Frequency Analysis of Ship Collision and Its Impact on The Fulfillment of Supporting Facilities and Route Changes Due to Implementation of Sunda Strait TSS

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Abstract. The Government of Indonesia has adopted such routing measures namely Traffic Separation Scheme (TSS) for the Sunda Strait and the Lombok Strait from the decision of the plenary session of the International Maritime Organization (IMO). TSS is intended to reduce the frequency of ship accidents in a certain area. This research to identify the impact of the implementation TSS in the Sunda Strait on the frequency of ship collisions. So in this research, a ship collisions frequency study was conducted for the implementation of TSS. In the process of calculating the frequency of ship collisions using the IWRAP method in the form of IWRAP MK II software, and to calculate the estimated increase in ship fuel consumption using the Trozzi method in calculating changes in shipping distance using the assistance of the Google Earth virtual program and Triangle Ball method. Based on the calculation of the frequency of ship collisions in the Sunda Strait using the IWRAP software, the results of the frequency of Head-On collisions are 0.003149 per year, Overtaking is 0.070270 per year, and Crossing is 0.079589 per year after the TSS was implemented. However, during the implementation of the TSS by the government of Indonesia, several expenses need to be made to support this TSS implementation. In the first category, the government needs to do the investment to make some new facilities such as Vessel Traffic Systems (VTS), Coast Station (SROP), Marine Aids to Navigation (SBNP) and the latest electronic map and guarantee the operation of the supporting devices for the safety of the voyage. The determination of TSS in the

1. Introduction
Since 2019, Indonesia has a TSS by the decision of the plenary session of the 6th IMO Navigation Communication and Search and Rescue (NCSR). So with the trust of Indonesia by IMO to regulate TSS in the Sunda Strait and Lombok Strait shows Indonesia's active in the field of international shipping safety and security as well as strengthening Indonesia's identity as the world's maritime axis. With the approval of the TSS in the Sunda Strait and the Lombok Strait, a tough task awaits Indonesia considering that IMO continues to monitor the implementation of the TSS in the two Straits. Indonesia still has obligations that must be implemented, including fulfilling shipping safety supporting facilities and infrastructure in the TSS areas, VTS, SROP, SBNP, and the latest electronic map and guarantee the operation of the supporting devices for the safety of the voyage. The determination of TSS in the
Sunda Strait and the Lombok Strait by IMO is needed to ensure the safety of shipping in the Strait. From the available data, it is mentioned that as many as 53,068 ships of various types and sizes pass through the Sunda Strait every year and as many as 36,773 units of ships of various types and sizes pass through the Lombok Strait each year [1]. Sunda Strait is one of the most important straits in Indonesia. In the Sunda Strait, there are also several areas designated as marine conservation areas and marine park tourism that must be protected, one of which is the Sangiang Island area which has been designated as a marine nature park. In the Sunda Strait, there are also 2 groups of coral reefs, namely Koliot Reef and Gosal Reef which are dangerous for shipping. Based on the above explanation, further research is needed to determine the effectiveness of the impact of the implementation of TSS Sunda Strait.

2. Method

In this research there are 2 scopes of discussion, the first discussion is comparing the value of ship collisions frequency in Sunda Strait with conditions before and after TSS implementation. The second discussion is about impact of TSS implementation in Sunda Strait on the costs that must be incurred which are seen from 2 points of view, the first is seen from the point of view of the government in the form of investment costs supporting equipment for shipping facilities, and the second is seen from the viewpoint of the shipping company in the form of the cost of adding fuel to the ship caused by changes in some shipping routes that adjust the TSS design in Sunda Strait. In the process of calculating the frequency of ship collisions using the IWRAP method in the form of IWRAP MK II software, and to calculate the estimated increase in ship fuel consumption using the Trozzi method in calculating changes in shipping distance using the assistance of the Google Earth virtual program and Triangle Ball method.

2.1. IWRAP Mk II

In addition to manually calculating ship collision prediction can be done using the software. IWRAP Mk II is a software to calculate the frequency of ship collisions, both Head-On, Overtaking or Crossing Collision [2]. IWRAP Mk II Software can also calculate the frequency of collisions in any given part.

![Figure 1. IWRAP Mk II](image)

2.2. Trozzi Method

In the process of estimating the calculation of fuel consumption can be determined based on the European methodology standard MEET (Methodologies for Estimating Air Pollutant Emissions from Transport) [3], which methodology is used to obtain the results of emission values, but in the process also calculates the ship's fuel consumption approach, where this calculation has been applied by Trozzi
and is known as the Trozzi et al [4]. By knowing the Gross Tonage (GT) value of each ship, it can be estimated the amount of fuel consumption through the fuel calculation formula for each type of ship [5], as follows:

| No. | Ship Class                        | Consumption (tons/day) as a function of Gross Tonage (GT) |
|-----|-----------------------------------|----------------------------------------------------------|
| 1   | Solid Bulk                        | $C_{jk} = 20.1860 + 0.00049 \times GT$                  |
| 2   | Liquid Bulk                       | $C_{jk} = 14.6850 + 0.00079 \times GT$                  |
| 3   | General Cargo                     | $C_{jk} = 9.8197 + 0.00143 \times GT$                   |
| 4   | Container                         | $C_{jk} = 8.0552 + 0.00235 \times GT$                   |
| 5   | Passenger/Ro-ro/Cargo             | $C_{jk} = 12.8340 + 0.00156 \times GT$                  |
| 6   | Passenger                         | $C_{jk} = 16.9040 + 0.00198 \times GT$                  |
| 7   | High Speed Ferry                  | $C_{jk} = 39.4830 + 0.00972 \times GT$                  |
| 8   | Inland Cargo                      | $C_{jk} = 9.8197 + 0.00143 \times GT$                   |
| 9   | Sail Ship                         | $C_{jk} = 0.4268 + 0.00100 \times GT$                   |
| 10  | Tugs                              | $C_{jk} = 5.6511 + 0.01048 \times GT$                   |
| 11  | Fishing                           | $C_{jk} = 1.9387 + 0.00448 \times GT$                   |
| 12  | Other Ship                        | $C_{jk} = 9.7126 + 0.00091 \times GT$                   |

2.3. **Triangle Ball Method**

Triangle Ball method is a theorem that can be used to determine a distance on the surface of the earth. In other words, the spherical triangle method is a measure of distance that takes into account the shape of the earth's curved surface [6]. In this case, distance measurement due to changes in some sailing routes by the Triangle Ball method. Calculation of distances on the surface of the earth using the following formula:

$$\cos A = \cos B \times \cos C + \sin B \times \sin C \times \cos A$$  \hspace{1cm} (1)

$$A = (\arccos(\cos B \times \cos C + \sin B \times \sin C \times \cos A))^\circ$$  \hspace{1cm} (2)

$$A \text{ (NM)} = (\arccos(\cos B \times \cos C + \sin B \times \sin C \times \cos A))^\circ \times 60$$  \hspace{1cm} (3)

Where,

- $A = \text{origin}^\circ \text{ (BT)} - \text{destination}^\circ \text{ (BT)}$
- $B = 90^\circ + \text{destination}^\circ \text{ (LS)}$
- $C = 90^\circ + \text{origin}^\circ \text{ (LS)}$

3. **Case Study**

3.1. **Ship Data**

Traffic data for ships in the Sunda Strait at 2017 is in length grouping and also ship types as in Table 2 below. The format of the table is adjusted to the format of the existing tables in the IWRAP Mk II software, starting from naming the type of ship and also the length of the ship [7]. This is useful to facilitate the process of inputting ship distribution data.
Table 2. Data Clustering of Ship Traffic 2017 in Sunda Strait

| Ship Length (meters) | Crude oil | Oil prod | Chemical tanker | Gas tanker | Container ship | Gen. cargo | Bulk carrier | Ro-Ro cargo | Passen ger ship | Sup port ship | Fishing ship | Other ship | Total |
|----------------------|-----------|----------|-----------------|------------|---------------|------------|-------------|-------------|----------------|--------------|--------------|------------|-------|
| 0-25                 | 0         | 0        | 0               | 0          | 0             | 0          | 0           | 0           | 0              | 0            | 0            | 0          | 0     |
| 25-50                | 0         | 1        | 0               | 1          | 0             | 0          | 0           | 0           | 0              | 0            | 0            | 0          | 2     |
| 50-75                | 9         | 184      | 102             | 2          | 0             | 88         | 8           | 7           | 7              | 6            | 0            | 40         | 453   |
| 75-100               | 16        | 273      | 244             | 298        | 12            | 207        | 2           | 0           | 4              | 0            | 1            | 13         | 1070  |
| 100-125              | 16        | 141      | 457             | 243        | 101           | 235        | 192         | 6           | 3              | 1            | 0            | 7          | 1402  |
| 125-150              | 5         | 68       | 238             | 99         | 106           | 156        | 339         | 2           | 78             | 0            | 0            | 6          | 1097  |
| 150-175              | 15        | 176      | 55              | 235        | 96            | 25         | 203         | 2           | 626            | 0            | 0            | 8          | 1441  |
| 175-200              | 44        | 190      | 88              | 0          | 44            | 93         | 744         | 57          | 1              | 0            | 0            | 1          | 1262  |
| 200-225              | 1        | 4        | 0               | 32         | 26            | 24         | 204         | 0           | 0              | 0            | 0            | 2          | 293   |
| 225-250              | 110       | 57       | 3               | 22         | 14            | 9          | 220         | 9           | 0              | 0            | 0            | 0          | 444   |
| 250-275              | 19        | 0        | 0               | 1          | 80            | 0          | 19          | 6           | 0              | 0            | 0            | 0          | 125   |
| 275-300              | 4         | 1        | 0               | 26         | 116           | 0          | 286         | 0           | 0              | 0            | 0            | 0          | 433   |
| 300-325              | 0         | 0        | 0               | 4          | 0             | 25         | 0           | 0           | 0              | 0            | 0            | 0          | 29    |
| 325-350              | 46        | 2        | 0               | 1          | 0             | 86         | 0           | 0           | 0              | 0            | 0            | 0          | 135   |
| 350-375              | 0         | 0        | 0               | 0          | 5             | 0          | 3           | 0           | 0              | 0            | 0            | 0          | 8     |
| 375-400              | 0         | 0        | 0               | 0          | 0             | 0          | 0           | 0           | 0              | 0            | 0            | 0          | 0     |
| 400-                 | 0         | 0        | 0               | 0          | 0             | 0          | 0           | 0           | 0              | 0            | 0            | 0          | 0     |

3.2. Ship Clustering Based on Traffic Direction

In the process of calculating the ship collisions frequency using the IWRAP method both manually and by using software, a traffic direction is required that must be modeled to get accurate and optimal results, because if there is no modeling for the traffic direction, the frequency value will be messy, the direction of the ship traffic will not be detected correctly, whether the ship passage from south to north, or from north to south and so on. Then the clustering of ships is conducted based on the direction of the shipping passage as shown in Table 3. Each cluster has its own distribution of vessels as shown in Table 3.

Table 3. Traffic Direction Clustering

| No. | Cluster                          | Total Distribution (Vessels) |
|-----|---------------------------------|------------------------------|
| 1   | Passing                         |                              |
| 1   | From South to North             | 2472                         |
| 2   | From North to South             | 2294                         |
| 2   | In                              |                              |
| 1   | From South to East              | 740                          |
| 2   | From North to East              | 1314                         |
| 3   | Out                             |                              |
| 1   | From East to South              | 431                          |
| 2   | From East to North              | 1039                         |
| 4   | Crossing                        |                              |
| 1   | From East to West               | 30887                        |
| 2   | From West to East               | 30887                        |

3.3. Design Leg of TSS Sunda Strait by IWRAP Mk II

TSS or sea water separator chart, which is in the Sunda Strait and also the Lombok Strait has its own pattern design for each Strait [8]. So, in the modeling of the traffic direction for the process of calculating the ship collisions frequency after implementation TSS in the Sunda Strait is adjusted to the determined chart as shown in Figure 2. In the TSS in the Sunda Strait is modeled to consist of 7 Legs as shown in Figure 3. Each Leg has the level of density of each ship that is adjusted to the track data of each ship.
4. Discussion and Result

4.1. Frequency of Ship Collision Before Implementation TSS Sunda Strait

Besides sourced from the National Transportation Safety Committee (KNKT), ship accident data on the Sunda Strait area was also recorded at Base TNI AL (LANAL) Banten and also Proposal TSS submitted Indonesian. Ship accident data in the form of accident, the name of the ship that crashed, and also the date of the accident [9]. So that the data of ship accidents in the Sunda Strait sourced from KNKT, LANAL Banten, and TSS Proposals can be seen in Table 4 below:

| No. | Date                | Name Ship                                | Accident | Location                  |
|-----|---------------------|------------------------------------------|----------|---------------------------|
| 1.  | 26 September 2012   | KMP. Bahuga Jaya, MT. Norgas Cathinka    | Collision| The Sunda Strait Cruise Line, 4 NM East, Rimau Balak Island, Bakauheni-South Lampung |
| 2.  | 28 January 2014     | KMP. Jatra III, MT. Soechi Chmeical VII  | Collision| -                         |
| 3.  | 3 May 2014          | KMP. Marisa, MV. Qihang                  | Collision| -                         |
| 4.  | 1 October 2014      | KMP. Portlink, Cargo FGA 138             | Collision| -                         |

Based on the recapitulation of the data, it is known that within a period of 12 years (years 2007-2019), in the Sunda Strait there were 7 ship accident incidents, namely: fire, collision, and also ship grounding. Collision type ship crashes occur 4 times during the 12-year period. So that the average frequency of ship-type collision in the Sunda Strait area every year is 0.333 accidents per year.

4.2. Frequency of Ship Collision After Implementation TSS Sunda Strait

The value results calculation of the frequency of ship collisions in the Sunda Strait with the IWRAP method which in the calculation process is adjusted to the design of the Sunda Strait TSS design that has been determined and uses the IWRAP Mk II software, and the results are:
Table 5. Ship Collisions Frequency in Sunda Strait

| No. | Collision | Frequency/year |
|-----|-----------|----------------|
| 1   | Head-On   | 0.003149       |
| 2   | Overtaking| 0.070270       |
| 3   | Crossing  | 0.079589       |
|     | Collision Total | 0.153008 |

| Leg | Head-On Freq. | Overtaking Freq. | Waypoint | Crossing Freq. |
|-----|---------------|------------------|----------|----------------|
| 1   | 1.08E-12      | 0.000180         | 1        | 0.002167       |
| 2   | 1.40E-09      | 0.000135         | 2        | 0.009170       |
| 3   | 1.99E-09      | 0.000229         | 3        | 0.053240       |
| 4   | 6.90E-13      | 0.000148         | 4        | 0.015013       |
| 5   | 1.93E-12      | 0.000312         |          |                |
| 6   | 0.002628      | 0.058203         |          |                |
| 7   | 0.000522      | 0.011063         |          |                |

So, it can be seen that the value of the frequency of ship collisions in the Sunda Strait before the TSS was determined based on previous research is greater than after the TSS was determined, so that the TSS design implemented in the Sunda Strait has a great opportunity to reduce the frequency of ship collisions in the Sunda Strait.

4.3. Cost of Supporting Facilities for Implementation TSS Sunda Strait

Based on the presentation of the Head of the Dumai Navigation Class I District Office, Raymond Ivan H. Santuri at the International Workshop on The Designation of TSS and Its Associated Route Measuring in Sunda and Lombok Straits at Jakarta on June 30, 2019. To implement TSS in the Sunda Strait, Indonesia must make some preparations, including carrying out the facilities and infrastructure to support shipping safety in the designated TSS area [10] [11], including:

Table 6. Investment Cost of TSS Implementation in Sunda Strait

| No. | Object Description | Invest Cost         |
|-----|--------------------|---------------------|
| 1   | VTS includes several equipment lists and jobs | Rp 69.300.000.000,00 |
| 2   | SROP includes the procurement of the GMDSS with a list of equipment | Rp 6.692.000.000,00 |
| 3   | SBNP includes several equipment lists and jobs | Rp 6.461.950.000,00 |
| 4   | Electronic Map     | Rp 154.000.000,00   |
|     | Total              | Rp 82.607.950.000,00|

So, the total estimated investment costs that must be incurred by the Government in implementing TSS Sunda Strait in the form of supporting facilities for shipping safety in the Sunda Strait consisting VTS, SROP, SBNP, and also electronic maps of approximately Rp 82,607,950,000.00.

4.4. Increasing Shipping Distance

With the implementation of TSS in the Sunda Strait, it will affect the length of the shipping route, some shipping routes were shorter than after that. In the process of estimating the calculation of changes in the distance of the shipping route before and after the TSS is implemented in the Sunda Strait using the of Google Earth’s virtual program and Triangle Ball method. The length of the cruise route is calculated in units of Nautical Miles (NM). Where when the measurement process of the cruise route using Google Earth, there is a tool to determine the position of the coordinates of the starting point and destination point and then the distance value is calculated using Triangle Ball method. The estimation process of calculating changes in the distance of the shipping routes before and after of implementation TSS in the Sunda Strait is grouped based on traffic direction clusters in
the Sunda Strait, namely Passing, In, Out and also Crossing. Then the results in the table are as follows:

**Table 7. Changes in The Distance of Cruise Route Before and After Implementation TSS**

| No. | Cluster | Addition Distance (NM) |
|-----|---------|------------------------|
| 1   | Passing |                        |
|     | 1. From South to North |                  |
|     | a. From East | 16.95              |
|     | b. From South | 5.28               |
|     | c. From West | 12.38              |
|     | 2. From North to South |                  |
|     | a. To East | 16.95              |
|     | b. To South | 5.28               |
|     | c. To West | 12.38              |
| 2   | In       |                        |
|     | 1. From South to East |                 |
|     | a. From South | 5.28              |
|     | b. From West | 12.38             |
| 3   | Out      |                        |
|     | 1. From East to South |                  |
|     | a. To South | 5.28               |
|     | b. To West | 12.38              |

4.5. *Addition of Fuel Consumption After Implementation TSS Sunda Strait*

In calculating the estimation of the addition of fuel consumption due to the implementation of TSS in the Sunda Strait, clustering of shipping routes is made, to facilitate the calculation and analysis process. However, the existence of TSS in the Sunda Strait does not necessarily affect all shipping clustering routes, including clustering that is not affected by the TSS in the Sunda Strait, namely In (North to East), Out (East to North), Crossing (East to West) and Crossing (West to East). Following are the results of the calculation of the estimated increase in fuel consumption by the TSS implementation in the Sunda Strait:

**Table 8. Addition Fuel Consumption Cluster Passing (From South To North)**

| No. | Passing (From South to North) | Total Ship Movement | Fuel Consumption Addition (Ton) |
|-----|--------------------------------|---------------------|--------------------------------|
| 1   | From East                      | 315                 | 472.01                         |
| 2   | From South                     | 1,022               | 913.95                         |
| 3   | From West                      | 1,135               | 1,027.99                       |
|     | Total                          | 2,472               | 2,413.95                       |

**Table 9. Addition Fuel Consumption Cluster Passing (From North To South)**

| No. | Passing (From North to South) | Total Ship Movement | Fuel Consumption Addition (Ton) |
|-----|--------------------------------|---------------------|--------------------------------|
| 1   | To East                        | 255                 | 417.87                         |
| 2   | To South                       | 762                 | 529.95                         |
| 3   | To West                        | 1,277               | 1,153.09                       |
|     | Total                          | 2,294               | 2,100.92                       |
Table 10. Addition Fuel Consumption Cluster In (From South To North)

| No. | In (From South to North) | Total Ship Movement | Fuel Consumption Addition (Ton) |
|-----|--------------------------|---------------------|--------------------------------|
| 1   | From South               | 313                 | 167.53                         |
| 2   | From West                | 332                 | 290.83                         |
|     | Total                    | 741                 | 458.36                         |

Table 11. Addition Fuel Consumption Cluster Out (From East To South)

| No. | Out (From East to South) | Total Ship Movement | Fuel Consumption Addition (Ton) |
|-----|--------------------------|---------------------|--------------------------------|
| 1   | To South                 | 94                  | 55.35                          |
| 2   | To West                  | 265                 | 244.92                         |
|     | Total                    | 434                 | 300.27                         |

Table 12. Addition Of Ship Fuel Consumption of TSS in Sunda Strait

| No. | Cluster                      | Fuel Consumption Addition (Ton) |
|-----|------------------------------|--------------------------------|
| 1   | Passing (From South to North)| 2,413.95                      |
| 2   | Passing (From North to South)| 2,100.91                      |
| 3   | In (From South to North)     | 458.36                         |
| 4   | Out (From East to South)     | 300.22                         |
|     | Total                        | 5,274                          |

Table 13. Addition Of Ship Fuel Consumption of TSS in Sunda Strait Based in Ship Type

| No. | Ship Type   | Total Ship Movement | Fuel Consumption Addition (Ton) |
|-----|-------------|---------------------|--------------------------------|
| 1   | Bulk Carrier| 1875                | 1,631.94                       |
| 2   | General Cargo| 606                | 406.80                         |
| 3   | Container   | 567                 | 567.22                         |
| 4   | Crude Oil Tanker | 214            | 398.58                         |
| 5   | Chemical Tanker | 498            | 313.05                         |
| 6   | Gas Tanker   | 556                 | 462.37                         |
| 7   | Product Oil Tanker | 681          | 640.02                         |
| 8   | Passenger    | 714                 | 652.46                         |
| 9   | Ro-ro        | 85                  | 97.94                          |
| 10  | Fishing      | 2                   | 0.347                          |
| 11  | Support      | 62                  | 59.87                          |
| 12  | Other Ship   | 75                  | 42.88                          |
|     | Total        |                     | 5,274                          |
So, the estimated total increase in fuel consumption by implementation TSS in the Sunda Strait is around 5,274 Tons or 5,274,000 Kg of fuel per year. Then after getting the fuel consumption value in units of weight (Kg) it is necessary to convert to a volume unit in the form of (liters), by adding fuel consumption weight in units (kg) divided by the specific gravity. The total addition of fuel consumption is 6,132,558 liters. And than to get the total cost of adding fuel consumption is by adding the volume of fuel consumption in units (liters) multiplied by the price of fuel per liter, estimated price of fuel per liter is Rp 12,570. The total cost of adding fuel consumption due to changes in shipping routes in the implementation of the TSS in the Sunda Strait is valued at Rp 77,086,256,000.00.

5. Conclusion
Based on the analysis of the ship collisions frequency in the Sunda Strait after the TSS has been implemented so it can be seen that the frequency of ship collisions is reduced. And with the implementation of TSS in the Sunda Strait, it is necessary to fulfill the facilities and infrastructure to support shipping safety in the form of VTS, SROP, SBPN and electronic maps that result in the State of Indonesia having to prepare investment costs for these matters. The implementation of TSS in the Sunda Strait also resulted in changes some of the shipping routes that adjust the TSS design, resulting an increase in fuel consumption for ships of shipping companies.

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