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Formal Safety Assessment of the Connection of the Sunda Strait and Java Sea Through the Implementation of IMO Routeing Measures

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Abstract

Safety management of maritime traffic is crucial for archipelagic states such as Indonesia, especially in areas like the connection between the Sunda Strait and the Java Sea. This study proposes a traffic lane design using the IMO routeing measures, employing the Formal Safety Assessment scientific method. The study recommends implementing Traffic Separation Schemes (TSS), precautionary areas with a recommended counterclockwise route, and inshore traffic zones. Results indicate that TSS is more effective in reducing collision frequency compared with two-way routes, with a counterclockwise flow further mitigating crossing situations. The proposed measures, particularly Risk Control Option 3, show a 54% reduction in collision frequency compared with the existing conditions. However, despite improvements, collision frequencies remain intolerable, necessitating additional strategies. The total collision frequency for all proposed measures is deemed unacceptable, requiring further methods to enhance safety. The economic evaluation shows potential savings, with estimated values for Gross Cost of Averting Fatality and Net Cost of Averting Fatality at US$ 3.21 million and US$ 2.9 million, respectively. Thus, while the proposed measures demonstrate some efficacy, additional strategies are imperative to adequately address collision risks in the designated area.

Keywords: IWRAP, maritime traffic, collision frequency, routeing measures

1. Introduction

Safety is a certain priority for all maritime operations, and it certainly has an effect on human lives, the environment, or the continuity of the operation. The concept of maintaining safety aspects aligns with the intention to avert a certain risk. In the case of maritime traffic, any effort to prevent risks should be addressed to all maritime operations related to vessels' movement from one significant place to another in a region that involves other vessels. However, the rights for ships to pass through a region of waters should essentially not be limited until there is a concern of accidents that may occur. Therefore, the idea of establishing maritime traffic lanes in some regions has always been influenced by the concern of safety in the area, and it is intended to prevent unwanted threats to human lives, the environment, or the vessels' operation. The necessity of maintaining the safety of maritime traffic goes along with the efforts of managing the traffic. Consider that managing maritime traffic is a certain way to keep the continuity of the traffic out of any obstruction. An example of managing traffic in Indonesia is through the enforcement of Indonesia's Archipelagic Sea Lanes (IASL), which, originally before its establishment, are naturally diverse and uncontrollable. The reason is that the waters have a strategic position to have many accesses for international shipping to pass through. Therefore, IASL was established through the United Nations Convention on the Law of the Sea in 1982 as procedures for international shipping to only pass through three separated main routes, in which each route has directions in passing among archipelago according to the situation in each area. However, IASL is only able to manage the entrance and exit that ships are allowed to access in and out of Indonesian waters, while the concern of an accident occurring is not in the context of its establishment. Therefore, maritime traffic lane establishment is the solution for preventing accidents. Accident cases that should be avoided in maintaining

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the continuity of maritime traffic include grounding and collision. To prevent grounding, it can be done by managing the direction of traffic flow that intentionally directs the passing ships out of shallow areas. To prevent collisions, efforts are quite varying, such as managing the traffic direction, reporting, and monitoring system through Vessel Traffic Service (VTS), or the separation of opposing traffic. Because collisions can be defined as when more than one moving vessel collides with each other in significant ways. The connection between the Sunda Strait and the Java Sea became the main focus of this study because of the location of IASL-1, where specifically IASL-1 passes through the Sunda Strait from the Java Sea toward the Indian Ocean on the south of Indonesia. The establishment of IASL is certainly to accommodate passages that are considered to have higher traffic density to allow international vessels to pass legally. Then, the Traffic Separation Scheme (TSS) of the Sunda Strait is established to prevent collisions in the area. The consideration for its establishment apart from the high traffic density is the existing traffic flow in the area. Where other than the traffic of vessels that are going south from Java Sea toward Indian Ocean and the other way around, there is also traffic that crosses the strait from the ports and terminals around Suralaya Water toward the Island of Sumatra. The most frequent vessel to cross the strait is the traffic of crossing ferries from the Port of Merak bound to the Port of Bakauheni and the other way around. Because of this crossing situation of different traffic flow, which at least has five crossing points in the area [1], the TSS of the Sunda Strait was established to prevent collisions in the crossing traffic.

There has been a case of collision that occurred in the area before the TSS of the Sunda Strait was established. In 2012, a collision between MV Bahuga Jaya and MT Norgas Cathinka in the Sunda Strait occurred on September 26th. At 03.05 local time, MV Bahuga Jaya was on its route from Port of Merak bounded to Port of Bakauheni with a speed of 10 knots, which usually takes 2 h. While MT Norgas Cathinka was approaching the Sunda Strait from the southern side heading toward the northeast direction of its position with a speed of 12 knots. At 04.44 local time, the collision occurred where the port bow of MT Norgas Cathinka collided with MV Bahuga Jaya's starboard side. With the TSS of the Sunda Strait being established, the effectiveness of maritime traffic lane was proven with reduced frequency of ship-to-ship collision. However, this study took a further step toward this concern through the evaluation of maritime traffic lane design that might be needed in the northern counterpart of the Sunda Strait, considering that there is no maritime traffic lane established in the area despite its high traffic density [2].

Despite the various kinds of efforts that can be implemented to prevent the risk, it is certain that each solution has its own concern, which will need relevant considerations. This study focuses on the effort in preventing ship-to-ship collision through the establishment of maritime traffic lanes by precisely considering the right designs based on the regulations for IMO Routeing Measures, which then compare the reduced frequency of collision and the economic benefits obtained by each design. Even though the real cases show that the efforts would only be effective if they are implemented altogether as a combination, such as the implementation of VTS along with maritime traffic lanes, which proves that implementing only one of them may not be effective.

2. Methods

A maritime traffic lane is an example of making and establishing a regulation that should be obeyed by the targeted parties, specifically because the purpose of a maritime traffic lane is to manage traffic through procedures of navigation. The consideration to establish maritime traffic lanes is also guided by the rules of IMO on Ships' Routeing that are already standardized and certainly align with other rules of IMO. Therefore, this study requires a method that is acceptable for evaluating a regulation with its existing situation and comparing it to possible development of the regulation. This necessity aligns with the purpose of Formal Safety Assessment (FSA) [3]. By conducting FSA for this study, this research could thoroughly determine the risk, provide possible solutions, calculate detailed cost requirements, and obtain recommendations for decision makers.

The study is carried out in sequence as shown in Figure 1. The flowchart is a modified version of the original flowchart for FSA as determined by the IMO [3]. However, its modification is intended to achieve a more suitable method that corresponds to the aim of this study. Since FSA is designed to evaluate safety and risk concerns, important criteria such as hazard, frequency, and consequences of accidents are the assessed parameters. In this case, the frequency of collision was designed to be the prioritized assessment to determine the number of collisions per year or the interval between collisions to occur.

Basically, finding the frequency of collision in an area can be carried out through a calculation method or using simulation software. This study used software called the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) Waterway Risk Assessment Program (IWRAP) as a simulation tool to obtain the frequency of collisions in the area. This software has been endorsed by the IALA to evaluate the risk of ship collision prior to implementing a new maritime traffic lane. The reason is that the tool is considered to be the most advanced methodology with its ability to assess the frequency based on the existing traffic records using the recorded Automatic Identification System (AIS) data.

3. Results and Analysis

3.1. Hazard Identification (FSA Step 1)

As part of identifying the hazard, this research collected some reports from The National Transportation Safety Committee, the National Shipping Court, and local news that reviewed some incidents that had occurred. It was found that from 2010 until 2023, there were nine incidents of collision that occurred in the focused area of this research. However, the nine incidents were limited to those that occurred around the Sunda Strait and extended to the area of Jakarta Bay; therefore, any collision incidents that occurred in the Java Sea but were outside of the limitation are not included in Table 1.

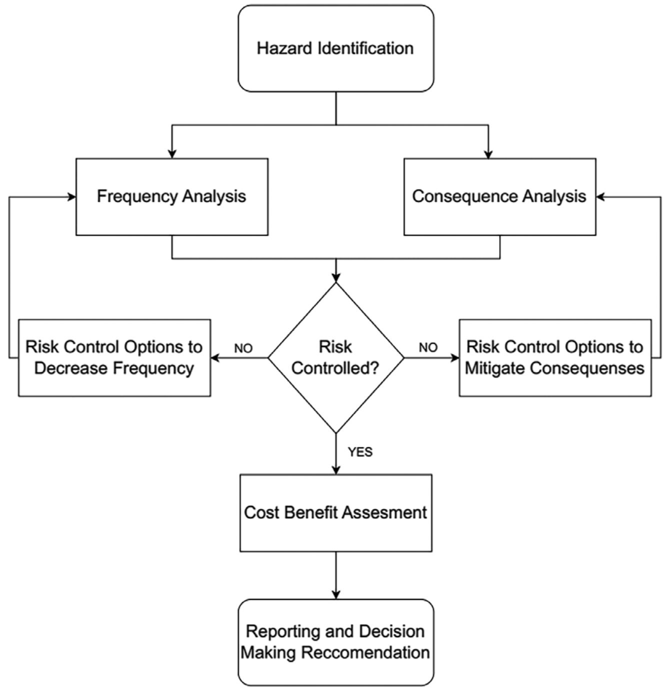

Figure 1. *Methodology for the study*

The incidents are categorized on the basis of the type of collisions, which are head-on, overtaking, and crossing collisions. The incidents are categorized on the basis of the collision scenario, as mentioned in their reports. However, three incidents are not categorized into any of the types since the reports stated them as bumping situations.

At the beginning of the study, hazard identification is important to specifically define the risk of each hazard. In this case, it is found that every type of collision scenario has a specific consideration in mitigating the risk, such as the need to separate opposing traffic to avoid a head-on collision. In this study, type of collisions are categorized before assessing the risk because each collision scenario is assessed differently when simulated in IWRAP. Some incidents that were not classified as one of them, such as bumping between ships, are neglected because the collision occurred because of extreme weather conditions and none of the ships were sailing or maneuvering during the incidents.

3.2. Risk Assessment (FSA Step 2)

After identifying the hazards, the study continued with risk assessment, which assessed the collision frequency using the IWRAP. One year interval of AIS data was collected from the VTS of Tanjung Priok, Indonesia. The data were imported in AIS RAW message format and underwent configuration for heatmap and density plot setup to assess the collision frequency and displayed accurately in the software. Specific setups were configured to limit the area of interest. The results are shown in a density plot indicating high-traffic areas. Legs are defined based on density plots of the highest traffic density at intervals of two weeks, although yearly intervals were also considered to accurately capture the overall frequency. Then, the frequency of collision is calculated on the basis of the specific traffic located in

Table 1. *Historical records of collision incidents in Sunda Strait and part of Java Sea*

No.	Date	Time	Collision Types	Waters	Weather Condition
1	19/05/2010	22:50:00	Head-on	Java Sea	Unstated
2	26/09/2012	4:44:15	Head-on	Sunda Strait	Soft Wind
3	31/05/2013	21:12:30	Head-on	Java Sea	Cloudy
4	7/4/2017	1:30:00	Crossing	Java Sea	Sunny
5	5/7/2017	18:32:00	Overtaking	Sunda Strait	Sunny
6	29/08/2017	17:10:00	Collision	Sunda Strait	Extreme Weather
7	23/6/2020	5:40:00	Collision	Sunda Strait	Harsh Current
8	22/4/2019	16:31:28	Overtaking	Sunda Strait	Cloudy, Soft Wind and Current
9	1/4/2023	6:55:00	Collision	Sunda Strait	Harsh Current

the legs and waypoints, as shown in Figure 2. The 2-week interval with the highest traffic indicated that the highest frequency is on Leg 5 and Waypoint 2. This study aims to compare the existing risk on Leg 5 and Waypoint 2 and the risk when several adjustments are made on both areas of interest. However, the obtained frequencies are classified on the basis of the individual risk acceptance criteria to consider the classification of risk into either tolerable, intolerable, or As Low As Reasonably Practicable. Based on the classification, the frequency on Leg 5 and Waypoint 2 are already classified as intolerable risk in which risk mitigation is needed to reduce the frequency.

3.3. Risk Control Option (FSA Step 3)

Risk Control Option (RCO) is required in an FSA study to define what suitable risk mitigation should be taken to reduce the risk. In this study, risk mitigation are arranged in the form of IMO routeing measure implementation [4]. The implementation of routeing measures as determined by the IMO is considered based on the specific hazard. Therefore, there are certain conditions that have to be met as a requirement to proposed routeing measure implementation. As an example, there must be an international seagoing vessel passing the area to implement TSS.

The result of the risk assessment indicates that the highest values are located in Leg 5 and Waypoint 2, which are

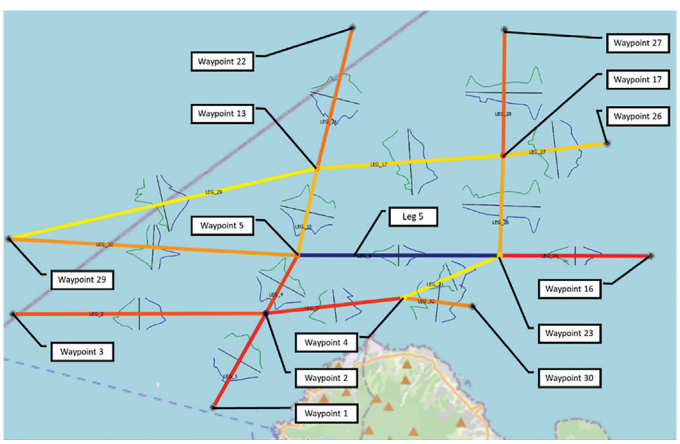

Figure 2. *Relative frequency analysis on each leg and waypoint plotting in IWRAP*

IWRAP: IALA Waterway Risk Assessment Program

considered to be intolerable risks and require further mitigation to reduce the frequency. Specifically, the assessment identified that Leg 5 has the highest frequency for head-on and overtaking collisions, while Waypoint 2 has the highest frequency for crossing collisions, and all of them are classified as intolerable. As for selecting the right routeing measures to mitigate the risk, the consideration was based on the requirement of each ships's routeing as regulated in [5] Ministerial Regulation 129 Year 2016 of the Indonesian Directorat General of Maritime Affairs.

Table 2 shows the proposed routeing measures as the chosen suitable routeing measures in addressing the identified hazard. As an example, in mitigating head-on collision at Leg 5, there are two possible routeing measures to implement: Traffic Separation by Separation Zone and Line or Two-Way Routes with One-Way Sections. In the case of mitigating the risk of crossing collision at Waypoint 2, the possible routeing measures to implement are either roundabouts or precautionary areas with recommended traffic flow. Then, several RCOs are determined as the combination of the proposed routeing measures in the design to thoroughly mitigate all the risks. A similar case to which this study also reflected to similar routeing measures selection and design is the implementation in the Sunk Area and Northern Approach to the Thames Estuary, as shown in Figure 3.

In most cases, in establishing any regulations or procedures, there must be an evaluation of the regulation's relevance to its application. Therefore, this study also evaluated its implementation assuming that the implementation of routeing measures will be established for 25 years of application. The most important consideration to this evaluation is regarding the traffic volume in the area that will certainly grow. The assumption for this consideration is based on the growth of traffic volume in the area over the last decade, and the growth rate is used to forecast the growing traffic for 25 years in the future. Therefore, the proposed RCOs are differentiated based on the implementation for the present and the forecasted traffic volume, in which the traffic in 2022 has an hourly traffic of 1.65 ships/hour and the escalated traffic on the same location in 2047 has an hourly traffic of 6.79 ships/hour.

Table 2. *Proposed routeing measures based on identified hazard*

Hazard Identification	Frequency	Proposed Routeing Measures
Head-on collision at Leg 5	4.69E-04	• Traffic separation by separation zone and line
		• Two-way routes (with one-way sections)
Overtaking collision at Leg 5	1.91E-04	• Traffic separation by separation zone and line
Crossing collision at waypoint 2	2.68E-04	• Roundabouts
		• Precautionary area with recommended traffic flow

The consideration to propose TSS and two-way routes is to accommodate the opposing traffic in Leg 5, which is theoretically able to minimize the risk of both head-on and overtaking collisions, and the consideration to implement roundabouts is to minimize the crossing situation in Waypoint 2. As for overtaking collision, efforts can be made by adjusting the width of a fairway, where a greater width of a fairway will provide better space for an overtaking scenario and consequently prevent collision. For inshore traffic zone, this measure is considered in this study as a recommendation from the Navigation District of Tanjung Priok. Inshore traffic zones might be needed due to the frequent port activity in Suralaya Waters, even though no assessment using IWRAP was conducted for evaluating inshore traffic zones.

An additional step of the design process is required in this study, although it is not included as a step of FSA. The design process is conducted after the RCOs have been determined. Each RCO is a combination of routeing measures in the design of a maritime traffic lane. With the planned designs, the next consideration is the dimension of the lane, which certainly could affect the frequency of collision. The length of a fairway is adjusted to the length

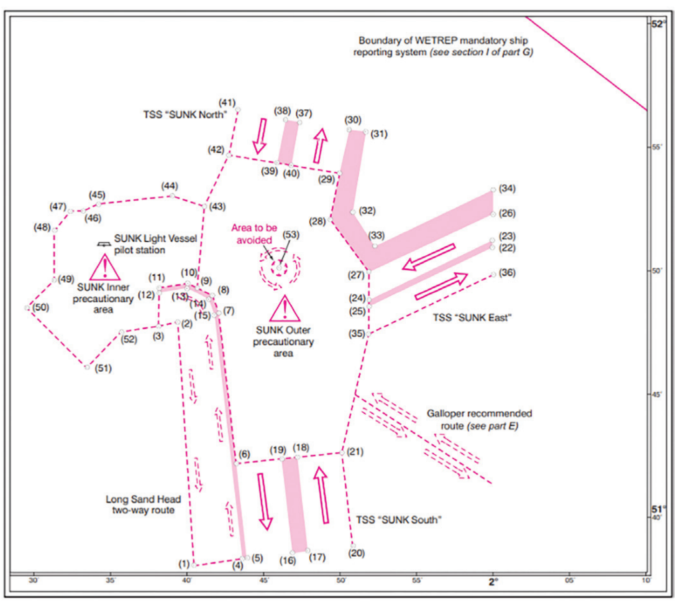

Figure 3. Routeing measures implementation in the sunk area and northern approach to thames estuary

Source: IMO Ships Routeing, 2010

of conventional routes, while the width of the fairway is determined based on the existing width of the passage, ship dimensions, and traffic volume in the area [6]. In this case, the existing situation in the area of interest is located in an open sea with few natural obstructions. However, the width of the fairway essentially determines the standard deviation of the traffic distribution [7].

The decision to determine the width of a fairway based on the existing traffic volume refers to the guidelines of the Permanent International Association of Navigation Congresses and a study from the Maritime Research Institute Netherlands. The study recommends that the minimum width of a fairway is 4 L for areas with the number of annual trips less than 4400, 6 L for areas with the number of annual trips between 4400 and 18000, and 8 L for annual trips above 18000, where L is 98.5% of the length overall of the largest vessel passing through.

Because the length of the planned fairways is adjusted to the length of the conventional routes, the required fairways are assumed to have the same length as the defined legs, as shown in Figure 2. Then, they are adjusted to prevent overlapping of any obstructions nearby, other fairways, and adjusted to the safety and maneuver margin [8]. An example for Leg 1 in Figure 2, when a fairway is designed to have the same length as the leg, it will overlap the route of crossing the ferry Merak-Babakauheni. Therefore, the traffic lane on the leg should be shortened to the north.

Roundabouts that need to reduce the frequency of crossing collisions at Waypoint 2 require a vast area to accommodate ships for maneuvering, and this study arranges the location of the center of the roundabout to be exactly at Waypoint 2. However, as the condition led to overlapping between the roundabout and the nearby anchorage areas in Suralaya Waters, the location is shifted a little bit toward the northwest for 60° from the North for 2 km. The final designs are four different traffic lane designs with various dimension and routeing measures selection. An example of RCO 3 is shown in Figure 4, which shows the location of the proposed RCO, TSS Sunda Strait, and nearby anchorage areas in Suralaya Waters.

In duplicating the design of RCOs and the forecasted traffic volume for simulation, additional configurations are required in IWRAP (Table 3). The intention is to modify

***Table 3.** List of RCO*

RCO	Routeing Measures	Traffic Analysis
1	Roundabouts, two-way routes, and inshore traffic zone	RCO for traffic analysis in 2022
2	Roundabouts, traffic separation scheme, and inshore traffic zone	RCO for traffic analysis in 2047
3	Roundabouts, two-way routes, and inshore traffic zone	RCO for traffic analysis in 2022
4	Roundabouts, traffic separation scheme, and inshore traffic zone	RCO for traffic analysis in 2047

the existing traffic to adjust the natural characteristics with the mannered version as the impact of the establishment of routeing measures. The modification in IWRAP is by scaling the traffic volume specifically on each leg depending on the growth of the traffic, the distance between opposing routes, and the traffic distribution. Assuming the traffic is in a form of normal distribution, the distribution has a standard deviation of 40% of the width of a fairway, which is an approach as explained in the module of IWRAP theory.

The results from IWRAP are the frequency of each type of collision obtained in four different scenarios with each value of frequency and in total, as shown in Table 4, and the value of reduction rate, as shown in Table 5. Even though the only applicable one is RCO 3 as it is the only one able to reduce the frequency of collision, none of them did not show any potential to be implemented as all their frequencies are still classified as intolerable.

3.4. Cost Benefit Analysis (FSA Step 4)

Although all RCOs have been assessed using IWRAP, the selection of RCO was not only based on the effectivity of the RCO in reducing the risk but also should be seen from an economical perspective, in which this FSA study considered the selection of RCO through cost-benefit assessment. This step assessed the cost per ship for the implementation of each RCO, the reduced risk, and the expense cost from a fatality,

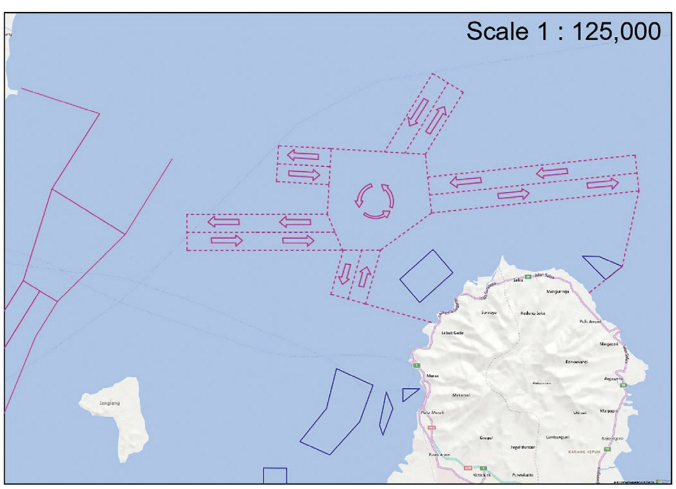

Figure 4. *Design of traffic lane proposed as RCO 3*

RCO: Risk Control Option

which is assumed to be averted through the implementation of the RCOs. The parameters used to select the RCO based on the three components are the value of Net Cost of Averting Fatality (NCAF) and Gross Cost of Averting Fatality (GCAF), which consist of the three assessed factors. The formulas to calculate NCAF and GCAF are, respectively, shown below:

$$\mathrm{GCAF} = \frac{\Delta \mathrm{C}}{\Delta \mathrm{R}} \tag{1}$$

where ΔC is the cost per ship of the RCO under consideration while ΔR stand for risk reduction per ship, implied by RCO.

$$\mathrm{NCAF} = \frac{(\Delta \mathrm{C} - \Delta \mathrm{B})}{\Delta \mathrm{R}} \tag{2}$$

Where ΔB is an economic benefit per ship resulting from the implementation of RCO.

All three components should be determined by the objective of the research itself. In this study, ΔC was defined as the total survey cost on the area of research with the cost required for additional fuel due to the extended distance of the ship accessing the routes, ΔB was the cost of averted fatality, which in this study is assumed for the case of an oil spill occurring in the area due to ship collision. The value of ΔR is the difference between the frequency of collision on the existing assessment and the frequency assessed with each RCO implementation.

The calculation of ΔC was based on survey cost which estimated about USD. 133,422 by the District Navigation of Tanjung Priok, adding up to the additional operating cost of the ship due to the additional voyage duration.

The calculation of the additional operating cost was based on the length of the route, which led to the increase in voyage duration, assuming that the ship was traveling at the same average speed. In calculating the extended distance of the ships to pass through, a list of dominant routes that mostly pass by are determined based on the existing traffic. Where 11 routes are defined as in Figure 5, and Table 6 shows the difference between each RCO. It selected the most frequent trajectories for vessels to pass the area, and the total distance

Table 4. *Frequency of collision of all RCOs*

	RCO 1	RCO 2	RCO 3	RCO 4
Overtaking	8,91E-04	1,18E-02	2,80E-04	3,94E-03
Head-on	8,73E-04	1,24E-02	4,36E-04	1,08E-02
Crossing	8,60E-04	1,45E-02	4,39E-04	7,22E-03
Total	2,59E-03	3,87E-02	1,15E-03	2,20E-02

of each trajectory is represented by the summation of several connecting legs located nearest to the actual trajectories of the ships.

The value of ΔB is based on the assumption that the amount of oil spill was from an oil product tanker with the characteristics shown in Table 7, where the amount of oil spilled is assumed to be the volume of an oil cargo tank located in the midship section of the vessel. The estimation method used in this study is based on an approach conducted by [9] because most cargo tanks located in the midship section have more volume than the others. Therefore, the approach used to calculate the cargo tank volume is based on the formula as follows.

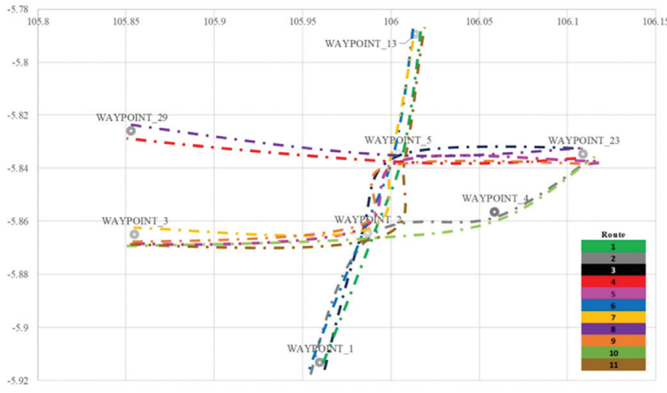

Figure 5. Dominant routes of ships passing through Suralaya Waters

$$B_T = \frac{B - 2w}{m} \tag{3}$$

where B_T is the breadth of cargo tank compartment (m), B is the breadth of vessel (m), w is the double hull width (m), and m is the number of tanks in the transverse direction.

$$D_T = D - h \tag{4}$$

where D_T is the draught of the cargo tank compartment (m), D is the draught of the vessel (m), and h is the height of the double bottom (m).

The double hull width and the height of the double bottom are calculated using the rules determined by Det Norske Veritas (DNV) in the DNV Rules for Classification Part 5 Chapter 5 that specifically regulate the requirements for tankers. The formula is specifically targeted to ships of 600 DWT to 5000 DWT and ships above 5000 DWT. The selected vessel is classified as ships of above 5000 DWT, which means the formula is applicable for the sample, and the estimation method is for general conventional design of monohull tankers with double skin. The following are the

***Table 5.** Reduction rate of all RCOs*

	RCO 1	RCO 2	RCO 3	RCO 4
Overtaking	-78%	-2259%	44%	-689%
Head-on	37%	-832%	67%	-711%
Crossing	-43%	-2312%	27%	-1105%
Total	-6%	-1489%	53%	-804%

***Table 6.** Extended distance due to RCO implementation*

Routes	Existing 2022			RCO 1	RCO 2	RCO 3	RCO 4
	Course (waypoint to waypoint)	Course (leg to leg)	Route distance (m)	Route distance (m)	Route distance (m)	Route distance (m)	Route distance (m)
1	1,2,5,13	1,4,10	15069	17058	17058	16896	17065
2	1,2,4,23	1,3,31	20223	21049	21049	20658	20374
3	1,2,5,23	1,4,5	21598	21049	21049	20658	20374
4	23,5,29	5,30	28378	29322	29322	29473	29854
5	23,5,2,3	5,4,2	30059	32780	32780	32667	33518
6	13,5,2,1	10,4,1	15069	17667	17667	17971	17894
7	13,5,2,3	10,4,2	23530	23753	23753	23301	23548
8	29,5,23	30,5	28378	33049	33049	31818	31921
9	3,2,5,23	2,4,5	30059	29327	29327	28986	28855
10	3,2,4,23	2,3,31	28684	29327	29327	28986	28855
11	3,2,5,13	2,4,10	23530	25336	25336	25224	25546

equations used for calculating double hull width and height, respectively.

$w = 0.5 + \frac{DW}{20000}$ or w = 2.0, whichever is lesser, but not less than 1.0 m (5)

$h = \frac{B}{15}$ or h = 2.0, whichever is lesser, but not less than 1.0 m (6)

The length of the cargo tank compartment L_T was estimated using the following equation (7).

$$L_T = \frac{L - L_A - L_F}{n} \quad (7)$$

The values of LA and LF are based on the vessel's DWT and length, as shown in Table 8.

After all the above components have been calculated, which indicate the dimensions of a cargo tank compartment, the formula below can be applied to calculate the specific volume for the cargo tank located in the midship section.

$$V_i = C_i \times L_T \times B_T \times D_T \quad (8)$$

where, V_i is volume of a cargo tank (m^3) and C_i is the volumetric coefficient (equal to midship coefficient for cargo tank located at midship section).

As the volume of the cargo tank has been calculated, the estimation of the oil spill response cost per unit (US$/ton), C_u, is based on the weight of the spilled oil from the calculated volume of the cargo tank. Where the weight is obtained by assuming the density of the oil spilt to be 0.86 ton/m^3, and the response cost is basically the estimated cleanup cost (US$), C multiplied by the cost modifiers and the amount of oil spilt, as discussed in a previous study [10]. The estimated cleanup cost, C_e (US$), refers to a study [11] where the estimation is classified based on the amount of oil spilt, the type of oil, and the location of the oil spill scenario. Then, the total cleanup cost is obtained by linear regression of the classification.

The cleanup cost was modified by considering cost factors [12] such as oil type, spill size, location type, primary method cleanup, and shoreline oiling modifiers to obtain the response cost per unit. Therefore, the total response costs are obtained by multiplying the response cost per unit with the amount of oil spilt. The estimation of the total response cost is considered the benefit due to the averted fatality, which would cost when an oil spill scenario occurs. The response cost per unit and the estimated total response cost are given in Equations (9) and (10).

$$C_U = C \times l \times t \times o \times m \times s \quad (9)$$

Where l is a local location, t is an oil type modifier, o is a shoreline oiling modifier, m refers to cleanup methodology, and s is the size of the oil spill.

$$C_e = C_u \times A \quad (10)$$

where A is the specified spill amount for scenario (ton).

Then, the estimated cost of ΔB is divided by the number of trips passing through the area to obtain the cost for each ship. The resulting ΔB for RCOs analyzed in 2024 uses the same value, while for RCO 2 and RCO 4, the result is escalated as an impact of inflation through the years, and the same adjustment is also taken for ΔC.

The ΔR is only based on the frequency of collision assessed by using IWRAP, as discussed previously. The results of ΔC, ΔB, and ΔR to calculate the value of NCAF and GCAF are shown in Table 9. The main consideration in selecting the RCOs through cost-benefit assessment is based on the comparison of NCAF and GCAF between each RCO. In most cases, the selected RCO is simply the RCO with the lowest GCAF and highest ΔR. However, any RCO would only be accepted when both NCAF and GCAF are below

Table 7. *Ship characteristics of the selected vessel*

Ship data and characteristics		
Name : Rosa Dini	Loa : 182.55 m	Δ : 45118.137 ton
IMO : 9240718	LPP : 175 m	∇ : 44017.68 m^3
MMSI : 525119081	Beam : 27.74 m	Am : 304.734 m^2
DNV id : 9240718	Breadth : 27.34 m	Cb : 0.789
Flag : Indonesia	Depth : 16.7 m	Cp : 0.794
Type : Products Tanker	Draught : 11.216 m	Cm : 0.994
GT (ITC 69) : 23217	Height : 46 m	Cwp : 0.867
NT (ITC 69) : 11217	Cargo Tanks : 14	Δ : 45118.137 ton
DWT : 37155	TPC : 46.1	∇ : 44017.68 m^3

Table 8. L_A and L_F of tankers based on DWT

	Below 35k DWT	35k-50k DWT	50k-80k DWT	Above 80k DWT
L_A	0.24 L	0.22 L	0.21 L	0.195 L
L_F	0.06 L	0.055 L	0.055 L	0.05 L

Table 9. Summary of cost benefit assessment

RCO	ΔR	ΔC (US$ m)	ΔB (US$ m)	ΔC - ΔB (US$ m)	GCAF (US$ m)	NCAF (US$ m)
RCO 1	-0.0002	0.0100	0.0095	0.0005	(65.33)	(3.44)
RCO 2	-0.0565	0.0290	0.0029	0.0261	(0.51)	(0.46)
RCO 3	0.0013	0.0080	0.0095	(0.0015)	6.25	(1.18)
RCO 4	-0.0196	0.0254	0.0029	0.0225	(1.30)	(1.15)

US$ 3 million based on the US$ 3 million criterion, and this condition also the effect of the reduced frequency of collision where the reduced frequency of RCO 3 is considered too low and not effective enough.

3.5. Recommendation for Decision Making (FSA Step 5)

The recommendations obtained from this study conducted through FSA are addressed to the authority in the establishment of maritime traffic lanes. The result shows the inefficient effort to establish a maritime traffic lane in this specific case. This is due to the increasing traffic that will not be accommodated in the near future, thus requiring additional efforts in managing the traffic. Therefore, further evaluation that could affect the causation probability and not only from the geometric number perspectives like traffic volume, traffic direction, traffic lane width, and traffic distribution.

4. Conclusion

The traffic volume in the designated area has 14492 ship trips passing through in 2022, with the number of ships being 1928 vessels having a total collision frequency of 2.43E-03, while the frequency of head-on collisions, overtaking collisions, and crossing collisions is 1.34E-03, 4.99E-04, and 5.99E-04, respectively. The main priority in selecting routeing measures is to avoid head-on, crossing, and overtaking collisions. Both head-on and overtaking collisions can be prevented through the implementation of two-way routes or TSS, and the frequency of crossing collisions can be prevented by implementing roundabouts or precautionary areas with recommended counterclockwise traffic flow. However, routeing measures that have been assessed are not effective enough to support their implementation considering the insignificant reduction rates to prevent the risk. This study shows the limitation of reducing the risk of collision by only affecting the geometric number. Thus, future studies should discuss efforts to reduce the frequency of collision by the influence of both geometric number and causation probability for a more efficient solution.

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Authorship Contributions

Concept design: T. F. Nugroho, K. B. Artana, A. A. B. Dinariyana, Data Collection or Processing: T. F. Nugroho, K. B. Artana, A. A. B. Dinariyana, Z. F. Suwardana, and F. H. Javanica, Analysis or Interpretation: T. F. Nugroho, K. B. Artana, A. A. B. Dinariyana, Z. F. Suwardana, and F. H. Javanica, Literature Review: T. F. Nugroho, K. B. Artana, A. A. B. Dinariyana, Z. F. Suwardana, and F. H. Javanica, Writing, Reviewing and Editing: T. F. Nugroho, K. B. Artana, A. A. B. Dinariyana, Z. F. Suwardana, and F. H. Javanica.

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