ as two vessel type is already counted in one crossing situation. Thus, the crossing situation probability under the vessel type basis or $P_{V_i}$, can be defined as the chance of a trip made by a type of vessel $V_i$ to have a crossing situation.

4.2. Annual frequency of crossing situations

Equations for the annual frequency assessment are also proposed to give an alternative to the crossing situation probability analysis discussed in the previous part. Another reason is that in the field of marine risk, the term of annual frequency is commonly used rather than probability. The annual frequency of a crossing situation is defined as the number of crossing situation occurrence within one year. The definition is different from the definition of the probability, which is the chance of a trip to be involved in a crossing situation in a set of all possible situation. The following paragraphs outline the formulas used to analyze the annual frequency as well as the description for all bases.

4.2.1. Crossing zone basis. The annual frequency of crossing collision using the crossing zone basis $CZ_i$ is:

$$F_{CZ_i} = \frac{P_{CZ_i}}{N_i} \times 365$$

(8)

Where $P_{CZ_i}$ is the probability of crossing situation in crossing zone $CZ_i$ and $N_i$ is the total number of trips in a day (24 hours). The frequency of the crossing zone basis in this study is translated as the number of crossing situation occurred in the $CZ_i$ for one year when there are $N_i$ trips a day. The result of this calculation is the daily frequency. Thus, to make it becomes an annual frequency, the result is multiplied with 365.
4.2.2. Course basis. The annual frequency of crossing collision using the course basis $C_i$ is:

$$F_{C_i} = \frac{P_{C_i}}{N_t} \times 365 \quad (9)$$

Where $P_{C_i}$ is the probability of crossing situation in course $C_i$.

4.2.3. Vessel type basis. The annual frequency of crossing collision using the vessel type basis $V_i$ is:

$$F_{V_i} = \frac{P_{V_i}}{N_t} \times 365 \quad (10)$$

Where $P_{V_i}$ is the probability of crossing situation of vessel type $V_i$.

4.3. Acceptance Criteria

The annual frequency of the crossing situations in the Sunda Strait shall be categorized under the acceptance criteria to understand whether the TSS is improving the frequency or make it even worse. It is supported by the International Maritime Organization Maritime Safety Committee (IMO MSC) 72/16 about the Formal Safety Assessment (FSA) decision parameters including risk acceptance criteria [16]. Hence, an acceptance criteria from the UK HSE [17] for individual risk is used to categorized the level of frequency of crossing situations and it is shown in Figure 10. The figure separates the reversed triangle into three parts: unacceptable, As Low as Reasonably Practicable (ALARP), and acceptable. The situation falls under the unacceptable level when the frequency is more than 1.00E-03 per year. All efforts shall be made despite of the cost when the situation is on this level. Right below the unacceptable is the ALARP, when the frequency of 1.00E-03 until 1.00E-06. The mitigation action might be carried out to keep the risk at that level or even reduce it, not increase it. The last one is the acceptable level that can be achieved when the frequency is less than 1.00E-06. If the risk falls in this region, a good practice is needed to keep the situation.

![Figure 9. Acceptance criteria for individual risk based on UK HSE [15.]]
5. Result and Discussion

5.1. The summary of the crossing situation

The information of crossing situation is collected and constructed to be a database. The total number of crossing situations for TI 1 (October 8th – 14th, 2018), TI 2 (April 13th-18th, 2019), and TI 3 (July 1st-7th, 2021) are 22, 22, and 43, respectively. The example of the crossing situations database for TI 2 is given in Table 1. Although all time intervals have 7 days in a week, but the number of hours and data to be analysed between before the TSS (TI 1 and TI 2) and after (TI 3) is different from one to another as outlined in Chapter 2. This is suspected to the reason why the total crossing situations number is also different if TI 1 and TI 2 are compared to the TI 3.

5.2. Probability and annual frequency of the crossing situation

The result of probability and annual frequency of the crossing collision for crossing zone basis, course basis, and vessel type basis are obtained from the Equation 4-9 and shown in Table 2-4, respectively. To begin with, the traffic in Sunda Strait over time is experiencing a gradual increase. The number of trips in each CZ are also increasing. Despite of the increasing traffic flow, a low number of crossing situation is expected to prove that the TSS is followed by all vessels operating in Sunda Strait. In the CZ 3, the number of crossing situation is eliminated until 0. This is supported by the fact that the number of vessels trips in Course 7 and 8 is also decreased. The traffic in Course 7 and 8 are forced to follow the TSS, although it can enter or exit the TSS at any points with a small angle as possible. The vessels following Course 7 are now following the southern TSS, while vessels sailing in Course 8 are following the northern TSS. In the vessel type point of view, all type is facing an incline in terms of number of trips. In addition, a better coverage is found for the Time Interval 3, because the trips of fishing vessels, pleasure vessels as well as support vessels are more discoverable in this period. The result of probability calculation for the CZ basis shows a decreasing trend, except for the CZ 1 after TI 2, because the traffic is increased in this crossing zone that leads to a higher number of crossing situations too. In the course basis, a declining trend is also experienced, but not for the Course 1. As the TSS is applied, more vessels choose to navigate in the Course 1 and 2, rather than Course 7 and 8. As it has been previously mentioned that the traffic in Course 7 and 8 is effectively reduced. Another reason is due to the unclear regulation of the precautionary area that makes the vessel operators do not understand about the priority in the PA.

Table 1. Example of the crossing situation database for TI 2.

| Crossing situation ID | TI 2 - 1 | TI 2 - 2 |
|----------------------|----------|----------|
| Date                 | 14/04/2019 | 14/04/2019 |
| Time start (GMT)     | 14:46:02  | 18:08:47  |
| Location             | CZ 4      | CZ 4      |
| MMSI of Vessel A     | 525012215 | 525007392 |
| MMSI of Vessel B     | 636014865 | 525200078 |
| Type of Vessel A     | Roro/Passenger ferry | Roro/Passenger ferry |
| Type of Vessel B     | General cargo | General cargo |
| Course of Vessel A   | 3         | 4         |
| Course of Vessel B   | 6         | 6         |
| Heading of Vessel A  | -         | -         |
| Heading of Vessel B  | 228       | 222       |
| COG of Vessel A      | 334       | 97        |
| COG of Vessel B      | 227       | 218       |
| Avg. speed of Vessel A | 7.46    | 5.57      |
| Avg. speed of Vessel B | 11.13   | 2.18      |
| Role of Vessel A     | Give way  | Stand on  |
| Role of Vessel B     | Stand on  | Give way  |
Next, is the vessel type basis that shows a slight decrease if the results from TI 1, 2, and 3 are compared. The probability of container, fishing vessel, general cargo, and oil product tanker experiencing a crossing situation is increased, especially the oil product tanker that always increased every year. The overall trend of the annual frequency from the crossing zone point of view is declining as shown in Table 2 that in TI 1 almost all CZ are in unacceptable level, while in TI 3 all of them are changed to ALARP. Meanwhile in the Table 3 that shows the course basis, from 6 courses that are categorized under the unacceptable level are improved in TI 2 and 3 to be only 4. Although the probability analysis of vessel type basis shows an increase, but the annual frequency is decreased from 7 vessel types under unacceptable level in TI 2, becomes 4 vessel types in TI 3. A different result from the probability and the annual frequency is due to a different basis. If the probability only counts the ratio of trips, the annual frequency includes the time dimension into account.

Although the results are produced from the dataset that has many data gaps, this study has selected time intervals that have sufficient data to be analysed. The consideration is made by looking at the number of the AIS data received in that day as well as it does not show a big gap. Hence, this study has already shown adequate results for the probability of crossing situation in Sunda Strait by referring to those data.

6. Conclusion
This paper is conducting a probabilistic risk assessment for crossing situation in Sunda Strait. The significance of this research is to evaluate the traffic pattern before and after the TSS is implemented. The analysis is performed in three time-intervals, October 8th-14th, 2018, April 13th-19th, 2019 and July

| Table 2. The result of probability and annual frequency for the crossing zone basis |
|-----------------------------------|-------------------|-------------------|-----------------|-----------------|
| Crossing zone | The num. of trips | The num. of crossings | Probability | Annual frequency |
| Time Interval 1 | | | | |
| CZ 1 | 172 | 2 | 2.33E-02 | 1.57E-03 |
| CZ 2 | 108 | 1 | 1.85E-02 | 1.25E-03 |
| CZ 3 | 205 | 4 | 3.90E-02 | 2.64E-02 |
| CZ 4 | 430 | 13 | 6.05E-03 | 4.09E-03 |
| CZ 5 | 368 | 2 | 1.09E-02 | 7.36E-04 |
| CZ 6 | 63 | 0 | 0.00E+00 | 0.00E+00 |
| CZ 7 | 91 | 0 | 0.00E+00 | 0.00E+00 |
| Time Interval 2 | | | | |
| CZ 1 | 260 | 1 | 7.69E-03 | 2.90E-04 |
| CZ 2 | 126 | 0 | 0.00E+00 | 0.00E+00 |
| CZ 3 | 305 | 0 | 0.00E+00 | 0.00E+00 |
| CZ 4 | 791 | 16 | 4.05E-02 | 1.52E-03 |
| CZ 5 | 500 | 5 | 2.00E-02 | 7.54E-04 |
| CZ 6 | 59 | 0 | 0.00E+00 | 0.00E+00 |
| CZ 7 | 80 | 0 | 0.00E+00 | 0.00E+00 |
| Time Interval 3 | | | | |
| CZ 1 | 845 | 8 | 1.89E-02 | 3.67E-04 |
| CZ 2 | 876 | 3 | 6.85E-03 | 1.33E-04 |
| CZ 3 | 796 | 0 | 0.00E+00 | 0.00E+00 |
| CZ 4 | 1040 | 19 | 3.65E-02 | 7.08E-04 |
| CZ 5 | 718 | 12 | 3.34E-02 | 6.47E-04 |
| CZ 6 | 79 | 0 | 0.00E+00 | 0.00E+00 |
| CZ 7 | 171 | 0 | 0.00E+00 | 0.00E+00 |
1st-7th, 2021. Three different bases are used to assess the probability and the annual frequency of crossing situations and those are crossing zone basis, course basis, and vessel type basis. There are eight courses (Course 1-8), two positions (Course 9 and 10), seven crossing zones (CZ 1-7), and twelve vessel types. The result of the probability assessment shows a declining trend in crossing zone, course, and vessel type bases, except for CZ 1, Course 1, and vessel type container, fishing vessel, general cargo, and oil product tanker.

Meanwhile, the result of the annual frequency assessment produces a good improvement in the risk acceptance criteria, which majority are on the unacceptable level during TI 1, but in TI 3 changed to ALARP. The insignificance change of the probability of the CZ 1 is thought to be the effect of the precautionary area that is in the crossing area between the passing vessels and crossing vessels.

**Table 3.** The result of probability and annual frequency for the course basis

| Course no. | The num. of trips | The num. of crossings | Probability | Annual frequency |
|------------|-------------------|-----------------------|-------------|------------------|
|            |                   |                       |             | Time Interval 1   |
| Course 1   | 17                | 0                     | 0.00E+00    | 0.00E+00         |
| Course 2   | 21                | 2                     | 9.52E-02    | 6.45E-03         |
| Course 3   | 328               | 17                    | 5.18E-02    | 3.51E-03         |
| Course 4   | 341               | 5                     | 1.47E-02    | 9.92E-04         |
| Course 5   | 92                | 7                     | 7.61E-02    | 5.15E-03         |
| Course 6   | 91                | 8                     | 8.79E-02    | 5.95E-03         |
| Course 7   | 32                | 3                     | 9.38E-02    | 6.35E-03         |
| Course 8   | 36                | 2                     | 5.56E-02    | 3.76E-03         |
| Course 9   | 144               | 0                     | 0.00E+00    | 0.00E+00         |
| Course 10  | 119               | 0                     | 0.00E+00    | 0.00E+00         |
|            |                   |                       |             | Time Interval 2   |
| Course 1   | 27                | 0                     | 0.00E+00    | 0.00E+00         |
| Course 2   | 22                | 0                     | 0.00E+00    | 0.00E+00         |
| Course 3   | 538               | 15                    | 2.79E-02    | 1.05E-03         |
| Course 4   | 542               | 7                     | 1.29E-02    | 4.87E-04         |
| Course 5   | 92                | 10                    | 1.09E-02    | 4.10E-03         |
| Course 6   | 99                | 11                    | 1.11E-02    | 4.19E-03         |
| Course 7   | 32                | 1                     | 3.13E-02    | 1.18E-03         |
| Course 8   | 31                | 0                     | 0.00E+00    | 0.00E+00         |
| Course 9   | 98                | 0                     | 0.00E+00    | 0.00E+00         |
| Course 10  | 69                | 0                     | 0.00E+00    | 0.00E+00         |
|            |                   |                       |             | Time Interval 3   |
| Course 1   | 95                | 5                     | 5.26E-02    | 1.02E-03         |
| Course 2   | 97                | 6                     | 6.19E-02    | 1.20E-03         |
| Course 3   | 730               | 21                    | 2.88E-02    | 5.57E-04         |
| Course 4   | 732               | 20                    | 2.73E-02    | 5.29E-04         |
| Course 5   | 272               | 16                    | 5.88E-02    | 1.14E-03         |
| Course 6   | 269               | 15                    | 5.58E-02    | 1.08E-03         |
| Course 7   | 22                | 1                     | 4.55E-02    | 8.80E-04         |
| Course 8   | 13                | 0                     | 0.00E+00    | 0.00E+00         |
| Course 9   | 259               | 0                     | 0.00E+00    | 0.00E+00         |
| Course 10  | 108               | 0                     | 0.00E+00    | 0.00E+00         |
The legal regulation of the implementation of the routeing measures in the Sunda Strait (Decree of the Minister of Transportation no. 130 Year 2020) give order to the vessels facing a crossing encounter shall follow the COLREG 1972 Rule 15 about the Crossing Situation. However, as shown in the crossing

| Type of vessel       | The num. of trips | The num. of crossings | Probability Annual frequency |
|----------------------|-------------------|-----------------------|-----------------------------|
| Time Interval 1      |                   |                       |                             |
| Bulk carrier         | 78                | 8                     | 1.03E-01 6.94E-03           |
| Chemical tanker      | 24                | 5                     | 2.08E-01 1.41E-02           |
| Container            | 10                | 0                     | 0.00E+00 0.00E+00           |
| Crude oil tanker     | 3                 | 1                     | 3.33E-01 2.26E-02           |
| Fishing vessel       | 1                 | 0                     | 0.00E+00 0.00E+00           |
| Gas tanker           | 15                | 1                     | 6.67E-02 4.51E-03           |
| General cargo        | 43                | 2                     | 4.65E-02 3.15E-03           |
| Oil products tanker  | 110               | 4                     | 3.64E-02 2.46E-03           |
| Roro/passenger ferry| 808               | 23                    | 2.85E-02 1.93E-03           |
| Pleasure vessel      | 0                 | 0                     | 0.00E+00 0.00E+00           |
| Support vessel       | 104               | 0                     | 0.00E+00 0.00E+00           |
| Other vessel         | 25                | 0                     | 0.00E+00 0.00E+00           |
| Time Interval 2      |                   |                       |                             |
| Bulk carrier         | 78                | 7                     | 8.97E-02 3.38E-03           |
| Chemical tanker      | 7                 | 1                     | 1.43E-01 5.38E-03           |
| Container            | 11                | 0                     | 0.00E+00 0.00E+00           |
| Crude oil tanker     | 20                | 1                     | 5.00E-02 1.88E-03           |
| Fishing vessel       | 0                 | 0                     | 0.00E+00 0.00E+00           |
| Gas tanker           | 26                | 1                     | 3.85E-02 1.45E-03           |
| General cargo        | 47                | 5                     | 1.06E-02 4.01E-03           |
| Oil products tanker  | 93                | 5                     | 5.38E-02 2.03E-03           |
| Roro/passenger ferry| 1184              | 22                    | 1.86E-02 7.00E-04           |
| Pleasure vessel      | 0                 | 0                     | 0.00E+00 0.00E+00           |
| Support vessel       | 60                | 0                     | 0.00E+00 0.00E+00           |
| Other vessel         | 24                | 2                     | 8.33E-02 3.14E-03           |
| Time Interval 3      |                   |                       |                             |
| Bulk carrier         | 127               | 5                     | 3.94E-02 7.63E-04           |
| Chemical tanker      | 63                | 1                     | 1.59E-02 3.07E-04           |
| Container            | 24                | 2                     | 8.33E-02 1.61E-03           |
| Crude oil tanker     | 36                | 0                     | 0.00E+00 0.00E+00           |
| Fishing vessel       | 29                | 2                     | 6.90E-02 1.34E-03           |
| Gas tanker           | 87                | 3                     | 3.45E-02 6.68E-04           |
| General cargo        | 113               | 11                    | 9.73E-02 1.89E-03           |
| Oil products tanker  | 189               | 15                    | 7.94E-02 1.54E-03           |
| Roro/passenger ferry| 1674              | 41                    | 2.45E-02 4.74E-04           |
| Pleasure vessel      | 4                 | 0                     | 0.00E+00 0.00E+00           |
| Support vessel       | 319               | 3                     | 9.40E-03 1.82E-04           |
| Other vessel         | 27                | 1                     | 3.70E-02 7.17E-04           |

Table 4. The result of probability and annual frequency for the vessel type basis

The legal regulation of the implementation of the routeing measures in the Sunda Strait (Decree of the Minister of Transportation no. 130 Year 2020) give order to the vessels facing a crossing encounter shall follow the COLREG 1972 Rule 15 about the Crossing Situation. However, as shown in the crossing
situations database, inconsistence actions performed either by both cargo vessels and roro/passenger ferries during their crossing situation. A further recommendation should be proposed in the future research to address this problem, so the number of crossing situation in the CZ I can be lowered. A probabilistic risk assessment with sufficient data would be the future work to prove the result of this paper.

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