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PRELIMINARY DESIGN OF A TRAFFIC SEPARATION SCHEME AT THE HUB PORT OF IKN: HYDRO-OCEANOGRAPHIC ANALYSIS FOR NAVIGATIONAL SAFETY IN THE MAKASSAR STRAIT

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Abstract:

The increasing maritime traffic density in the Makassar Strait, particularly due to the development of the Hub Port at Indonesia's new capital (IKN), necessitates a structured Traffic Separation Scheme (TSS) to ensure navigational safety. This study aims to design a preliminary TSS by integrating hydro-oceanographic data, vessel traffic analysis, and maritime risk assessment. A qualitative research methodology employing case studies and literature reviews was applied. Vessel movement patterns were analyzed using data from the Indonesian Maritime Security Agency (BAKAMLA RI) and vessel tracking applications. Safety assessments were conducted based on historical collision records and probabilistic modeling of grounding, stranding, and vessel collisions. Hydro-oceanographic data, including wind speed, wave height, and tidal currents, were sourced from secondary data and validated using numerical modeling. The findings suggest that the Makassar Strait TSS should consist of two separate lanes, each 3 km wide, with dedicated northbound and southbound routes. The design considers navigational obstacles such as subsea pipelines, offshore platforms, and coral reefs, ensuring safe passage. Hydro-oceanographic analysis confirms that prevailing conditions, including wind speeds below 15 knots and maximum wave heights of 1.25 meters, comply with recommended maritime safety standards. Additionally, statistical evaluations of vessel movement and collision probability indicate that a 3 km-wide channel effectively mitigates accident risks. This study provides an initial framework for optimizing TSS implementation in one of Indonesia's most strategic waterways. The results highlight the importance of structured traffic management in reducing navigational hazards and improving maritime efficiency. The proposed TSS design aligns with international safety regulations and aims to support the long-term development of the IKN Hub Port as a critical maritime node. However, this study relies on secondary data and does not incorporate real-time traffic monitoring or high-resolution hydrographic surveys. Future research should integrate real-time Automatic Identification System (AIS) data and in-situ hydrographic measurements to refine the TSS structure. Additionally, further hydrodynamic simulations should be conducted to enhance route optimization under extreme weather conditions.

Keywords: *traffic separation scheme (TSS), Ibu Kota Negara (IKN), Makassar Strait, maritime safety, hydro-oceanographic modelling*

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1. Introduction

Indonesia's existence as an archipelagic country has been officially recognized internationally based on the United Nations Convention on the Law of the Sea - UNCLOS adopted on December 10 1982, and came into force on November 16 1994 (Hung et al., 2019). Consequently, foreign ships must provide access rights by establishing Indonesian Archipelago Sea Lanes (ASLs/ALKI), which have been approved by the International Maritime Organization (IMO) (Guzman et al., 2020). Moving the National Capital (IKN) from Jakarta to East Kalimantan (Kalalinggi et al., 2023)was chosen by the Indonesian Government to realize the growth of new cities and reduce other problems that indicate that Jakarta is no longer supported as the nation's capital (Berawi, 2022; Habirun et al., 2023). The development of the main port into a Hub Port is directly adjacent to the Makassar Strait. The Makassar Strait is one of the world's eight main straits with important military and economic significance (Gani et al., 2022; L. Xiao et al., 2022). The Makassar Strait connects the western Pacific Ocean and the northeastern Indian Ocean and has become a vital node of the important route from the South China Sea, the Philippines, to Australia (Q. Xiao et al., 2020). ALKI II, which connects the Sulawesi Sea with the Indian Ocean via the Makassar Strait and Lombok Strait, is one of the critical routes (Ronaboyd et al., 2019). The Makassar Strait is also included in the four waters within Indonesia's sovereignty, along with the Malacca Strait, Sunda Strait and Lombok Strait, which have political and economic strategic importance because they involve the survival of a number of countries (Napang et al., 2022).

The role of sea transportation is significant in supporting various national development agendas, such as sea connectivity, integrated main port networks, and support for IKN (Direktur Jenderal Perhubungan Laut, 2020). In the port development process, it is essential to pay attention to the availability of shipping lanes that limit ship traffic and consider security factors (Huntington et al., 2015), navigation safety must first be strengthened to support maritime traffic safety capabilities (Hasbullah et al., 2023; Kuncowati et al., 2023). This can be realized through the Traffic Separation Scheme (TSS), a maritime traffic management route system regulated by the IMO (Pietrzykowski et al., 2015; Ronaboyd et al., 2019). TSS separates merchant shipping routes from national jurisdictional waters (Mamahit et al., 2020; Yu et al., 2023). TSS is applied to busy and narrow shipping lanes to improve navigation safety (Sobaruddin et al., 2017). Apart from that, TSS can also help reduce congestion in shipping lanes (Singh et al., 2019). Indonesia has the right to regulate TSS in its territorial waters based on Article 53 (6) UNCLOS 1982. TSS can also be used as a management tool to overcome and prevent the impact of shipping activities on the marine environment, known as Particularly Sensitive Sea Areas (PSSA) (Mamahit, 2020).

Previous research has revealed several findings regarding hub ports and the Traffic Separation Scheme (TSS) in K. Chen et al. (2020) developed a model to determine hub port locations and feeder network design in China-West Africa trade (Chen et al., 2020). Wu et al. (2020) used a fuzzy logic approach to select navigation strategies in TSS (Wu et al., 2020), while Yu et al. (2023) proposed a dynamic adaptive decision-making method for autonomous navigation in TSS waters (Yu et al., 2023). The high level of ship traffic density around the Makassar Strait and Balikpapan Bay (Fauzah et al., 2021; Judhariksawan et al., 2022). Moreover, when IKN starts to operate fully, it will pose a risk of accidents and oil spills, which could endanger shipping safety and security. It is necessary to separate ship traffic lanes using the TSS Model scheme to overcome this. Therefore, research on TSS in the Makassar Strait is significant in supporting the IKN Port Hub and ensuring shipping safety. The location of this research was carried out in the Makassar Strait area and at Balikpapan Harbor. The Makassar Strait is part of the Archipelagic Sea Channel and directly faces Balikpapan Bay. The research location map is shown in Fig. 1.

This research uses a case study approach in qualitative research methods. Qualitative research is a type of research that aims to provide a more in-depth description and analysis of the meaning process. Case studies are used as a qualitative research design that allows researchers to explore specific programs, events, activities, processes, or individuals (Priya, 2021). Through case studies, researchers can produce a comprehensive and in-depth understanding (Baxter & Jack, 2015). This study focuses on one of the mandatory elements of the Traffic Separation Scheme (TSS) in accordance with International Maritime Organization (IMO) standards, namely the determination of the initial traffic route. The research methodology involves an analysis of vessel traffic conditions in the Makassar Strait, including traffic density, potential risks of ship collisions, navigational obstacles, and hydro-oceanographic conditions. This area serves as a primary corridor for Hub Port operations supporting maritime activities.

The novelty of this study lies in the development of a TSS scheme specifically designed to support the growth of the Hub Port in IKN, Indonesia. This research serves as a preliminary study before conducting a more comprehensive analysis of TSS planning in the Makassar Strait. Consequently, the data utilized remain limited and are derived from secondary sources available in previous studies and relevant authorities in Indonesia. The primary contribution of this study is the provision of an essential preliminary guideline for the future development of maritime infrastructure in IKN and the Makassar Strait, while also supporting economic growth in the region. The objective of this research is to facilitate the development of the Hub Port by offering initial recommendations to enhance the preparedness of the IKN Hub Port in designing and eventually implementing TSS. This preliminary TSS study is formulated based on applicable legal regulations and considers the initial traffic routes determined through Obstacle Studies, the Ship Accident Potential Study, and an analysis of hydro-oceanographic conditions.

2. Literature review

Several studies show that the importance of TSS is highly correlated with the condition of Indonesia. As the first archipelagic state in the world with separations in its narrow waters, Indonesia should have no doubts about the benefits of TSS. TSS serve as a "win-win solution" for both users and coastal nations. Therefore, Indonesia should focus on optimizing its existing obligations by providing maximum service to user countries as well as to its own interests (Anwar, 2021; Fadli et al., 2021; Mamahit et al., 2020). TSS are essential maritime navigation frameworks that enhance safety in congested waterways by systematically organizing vessel traffic, particularly in regions characterized by high traffic density or navigational constraints. By distinctly delineating lanes for vessels traveling in opposing directions, TSS significantly reduce the probability of collisions between vessels navigating in opposite directions or intersecting paths, thereby augmenting navigational safety (Park, 2007).

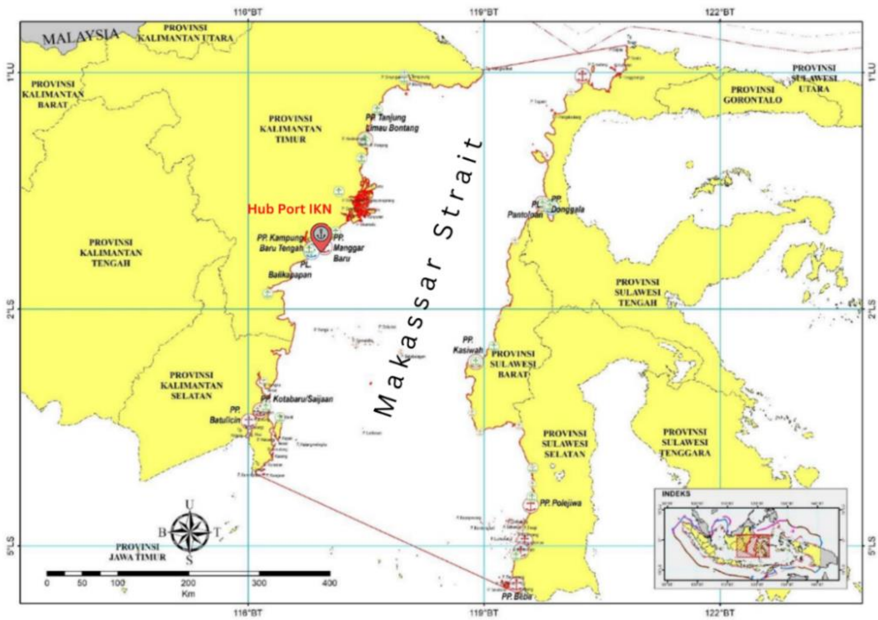


Fig. 1. Research location: Makassar Strait (Analysis, 2024)

Additionally, the design of TSS incorporates considerations for environmental sustainability, aiming to safeguard marine ecosystems by redirecting traffic away from ecologically sensitive areas; for example, the TSS in the Lombok Strait was developed with a dual focus on environmental conservation and navigational safety (Anwar, 2021). Furthermore, TSS must conform to international standards established by organizations such as the International Maritime Organization (IMO), which entails adherence to prescribed design criteria and planning considerations to ensure both effectiveness and safety in maritime navigation (Guzman et al., 2020).

TSS are designed to alleviate congestion, facilitate traffic flow, and minimize collisions by segregating opposing traffic streams in busy maritime areas. This is achieved by creating designated lanes in the water, which enhances navigational safety. Governed by the International Regulations for Preventing Collisions at Sea 1972 (COLREGS), particularly Rule 10, TSS regulations stipulate that vessels must navigate within the designated lanes in the general direction of traffic, avoid crossing separation lines whenever possible, and cross traffic lanes at right angles only when necessary. Additionally, inshore traffic zones should be used sparingly, primarily by smaller vessels or those engaged in fishing activities (Pietrzykowski et al., 2015). The planning process for TSS encompasses several critical stages, typically informed by international maritime regulations and safety standards. Initially, the need for a TSS is identified, particularly in narrow waterways and turning points where collision risks are heightened due to heavy traffic and navigational difficulties. Subsequently, comprehensive data collection is conducted, which includes bathymetric surveys to assess the seafloor's depth and configuration, as well as an analysis of traffic density to discern vessel movement patterns. Additionally, navigational traffic patterns are examined to pinpoint potential conflict areas, while water and wind currents are evaluated for their impact on navigation (Priadi et al., 2024; Szłapczyński, 2012). Finally, visibility conditions and the maneuverability of vessels are assessed to ensure safe navigation within the proposed TSS.

Based on the Decree of the Minister of Transportation Number KP 432 of 2017 concerning the National Port Master Plan as most recently amended by the Decree of the Minister of Transportation Number KP 172 of 2021, the hierarchy of the Port of Balikpapan is designated as a Main Port. The development of TPKL at the port of Balikpapan is by government policy stated in the Joint Decree of the Minister of Transportation and the Minister of Finance Number 885JKpb1Vll/1985, Number KM.139IMK/Phb-85 and Number 667JKMK.0511985 dated July 26 1985, which states the Port of Balikpapan as one of the seaports open to foreign trade. In order to support the development of the National Capital in the future, the Semayang port has the potential to be developed further and to serve cargo ships and passenger ships efficiently. A separation is carried out between passenger and goods services, especially container goods (Malisan et al., 2021). Based on data from Bakamla, ship movements during 2022 in the waters of the Makassar Strait reached 12,114 ships, with the dominance of the three most significant: 40.99% were cargo ships, 21.93% tanker ships and 16.27%. Meanwhile, data from the Ministry of Transportation states that in 2022, will be 1,616 ships operating in Balikpapan Bay close to the planned IKN Hub Port. It is estimated that by 2035, the annual movement of ships will reach more than 3,000 ships; this is a serious concern, so it is necessary to regulate ship traffic using TSS.

In Indonesia, TSS is regulated in the Regulation of the Minister of Transportation of the Republic of Indonesia Number PM 40 of 2021 concerning Amendments to the Regulation of the Minister of Transportation Number PM 129 of 2016 concerning Shipping Routes at Sea and Buildings and Installations in Waterways. TSS is a travel scheme that aims to separate ship traffic moving in opposite directions using designated traffic lanes. This scheme is used in busy and narrow shipping lanes, and its determination is based on factors such as the Width of the shipping lane, ship dimensions, traffic density and possible dangers. Ships within the TSS must follow the designated traffic lanes and stay as far away from the separation zone boundaries as possible. Traffic regulations on the TSS are explained in Minister of Transportation Regulation No. PM 40 of 2021. Ships within the TSS must follow the designated traffic lanes and stay as far away from the separation zone boundaries as possible. Ships should avoid cutting across traffic lanes, but if forced to, should cut at the smallest angle from the general traffic direction. The traffic zone adjacent to the coast may only be used by general traffic for vessels less than twenty meters long and sailing vessels. Vessels with limited manoeuvrability carrying out special tasks, such as laying, repairing or lifting pipelines and submarine cables, are free of the TSS rules.

An obstacle in maritime shipping refers to any physical or navigational impediment that disrupts the safe and efficient transit of vessels along a specified route (Li et al., 2024). These obstacles can be categorized into static obstacles, such as fixed structures like piers, buoys, rocks, or underwater hazards, and dynamic obstacles, which include moving vessels or floating debris that may present risks during navigation. Additionally, environmental conditions, including shallow waters, ice, or severe weather, can further restrict navigation (Li et al., 2024). Recognizing these obstacles is essential for maritime safety, as they can lead to accidents such as collisions or groundings if not adequately addressed. Consequently, shipping companies must meticulously plan their routes to circumvent these hazards, often employing traffic separation schemes and navigational aids provided by organizations like the International Maritime Organization (IMO) to improve safety in congested areas (Gan et al., 2022; K. Liu et al., 2021).

The obstacle data search method uses a literature review by looking at related research journals, regulations, and map products issued by related institutions involving identifying keywords, searching for related research journals through scientific journal databases, searching for related regulations through websites of related government institutions, searching for products maps through related institutions, analysis and evaluation of information found, as well as preparation of reports or literature reviews regarding obstacle data. Obstacle mapping aims to determine obstacles' number, type and location along the Makassar Strait. In determining the TSS route, it is vital to carry out an inventory of the obstacles or obstacles around the Makassar Strait, so that the TSS route that has been determined can later be used as a safe channel for passing ships.

A shipping lane is a designated area with sufficient depth and width that is considered safe for ships to navigate through without encountering any hazards. In the context of marine traffic planning or Traffic Separation Scheme (TSS) studies in the waters of the Makassar Strait, several factors are taken into consideration. These include the water conditions such as channel depth, currents, wind, and waves, as well as ship traffic patterns and density. Data on passing ships, potential obstacles, shipping hazards like collisions, and the Indonesian archipelagic sea lanes (ALKI) are also important aspects that are analyzed in the planning and management of shipping lanes in the region.

3. Ship Collison

A ship collision is defined as any incident involving two or more vessels that results in loss or damage, regardless of actual contact (Kuznecovs et al., 2023; Z. Liu et al., 2023). To mitigate the risk of such collisions, Traffic Separation Schemes (TSS) are implemented, which designate specific sea routes to separate opposing streams of maritime traffic. By guiding vessels along designated paths and reducing interactions, TSS enhance navigational safety and play a crucial role in preventing accidents, thereby protecting both vessels and the marine environment (Wuryaningrum et al., 2020; Zhao et al., 2020). Analysis of the Frequency of collisions between ships and ships on platforms with powered vessel collision and drifting collision types was carried out to ensure that several alternative channel designs would remain safe in the future. To calculate the Frequency of ship accidents per year, it can be calculated (Kristiansen, 2005) as with the following equation:

$$Pa = \frac{Na}{Nm} \tag{1}$$

where :

Na – Number of accidents that occurred in a certain period,

Nm – Number of ships sailing in a certain period.

Under ideal conditions, the analysis of vessel collision risks should utilize primary data in the form of statistical records from the Automatic Identification System (AIS) or relevant radar observations, enabling analysis through the Formal Safety Assessment (FSA) framework (Deng et al., 2025; Kim et al., 2025). However, limitations in obtaining data from relevant authorities in Indonesia, including the Ministry of Transportation, as well as technological constraints related to AIS and radar in the region, necessitate an alternative approach. As an alternative, this study utilizes vessel traffic data from the Makassar Strait, obtained from the Indonesian Maritime Security Agency (BAKAMLA RI) for the year

2023, while incorporating the Vessel Finder application as a supplementary analytical method. The collected data include the number and types of vessels traversing the Makassar Strait, aimed at identifying patterns and trends in maritime traffic growth. To acquire more granular insights into vessel movements on a daily or hourly scale, analysis is conducted using the real-time Vessel Finder application. Overall, maritime traffic in this region is classified into two primary routes: the Kalimantan corridor and the Sulawesi corridor. This study does not incorporate meteorological and oceanographic factors as analytical variables, nor does it compare statistical accident data within the study area due to limitations in data accessibility and availability, which constrain a comprehensive analytical approach.

Data collection at the vessel finder facility is carried out by drawing a measuring distance line along the TSS route placement plan segment, divided into several sections. This is the limit for measuring the number of ships in each section. The number of ships passing through the channel is recorded during working hours with a duration of 1 hour and grouped based on ship type. This data will be used to analyze strading, grounding, head-on collision, crossing collision, and overtaking cases. The input used in this paper is the position/ordinate point and speed of ships passing around the Makassar Strait. The intended position of the ship is the initial position and destination position of the ship and the possibility that the ship will meet or collide with other ships in the shipping lane. Apart from the ship's position, other variables that influence it are the speed of the ship and the number of ships crossing the Makassar Strait (Fig. 2).

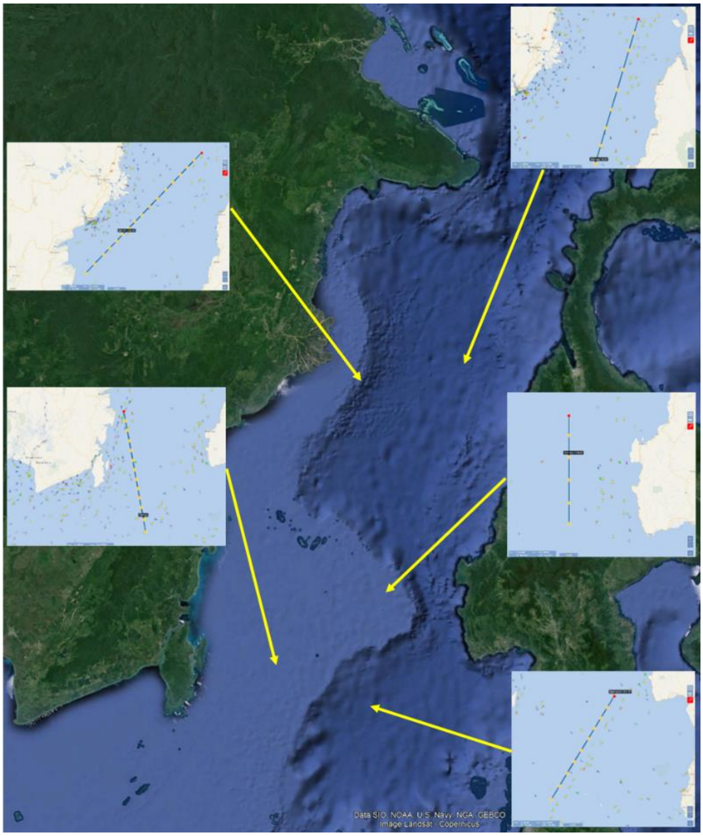


Fig. 2. Detailed traffic data collection

Potential ship collisions occur in five conditions: grounding, stranding, head-on collision, overtaking situations, and cross-collisions.

1. Grounding (Aground)

A ship sailing in a limited area has the potential to run aground and collide. Beach zones, corals, rocks and other sunken objects pose a danger to ships passing through the area. The model used to calculate the chance of failure can be seen in Fig. 3. The probability of a ship running aground can be calculated using an approximation formula, as in the formula:

$$Pi = \frac{B + d}{W} \tag{2}$$

where:
W – average shipping lane width (m),
d – width of an object in the sea (m),
B – width of the ship (m).

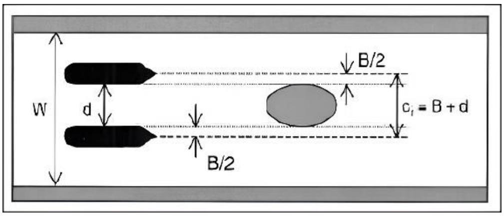


Fig. 3. Grounding accident model (Kristiansen, 2005)

2. Stranding (Drifting)

Stranding or drifting occurs when an object experiences mechanical failure and is carried away by the current, making it possible for accidents to occur due to drifting. Modelling of ship accidents due to stranding is shown in Fig. 4, where the ship sails in a shipping lane with width W and the relative shipping distance is D.

The probability of stranding occurring with the critical angle ratio (α) of the total angles drawn in one direction;

$$Pi = \frac{\alpha}{\pi/2} = \frac{arc.\tan\left(\frac{D}{2}\right) / \left(\frac{W}{2}\right)}{\pi/2} \tag{3}$$

This equation can be simplified with the approximation;

$$Pi \approx 1 - \frac{2}{\pi} . \frac{W}{D} \tag{4}$$

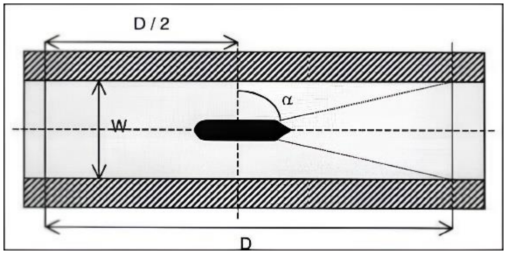


Fig. 4. Stranding accident model (Kristiansen, 2005)

3. Collision

A collision is a collision that occurs between two moving objects. The calculation of the probability of a collision occurring can be modelled into three types, namely a collision between the bow of the ship (Head on Collision), a collision between the bow and the hull of the ship (Crossing Collision), and a collision between the bow and stern of the ship (Overtaking Collision).

4. Head On Collision

In Fig. 5, a head-on collision ship accident model is shown, which shows that the ship entered a shipping lane with a width of W. The ship was travelling head-to-head with other ships in the opposite direction. This has the potential for accidents between the bows of the ship.

The number of ships encountered in a square nautical mile area is measured based on shipping lane traffic density. The formula used to calculate shipping lane density is:

$$\rho s = \frac{\mathrm{Nm1 + T}}{\mathrm{(V1.T).W}} = \frac{\mathrm{Nm1}}{\mathrm{V1.W}} \tag{5}$$

where:
ρs – traffic density encountered by ships (ships/nm2).

The approximate formula used to estimate ship accidents crossing a limited area is:

$$\mathrm{Ni} = 4.\mathrm{B.D.}\rho s \tag{6}$$

or

$$Ni = \frac{(B1 + B2)}{\mathrm{W}} . \frac{\mathrm{(v1 + v2)}}{\mathrm{v1.v2}} . \mathrm{D.Nm1} \tag{7}$$

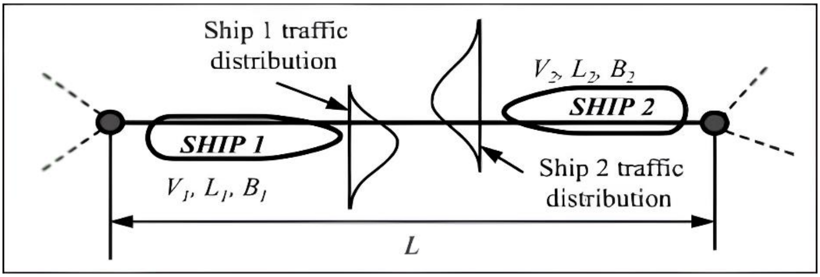


Fig. 5. Head on collision accident model. B1 – average ship width (m); V1 – average ship speed (Knots); B2 – width of the ship encountered (m); V1 – average speed of ships encountered (Knots); Nm – frequency of arrival of ships encountered (ships/unit time); D – relative sailing distance (m) (Dinariyana et al., 2020)

5. Crossing Collision

In Fig. 6, a model of a crossing collision ship accident is shown, which shows that the ships are crossing each other and meeting in a shipping lane with a lane width of W and a length of D. The ship is travelling transversely to other ships, in a direction that forms an angle to the lane. This has the potential for accidents between ships and the ship's bow, hull or stern.

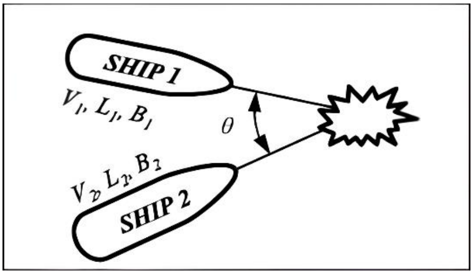


Fig. 6. Crossing collision accident model (Dinariyana et al., 2020)

Density from crossing traffic can be calculated using the formula;

$$\rho s = \frac{\mathrm{Nm1 + T}}{\mathrm{(v1.T).W}} = \frac{Nm1}{v1.W} \quad (8)$$

If the ships that collide with each other are assumed to have the same characteristics, the value of Pi can be calculated using the formula;

$$Pi = \frac{Nm1}{\mathrm{v}}.2.(\mathrm{B + L}) = \rho s.2.(\mathrm{B + L}).\mathrm{D} \quad (9)$$

Where;
B1 – Width of vessel 1 making the crossing (m)
L1 – Length of the ship making the crossing (m)
V1 – speed of the ship making the crossing (knots)
B2 – Width of the ship that is the subject of the crossing (m)
L2 – Length of the ship that is the subject of the crossing (m)
V2 – speed of the crossing subject ship (knots)

6. Overtaking Collision

In the ship accident model in Fig. 7, an overtaking collision occurs when ships sail in a shipping lane with a width of W. The ship is travelling in the same direction as the other ship, at a different speed and an angle from the other ship, making it possible for overtaking to occur. This has the potential for accidents between the bow of the ship and the stern of another ship and vice versa.

The potential value of accidents that occur can be approximated (Sumarsono et al., 2018)by using the formula;

$$Ni = \frac{(B1 + B2)}{\mathrm{W}} . \frac{\mathrm{(v1 + v2)}}{\mathrm{v1.v2}} . \mathrm{D.Nm1} \quad (10)$$

$$Ni = \frac{(B1 + B2)}{\mathrm{W}} \mathrm{D.Nm1}\ \Sigma\ \mathrm{fx.fy} \left(\frac{1}{\mathrm{vx - vy}} \right) \quad (11)$$

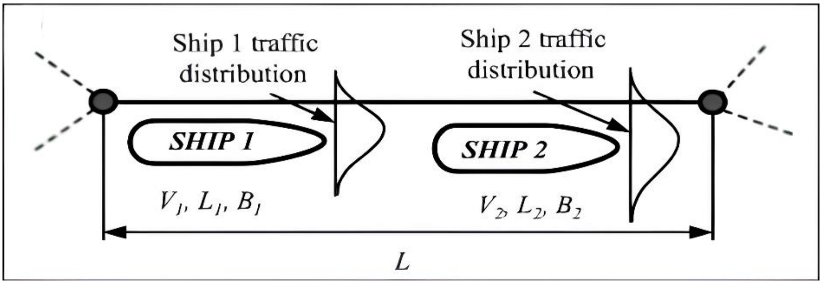


Fig. 7. Overtaking collision accident model (Dinariyana et al., 2020)

4. Results and discussion

4.1. Obstacle studies

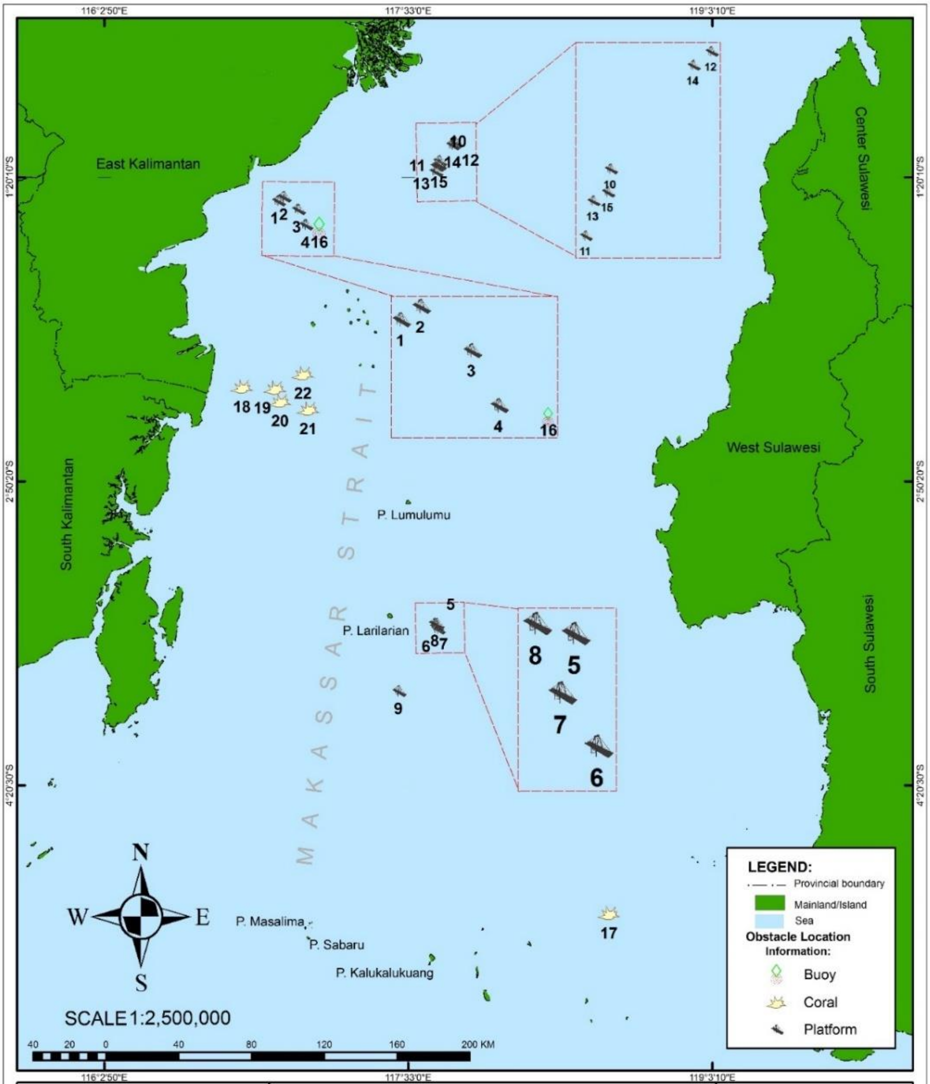
Based on its location, the distribution of obstacles in the Makassar Strait is divided into 2: the Kalimantan side and the Sulawesi side. For locations on the Kalimantan side, activities in the surrounding area are dominated by mining, port loading, and unloading, based on observations from www.navionics.com. On the eastern side of Kalimantan, many underwater platforms and pipes exist. Apart from that, due to natural factors, there are also many corals, small islands, and islands between Kalimantan and Sulawesi, namely the Balabalakang Islands. In contrast to the eastern side of Kalimantan, the western side of Sulawesi has fewer platforms, one of which is Exxon Mobile's platform. Apart from natural factors, there is the Indonesian cross current (Throughflow) which is a water current that occurs between the Pacific Ocean and the Indian Ocean. The Labani Channel has a relatively high current speed in the western part of Sulawesi. The region between Kalimantan and Sulawesi has a historical record of tsunami events triggered by activities in the Palu-Koro fault zone and the Paternoster fault zone. In this study, weather factors are not included as variables in the Obstacle Studies. Data on various navigational obstacles are compiled into a visual representation used to determine the Traffic Separation Scheme (TSS) route, as illustrated in Fig. 8. Meanwhile, the results of obstacle data collection are presented in Table 1.

4.2. Collision analysis

The results of calculating the number of vessels used are the result of data collection via a vessel finder, carried out previously using the method described. The Length of each segment is determined based on determining the Length of the segment when collecting data. Based on the data collection, the total number of segments on the Sulawesi side and Kalimantan side reached 50 segments, so under these conditions in the calculations 5 segments are displayed, representing each channel with the most extreme conditions, the summarized findings are depicted in Fig. 9, which illustrates the Ship Accident Potential Study Segment. Determining the channel width with a value of 3000 m is based on repeated tests for five conditions: grounding, stranding, head-on collision, overtaking situation, and crossing collision. The ship type is determined based on the type of ship recorded during the data collection process.

Table 1. Collection of Makassar Strait obstacles

No	Obstacle Type	Data source
1	Throughflow	(Anandathassa, 2019; Gordon et al., 2019; Gorgon et al., 1999)
2	Subsea Pipeline	(Koto & Putrawidjaja, 2018)
3	Earthquake/Tsunami	(G. S. Prasetya et al., 2001; Guntoro, 1999; Mann et al., 2016)
4	Platform Locations Around the Strait	(Gorsel & Helsing, 2014)
5	Island and Reef Locations	(Kuhnt et al., 2011)



Information Table of ID, Name and Coordinates of Obstacle Locations:

Coordinat System : Geographic
Datum : WGS84
Grid System : Geographic WGS84

Sources :
- Basemap RBI (2021)
- Obstacle location information via (www.navionics.com)

ID	Name	Longitude	Latitude	ID	Name	Longitude	Latitude	ID	Name	Longitude	Latitude
1	Offshore Platform 1	116.906	-1.449	4	Offshore Platform 4	117.041	-1.568	7	Petroleum C	117.687	-3.553
2	Offshore Platform 2	116.933	-1.431	5	Petroleum A	117.690	-3.540	8	Petroleum D	117.681	-3.538
3	Offshore Platform 3	117.004	-1.492	6	Petroleum B	117.695	-3.565	9	Platform	117.501	-3.873

ID	Name	Longitude	Latitude	ID	Name	Longitude	Latitude	ID	Name	Longitude	Latitude
10	Platform	117.703	-1.253	15	Fleet 4	117.701	-1.271	20	Gender Coral	116.915	-2.439
11	Platform	117.684	-1.305	16	Buoy	117.110	-1.583	21	Unarang Coral	117.055	-2.478
12	Platform	117.782	-1.162	17	Taka Bakang Coral	118.542	-4.971	22	Coral	117.028	-2.303
13	Fleet 1	117.690	-1.278	18	Suling Coral	116.727	-2.370				
14	Fleet 3	117.768	-1.173	19	Tifa Coral	116.890	-2.374				

Locations Distribution Map Of Obstacles inThe Makassar Strait

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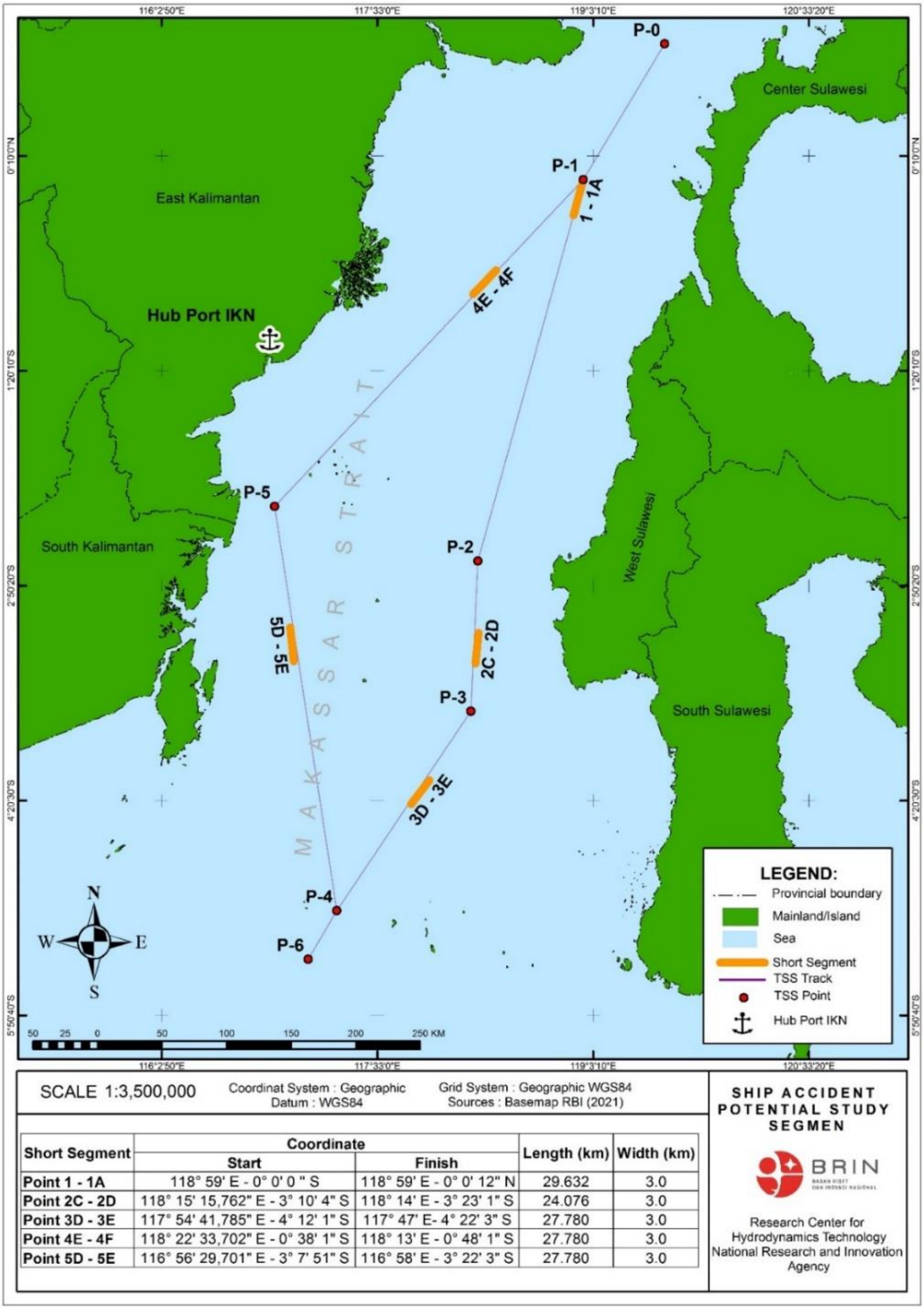
Fig. 8. Locations distribution map of obstacles in the Makassar Strait



Short Segment	Coordinate		Length (km)	Width (km)
	Start	Finish		
Point 1 - 1A	118° 59' E - 0° 0' 0 " S	118° 59' E - 0° 0' 12" N	29.632	3.0
Point 2C - 2D	118° 15' 15,762" E - 3° 10' 4" S	118° 14' E - 3° 23' 1" S	24.076	3.0
Point 3D - 3E	117° 54' 41,785" E - 4° 12' 1" S	117° 47' E- 4° 22' 3" S	27.780	3.0
Point 4E - 4F	118° 22' 33,702" E - 0° 38' 1" S	118° 13' E - 0° 48' 1" S	27.780	3.0
Point 5D - 5E	116° 56' 29,701" E - 3° 7' 51" S	116° 58' E - 3° 22' 3" S	27.780	3.0

Fig. 9. Ship accident potential study segment

Table 2. Number and type of ships for each channel segment

No	Sections	Segment Length (D)	Segment Width (W)	Boat				
		m	m	Cargo	Fishing	Passenger	Sailing vessels	Tanker
	Sulawesi							
1	Segment 1. A	29632	3000	3	2	-	-	-
2	Segment 2.D	24076	3000	2		1		
3	Segment 3.E	27780	3000	3	1			
	Kalimantan							
4	Segment 4.F	27780	3000	1	3			
5	Segment 5.E	27780	3000	2		1	1	

The condition of the Makassar Strait, which is very wide and has heavy shipping traffic, causes the division of segments in data collection to be quite large, with up to 50 segments, which can be grouped into 5 major shipping lanes. So, taking into account the efficiency of presenting the analysis results, the number of segments presented are segments that represent large shipping lanes and have shipping traffic that is quite dense so there is a risk of collisions. These segments include segment 1.A, segment 2.D, segment 3.E, segment 4.F, and segment 5.E, which are presented in full along with their segment lengths in Table 2. Meanwhile, the type, dimensions (Length and Width), and speed of the ships used in the calculations for the five conditions can be seen in Table 3.

Table 3. Ship type, dimensions and speed

No	Ship Type	Length	Beam	Average Speed
		m	m	knots
1	Cargo	323	43	18.2
2	Fishing	24	8	9.7
5	Passenger	145	24	15.6
7	Sailing Vessels	220	70	6
9	Tanker	333	60	10.9

The probability of control failure on the ship, which can cause grounding, is calculated based on the value (loss of control frequency value) results of previous studies (Kristiansen, 2005). The study was conducted on a Norwegian ship by an American with the values listed in the Table 4. By considering the safety factor, the μc value taken is 0.000028 failures/nm. Meanwhile, the probability of control failure in head-on, overtaking and crossing conditions can also be calculated based on the μc value (Kristiansen, 2005) or the Pc value analyzed in the Balikpapan Port Master Plan. By considering local condition factors, the Pc value refers to Balikpapan Port Master Plan.

Table 4. μc and Pc values

No	Encounter Situations	μc failures/nm	Pc failures/passages
1	Grounding	0.000028	
2	Overtaking vessels		0.0003950
3	Crossing traffic		0.0003950
4	Head-on traffic		0.0000176

1. Grounding

The Makassar Strait region on the Kalimantan side has many platforms, both still operating and no longer operating. Table 5 presents the calculated Pc values under grounding conditions. This grounding analysis is intended to estimate the opportunity for a ship sailing around the channel to hit the platform. So, in the calculations for all segments, it is assumed that the chance of a collision between the ship and the platform can occur on all types of ships. In the calculations, it is assumed that the platform width is 100 m. As a result, the grounding calculation for each segment is presented in Table 6.

2. Trading

Trading analysis is intended to estimate the chances of a ship drifting and then hitting another ship. The calculations assume that the data on ships that drift is 1 ship/year. The results of this analysis are presented in Table 7.

3. Head On

Analysis of ship collisions in head-on conditions is intended to estimate the probability of a ship-to-ship collision occurring in a shipping lane. The calculation results can be seen in the following table 8.

4. Overtaking

Overtaking analysis is needed to estimate the chance of a ship collision in an overtaking ship condition. In the 5 segments that have been determined, there are 2 or more types of ships in one segment, so that overtaking analysis can be carried out. Overtaking analysis can be seen in the following table 9.

5. Crossing Collision

Crossing analysis is intended to estimate the possibility of ship collisions due to crossings. In this analysis, the segment length is assumed to be the same as the width, so the length is calculated as 3000 m. Crossing analysis can be seen in the table 10.

Table 5. Calculation of Pc values in grounding conditions

No	Sections	Segment Length (D) m	Pc Grounding failures/passages
1	Segment 1.A	29632	0.000448
2	Segment 2.D	24076	0.000364
3	Segment 3.E	27780	0.000420
4	Segment 4.F	27780	0.000420
5	Segment 5.E	27780	0.000420

Table 6. Grounding calculation for each segment

No	Flow Segment	Cargo	Fishing	Passenger	Sailing Vessels	Tanker
1	Segment 1.A	0.0000214	0.0000161	-	-	-
2	Segment 2.D	0.0000174	-	0.0000150	-	-
3	Segment 3.E	0.0000200	0.0000151	-	-	-
4	Segment 4.F	0.0000200	0.0000151	-	-	-
5	Segment 5.E	0.0000200	-	0.0000174	0.0000238	-

Table 7. Stranding calculation for each segment

No	Flow Segment	Cargo	Fishing	Passenger	Sailing Vessels	Tanker
1	Segment 1.A	0.0000203	0.0000305	-	-	-
2	Segment 2.D	0.0000310	-	0.0000620	-	-
3	Segment 3.E	0.0000204	0.0000613	-	-	-
4	Segment 4.F	0.0000613	0.0000204	-	-	-
5	Segment 5.E	0.0000306	-	0.0000613	0.0000613	-

Table 8. Head on calculation for each segment

No	Flow Segment	Cargo	Fishing	Passenger	Sailing Vessels	Tanker
1	Segment 1.A	0.0699383	0.0108506	-	-	-
2	Segment 2.D	0.0252555	-	0.0041114	-	-
3	Segment 3.E	0.0655672	0.0025431	-	-	-
4	Segment 4.F	0.0072852	0.0228880	-	-	-
5	Segment 5.E	0.0291410	-	0.0047439	0.0359744	-

Table 9. Overtaking calculation for each segment

No	Flow Segment	Ship Type	Na accidents/year
1	Segment 1.A	Cargo - Fishing	0.16505
2	Segment 2.D	Cargo - Passenger	0.01050
3	Segment 3.E	Cargo - Fishing	0.12089
4	Segment 4.F	Cargo - Fishing	0.01343
5	Segment 5.E	Cargo - Passenger - Sailing Vessel	0.38586

Table 10. Crossing collision calculation for each segment

No	Flow Segment	Cargo	Fishing	Passenger	Sailing Vessels	Tanker
1	Segment 1.A	0.6763047	0.0493093	-	-	-
2	Segment 2.D	0.3005799	-	0.0404811	-	-
3	Segment 3.E	0.6763047	0.0123273	-	-	-
4	Segment 4.F	0.0751450	0.1109458	-	-	-
5	Segment 5.E	0.3005799	-	0.3005799	0.1806080	-

The value of the probability of grounding and trading, as well as collisions due to head-on, overtaking and crossing based on calculations in several tables above shows a value < 1 in all predetermined segments, so that a channel width of 3000 m is considered safe enough for these conditions.

4.3. Hydro oceanographic conditions

This study is limited to only secondary data, namely bathymetry data from the National Bathymetry, a product issued by the Geospatial Information Agency (BIG). Meanwhile, tidal data is obtained from interpolation from the Mike 21 module. Current wind and wave height data is obtained from the European Center for Medium-Range Weather Forecast (ECMWF) (Yesaya et al., 2023). The data sampling point is the Makassar Strait (point 1) with coordinates Lat: -3.16°, Long: 117.815° and on the Sentence side (point 2) with coordinates Lat: -2.172°, Long: 116.681° (Fig. 8). From the division of seasons, the most extreme conditions for the Makassar Strait region occur in the western season (Labania et al., 2021) Current, wind and wave height data were collected in the western season (January 2022) and as a complement, data was also collected in the east season (August 2022). Each of these data was taken for one month at intervals every hour. The pickup points are at North -1.75°, West 116°, South -4.25°, and East 119.25.

Wind data obtained from ECMWF is converted into .dfs0 format for MIKE 21 Spectral Waves (Chow et al., 2022). Then, input tidal data for hydrodynamic modelling and create boundaries according to the area to be reviewed for the Makassar Strait (point 1) and the Kalimantan side (point 2). Then, adjustments are made to the mesh model setup and bathymetry. After all the hydrodynamic model data is ready, run the model until appropriate results are obtained (Hernawan et al., 2020). The running results will be validated with numerical data from the Geospatial Information Agency.

Tidal data was validated by comparing tidal data from running Mike 21 with numerical tidal data from BIG. Both data are extracted with the same coordinate points for each point, then the error value is calculated. The calculations show that the error value of the tidal data from running using Mike 21 is less than 9%, or below the recommended root mean square error (RMSE) value is 10-15% (Williams & Esteves, 2017). The results of the numerical model calculations can be displayed in Table 11 and Fig. 10.

The calculation results found that at point 1, the wind speed value was 8.36 knots, and the average significant wave height was 0.44 m in January and 7.68 knots and 0.48 m in August. Meanwhile, at point 2, the wind speed value was 8.36 knots, and the average significant wave height was 0.35 m in January, 7.68 knots in August, and 0.44 m in August. By sailing safety advice from the Maritime Meteorology Center (Meteorological, Climatological, and Geophysical Agency) that the wind speed value is no more than 15 knots and the maximum wave height is 1.25 m, so it can be concluded that these two points are safe to use as shipping lanes.

4.4. TSS design

The proposed final design of the Traffic Separation Scheme (TSS) in this study focuses on one of the mandatory elements established by the International Maritime Organization (IMO) standards, namely the determination of the initial traffic route. This route is formulated based on findings from Obstacle Studies, the Ship Accident Potential Study, and an analysis of hydro-oceanographic conditions. The Makassar Strait TSS Flow Map is made on two sides, namely the Kalimantan side and the Sulawesi side. This is done because the waters in the Makassar Strait are vast, and there is a heavy traffic flow between ports on the islands of Kalimantan and Sulawesi. Apart from that, the large number of ports managed by Pelindo in the Makassar Strait, both on the Kalimantan and Sulawesi sides, is also a factor causing the density of shipping traffic. On the side of Kalimantan facing the Makassar Strait, there are around 9 Pelindo ports as well as dozens of public and private ports. Meanwhile, on the Sulawesi side, 4 Pelindo ports and many other small ports contribute to the density of shipping traffic in the Makassar Strait.

Based on the Makassar Strait TSS Flow Map that has been planned above, ships from the North and South of the Makassar Strait can enter the waters of Kalimantan and Sulawesi Islands using different channels, and each channel has 2 shipping lanes. Each shipping lane has a width of 3 km, which has been calculated to be safe for 2-lane shipping, especially for large ships. The Length of the TSS channel on the Kalimantan side is 664,586 km, while the Length of the TSS channel on the Sulawesi side is

608,002 km. The coordinate points of the TSS channel on the Kalimantan side start from 118° 59' E - 0° 0' 0" S to 117° 16' E - 5° 6' 42 S, where in the middle of the west (close to Kalimantan) there is a segment point located at coordinates 116° 50' E - 2° 17' 4 S. On the Sulawesi side of the TSS channel starting from coordinates 118° 59' E - 0° 0' 0 " S to 117° 16' E - 5° 6' 42 S, where there are 2 segment points, namely 118° 15' E - 2° 40' 1" S and 118° 12' E - 3° 43' 5" S. The TSS flow on the Sulawesi side follows the existing ALKI II and is still used in shipping lanes in the Indonesian archipelago. The results of the analysis and design are presented in Fig. 11, which illustrates the Traffic Separation Scheme (TSS) Plan Design in the Makassar Strait.

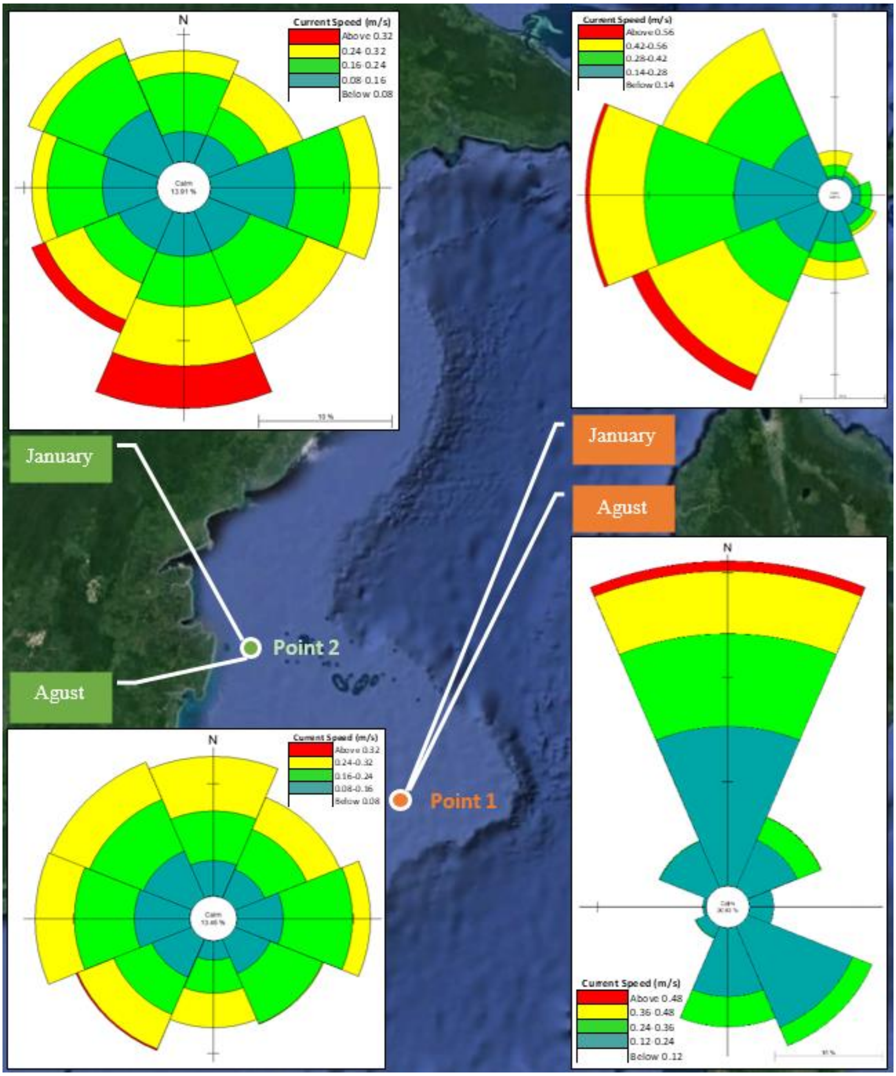


Fig. 10. The current rose at each point

Table 11. Numerical calculation results

Location	**Month**	**Current (m/s)**			**Significant Wave Height(m)**		**Wind velocity**
		Average	Maximum	Dominant Direction (from)	Average	Maximum	(knots)
Point 1	January	0.33	0.66	West	0.44	1.09	8.36
	August	0.3	0.67	North	0.48	0.87	7.68
Point 2	January	0.21	0.55	South	0.35	0.95	8.36
	August	0.2	0.69	West & North West	0.44	0.81	7.68

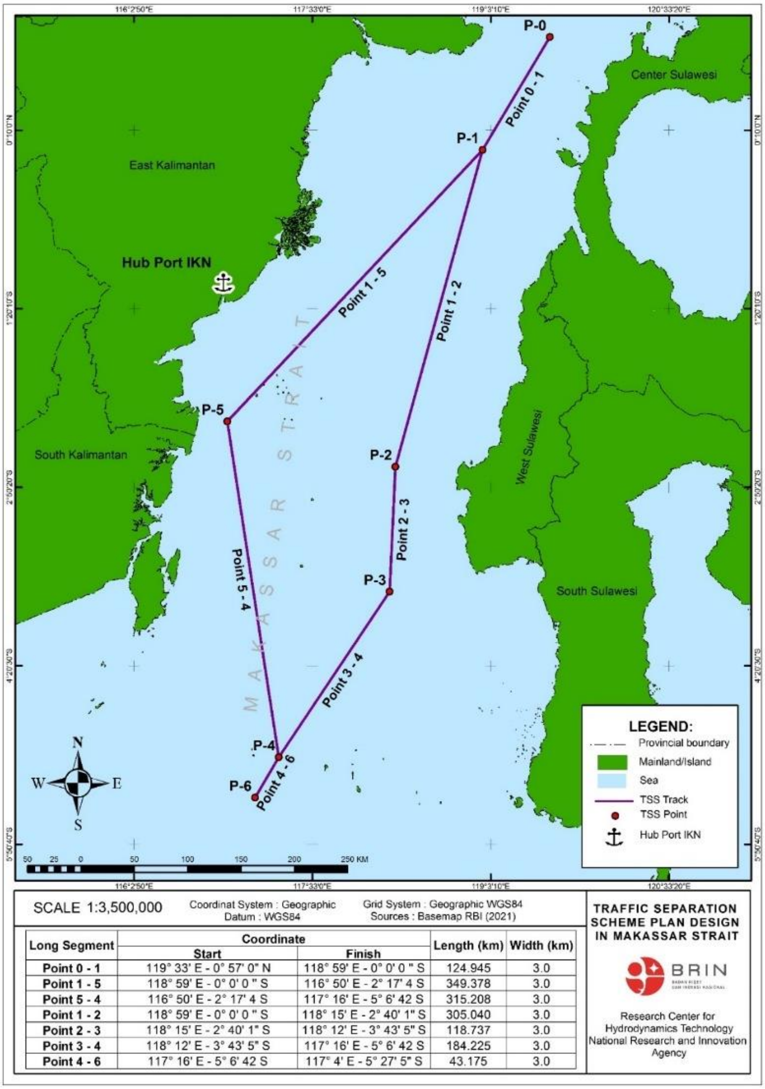


Fig. 11. Traffic Separation Scheme (TSS) plan design in Makassar Strait

5. Conclusion

This study successfully formulates a preliminary design for a Traffic Separation Scheme (TSS) to enhance navigational safety in the Makassar Strait, particularly in support of the development of the IKN Hub Port. Analysis of vessel traffic patterns, navigational obstacles, and hydro-oceanographic conditions indicates that a safe channel width of 3 km effectively minimizes the risk of maritime accidents, including collisions, groundings, and strandings. Hydro-oceanographic modeling results show wind speeds below 15 knots and maximum wave heights of up to 1.25 m, which empirically meet navigational safety standards.

The findings of this study have strategic implications for maritime traffic management and reinforce Indonesia's role in international maritime governance based on safety and sustainability. However, this study relies on secondary data and does not yet account for extreme weather conditions or field verification. Therefore, future research should integrate primary data from the Automatic Identification System (AIS) and radar for real-time traffic monitoring, as well as conduct high-resolution hydrodynamic simulations to optimize route design. Overall, the proposed preliminary TSS design meets navigational safety criteria, national regulations, and environmental considerations, demonstrating its potential to improve maritime traffic efficiency and support the development of the IKN Hub Port as a strategic node in the global shipping network.

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