2301-9069 (e)
1829-8370 (p)

Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan
(Kapal: Journal of Marine Science and Technology)

journal homepage: http://ejournal.undip.ac.id/index.php/kapal

Risk Analysis of Ship Collision and Modelling of Oil Spill Trajectory Study Case: Dumai Port

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Article Info

Keywords:
Ship Collision;
IWRAP;
Oil Spill;
WebGNOME;
Oil Cleanup;

Article history:
Received: 30/10/2024
Last revised: 30/12/2024
Accepted: 02/01/2025
Available online: 02/01/2025
Published: 10/01/2025

DOI:
https://doi.org/10.14710/kapal.v22i1.67794

Abstract

Dumai Port is a significant natural port in Sumatra, characterized by deep waters sheltered from waves and calm currents due to surrounding islands. It plays a crucial role in the export of Crude Palm Oil (CPO) and the operations of Pertamina's RU II, which are expected to increase, leading to a rise in ship traffic. In response to this growing vessel traffic, this paper analyzes ship collision frequency and models the dispersion of oil spills as a potential consequence. The ship collision analysis utilizes the Integrated Waterway Risk Assessment Program (IWRAP), combining vessel traffic data over a year with the port's bathymetric data. The analysis revealed a total collision frequency of 0.589766 across various scenarios, including head-on, overtaking, crossing, bending, and merging, which is considered acceptable as it falls below the threshold of one collision per year. Additionally, oil spill trajectory modelling was conducted using two types of oil and two wave heights. In the 2000 m³ oil spill modelling at a height of 0.5 m, the crude oil model showed 68.4% still floating, while the product oil model had 41.7% floating. In the 1.5 m modelling, the crude oil model had 29% floating, and the product oil model had 16.2% floating. Based on these results, the chosen cleanup methods include oil booms, skimming, and dispersants. Effective oil spill cleanup requires collaboration among various stakeholders to ensure the process is carried out efficiently and accurately.

1. Introduction

Dumai Port is one of the main ports in Riau Province, Indonesia. It is at the coordinates 01°-41'-14" LU / 101°-27'-42,1" BT, with a waterway length of 55 miles, a current speed of 2.5 to 3 knots, and a tidal range of 3.4 mLWS (Mean Lowest Water Spring) [1]. Dumai Port have an advantageous geographical location because it is a natural port protected by several islands, including Rupat Island, Payung Island, and Rampang Island. This provides deep and calm waters as a barrier against wave impact and a conducive climate throughout the year. Dumai Port has shipping routes that include Sekupang (Batam) to Dumai, Bengkalis to Dumai, and Dumai to Melaka (Malaysia). In Dumai, there exist two significant potential shipping from Crude Palm Oil (CPO) and the Refinery Unit II of Pertamina. The export volume of Crude Palm Oil (CPO) in 2023 reached 937.223 tons [2], while in 2019, the capacity of the Dumai Refinery Unit (RU) was 170 thousand barrels of oil per day (MBOPD), contributing 16% of Pertamina's total refinery capacity [3]. Considering these factors, the shipping traffic at Dumai Port is poised for significant growth, which is likely to lead to an increased volume of vessels transiting through the Dumai Port waterway. Figure 1 presents data on the types of vessels based on their cargo at Dumai Port, crude oil accounts for more than a quarter, and product oil and passenger each represent 20%.

The potential increase in vessel traffic at Dumai Port may result in risk of maritime accidents; therefore, a comprehensive risk assessment is essential to evaluate the likelihood of such incidents occurring in the area. Risk assessment is the all process of identifying risks, analyzing risks, and evaluating risks [4]. In the maritime industry, risk assessment can be implemented in various ways, including in paper Mulyatno et al. [5] used risk analysis for the development of preventive and corrective maintenance strategies in fuel oil systems. Handani and Uchida [6] Developing maintenance scheduling for ship machinery, and in paper Tam and Bucknall [7] Risk assessment is also applied for ship collisions. In 1971, Fujii and Shiobara [8] introducing a theoretical analysis of collision rates and frequency, and in 1974 McDuff [9] apply collision theory to estimate vessel collisions with assumptions about vessel movements along a specific route. Both of these research studies are considered pioneering in research related to the analysis of ship collisions which estimate the probability of ship collisions. This opened the door to numerous studies highlighting the importance of risk analysis, particularly focusing on ship collisions. These studies include Friis-Hansen et al. [10] performed risk assessment to reduce ship collisions, Pedersen

[11] reviewing and application of ship collision analysis, Weng et al. [12] analysis of vessel collision frequency using manual calculation, and Wulandari et al. [13] used finite element method for collision analysis. Furthermore, approaches using computer-based tools are applied in the analysis of ship collisions. Friis-Hansen [14] Introducing IWRAP (International Association of Marine Aids to Navigation and Lighthouse Authorities Waterway Risk Assessment Program) for conducting maritime risk assessments, specifically used for estimating the frequency of ship collisions in the specified navigational area. IWRAP using the paper of Fujii et al. [15] about the influence of various factors on the probability of ship collisions. as the conceptual procedure for calculating the frequency of ship collisions. IWRAP is used in various studies, including Khaled and Kawamura [16] risk analysis of ship collision in Chittagong Port using 4 collision scenarios, Cucinotta et al. [17] estimation of collision frequency in the Strait of Messina through regulatory and environmental constraints using 3 collision scenarios, and Handani et al. [18] Estimating ship collision frequency in the strait of Malacca and Singapore using 3 collision scenarios. All of these studies use AIS (Automatic Identification System) data to calculate the frequency of ship collisions. The difference in this research will involve the use of five types of collisions, whereas other studies only utilize a maximum of four types of collisions.

In this research, risk analysis is conducted to determine the frequency of ship collisions in Dumai Port to predict the total number of collisions occurring at Dumai Port, considering the anticipated increase in the number of vessels passing through the route in future. This paper uses vessel traffic data from AIS (Automatic Identification System) over a one-year period. AIS data will undergo clustering of vessels and will be combined with bathymetric data to determine the frequency of ship collisions using IWRAP. Potential collision scenarios will be analyzed, including head-on, overtaking, crossing, collision in bends, and collision in merging situations. Furthermore, oil spills will be considered as a potential consequence in the event of a collision. WebGNOME (Website-based General National Oceanic and Atmospheric Administration Operational Modeling Environment) will serve as a tool to estimate oil spill trajectories in the specified area, using two types of oil and two wave height situations. Oil spill modelling is used to predict the weathering processes of oil, which is intended to inform response strategies in the event of an oil spill, ensuring that oil spill response and cleanup can be carried out accurately and efficiently.

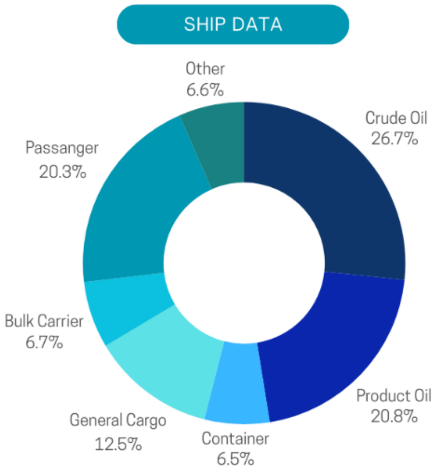


Figure 1. Ship Data in Dumai Port

2. Methods

2.1. Data Collection

The data used in this research consists of two types of data:

a. Ship Traffic Data

The ship traffic data is derived from AIS data obtained from the VTS (Vessel Traffic Service) Sub Center of Dumai Port, which includes information such as the ship's name, MMSI (Maritime Mobile Service Identity), arrival route, length, and width. This data will undergo a clustering process based on the type and length of the vessels and will subsequently be used as input for the IWRAP software.

b. Oceanographic Data

Oceanographic data is utilized to simulate the movement of oil spills as a potential consequence of a ship collision. The oceanographic data employed includes wind speed, wave height, wind direction, and water temperature, which are obtained from the Meteorology and Geophysics Agency [19], all of this data will serve as input for the oil spill modelling [20]. Figure 2 shows the flowchart of this research.

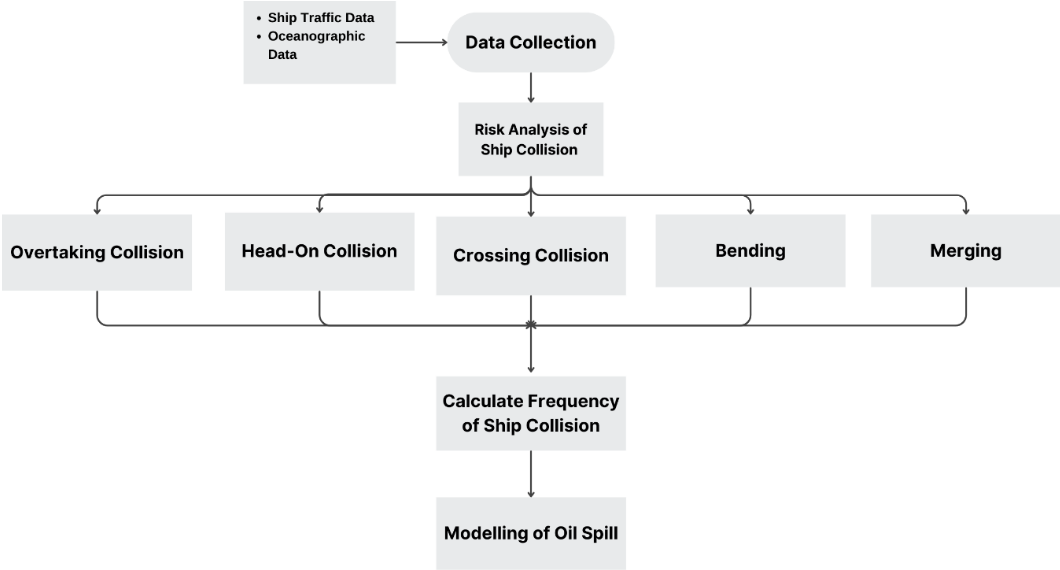


Figure 2. Risk Analysis of Ship Collision and Oil Spill Modelling Flowchart

2.2. Determine the Ship Collision Scenario

a. Frequency of Ship Collision

According [21], the concept of calculating ship collision frequency refers to a method used to estimate the collisions between vessels in a specific waterway. This method is often employed in risk analysis and maritime safety management. In this analysis, the frequency of collisions (λ_{col}) is determined by calculating the geometric number of ship collisions (N_G), which is then multiplied by a causation factor (P_C). This methodology provides a deeper insight into the various elements contributing to maritime collision incidents.

$$\lambda_{col} = P_C . N_G \tag{1}$$

b. Head-On and Overtaking Collision

Head-on and overtaking collisions can be classified as ship collisions along the navigation route as illustrated in Figure 3.

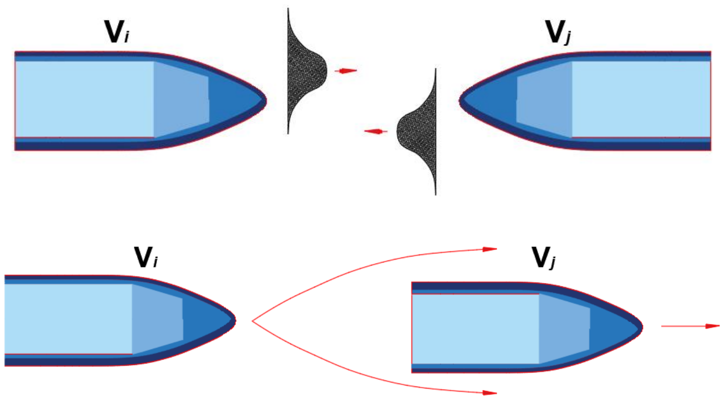


Figure 3. Illustration of Head-on Collision and Overtaking Collision

Both types of ship collisions are influenced by several factors, including the length of the navigation route (L_w), the composition of waterway traffic–specifically, the number and types of vessels traversing the channel of varying sizes ($Q_i^{(1)}, Q_j^{(2)}$), (1), (2) indicate each direction, and the relative velocities of the ships (V_i) and (V_j). Additionally, ($f_i^{(1)}(y)$) and ($f_j^{(2)}(y)$) represent the geometrical probability distributions or ϕ if normal distribution. The calculation of the geometric number be formulated as follows:

$$N_G^{head-on} = L_w \sum_{i,j} P_{Gij}^{head-on} \frac{V_{ij}}{V_i^{(1)} V_j^{(2)}} \left(Q_i^{(1)} Q_j^{(2)} \right) \tag{2}$$

$$N_G^{overtkaing} = L_w \sum_{i,j} P_{Gij}^{overtaking} \frac{V_{ij}}{V_i^{(1)} V_j^{(2)}} \left(Q_i^{(1)} Q_j^{(2)}\right) \tag{3}$$

For V_{ij}, there is a distinction between overtaking and head-on scenarios, where ($V_{ij}^{head-on} = V_i + V_j$) designates the head-on situation, and ($V_{ij}^{overtaking} = V_i - V_j$, $V_{ij} > 0$) designates the overtaking situation. (P_{Gij}), represents the probability that the two ships will experience either a head-on collision or an overtaking collision, which can be formulated as follows:

$$P_{Gi,j} = \Phi\left(\frac{Bij - \mu ij}{\sigma ij}\right) - \Phi\left(-\frac{Bij + \mu ij}{\sigma ij}\right) \tag{4}$$

Equation 4, Φ(x) indicates that the calculations are based on a normal distribution function. μ_{ij} , represents the average sailing distance between the two ships, with ($\mu_{ij} = \mu_i^{(1)} + \mu_j^{(2)}$,) used for head-on collisions and ($\mu_{ij} = \mu_i^{(1)} - \mu_j^{(2)}$), used for overtaking scenarios. Additionally, ($\sigma_{ij} = \sqrt{\left(\sigma_i^{(1)}\right)^2 + \left(\sigma_j^{(2)}\right)^2}$) denotes the standard deviation, and $B_{ij} = \frac{B_i^{(1)} + B_j^{(2)}}{2}$, represents the average breadth of the two ships.

c. Crossing Collision, Merging and Bending

Crossing collision is defined as a maritime incident that occurs between two ships a result of the intersection of their navigational routes, as depicted in Figure 4. This type of collision typically arises when the paths of the vessels converge at an angle.

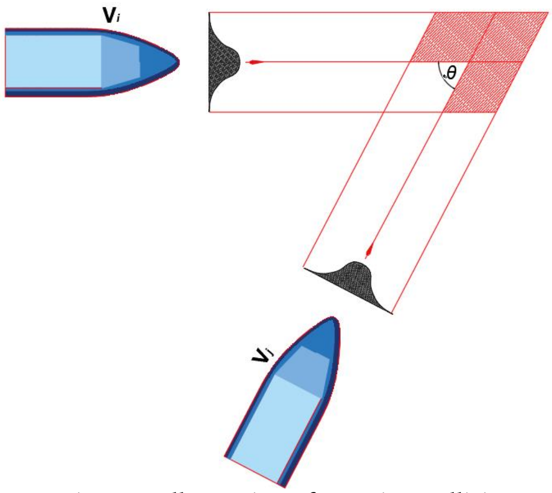


Figure 4. Illustration of Crossing Collision

$$N_{Gi,j}^{crossing} = \sum_{i,j} \frac{Q_i^{(1)} Q_j^{(2)}}{V_i^{(1)} V_j^{(2)}} D_{ij} V_{ij} \frac{1}{\sin\theta}, \qquad for\ 10^0 < |\theta| < 170^0 \tag{5}$$

The geometric number can be calculated using the following formula, where (V_{ij}) represents the relative velocity between two vessels, which can be determined by $V_{ij} = \sqrt{\left(V_i^{(1)}\right)^2 + \left(V_j^{(2)}\right)^2 - 2.V_i^{(1)} V_j^{(2)} cos\theta}$, and D_{ij} represents the collision diameter. The crossing angle shown in Figure 4 as (θ) is constrained between 10 and 170 degrees.

$$D_{ij} = \frac{L_i^{(1)} V_j^{(2)} + L_j^{(2)} V_i^{(1)}}{V_{ij}} sin\theta + B_j^{(2)} \left\{1 - \left(sin\theta.\frac{V_i^{(1)}}{V_{ij}}\right)^2\right\}^{1/2} + B_i^{(1)} \left\{1 - \left(sin\theta.\frac{V_j^{(2)}}{V_{ij}}\right)^2\right\}^{1/2} \tag{6}$$

As previously explained D_{ij} represents the geometrical collision diameter, as illustrated in Figure 5. The value of D_{ij} can be calculated using Equation 6, where (L) denotes the length of the vessel, (B) denotes the width of the vessel, and (V_{ij}) represents the relative velocity of the vessels. The calculations for merging collisions utilize the same formula as that employed for crossing collisions. Conversely, bending collisions are governed by a separate and distinct calculation methodology within the software system. This differentiation underscores the complexity of collision dynamics and the necessity for tailored approaches to model each type of interaction accurately.

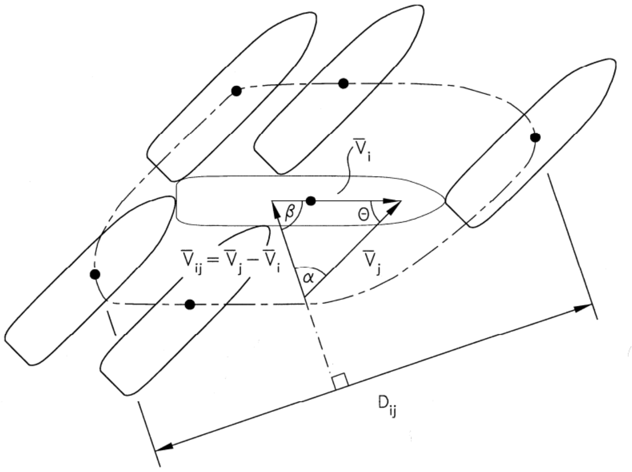


Figure 5. Illustration of Geometrical Collision Diameter [14]

2.3. Determination of Consequences Model

The impact of collisions involving vessels can lead to various forms of damage and loss. The consequences of oil spills are particularly significant, as tanker ships dominate the traffic among other types of vessels navigating the shipping routes of Dumai Port. The analysis of oil spills will be conducted using *webGNOME*, which is a web-based interface for the GNOME (General National Oceanic and Atmospheric Administration Operational Modeling Environment) model. This model simulates the trajectory and fate of oil spills, taking into account environmental factors such as winds, waves, and currents. The website can display various conditions related to the oil spill, including the amount of oil that remains floating, the volume that has evaporated, the extent of natural dispersion, sedimentation, and the quantity that has beached. This website was developed by the NOAA (National Oceanic and Atmospheric Administration) Office of Response and Restoration (OR&R) Emergency Response Division, GNOME is designed for use in oil spill response.

3. Results and Discussion

3.1. Analysis Frequency of Ship Collision

3.1.1. Design of Leg

In the context of conducting a risk assessment for the frequency of ship collisions utilising the IWRAP software, the initial phase involves delineating the geographical area where a leg will be established. This leg serves as the reference point for simulating the incident. The accompanying Figure 6 illustrates a density map for Dumai Port and Figure 7 indicates the designated leg for simulation risk assessment. This density chart is instrumental in providing a quantitative analysis of vessel traffic patterns, thereby facilitating a comprehensive understanding of the potential collision risks in the specified area.

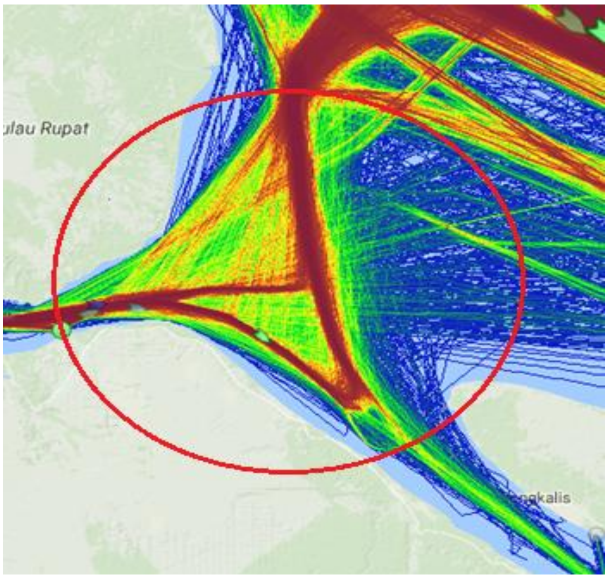


Figure 6. Density Map in Dumai Port

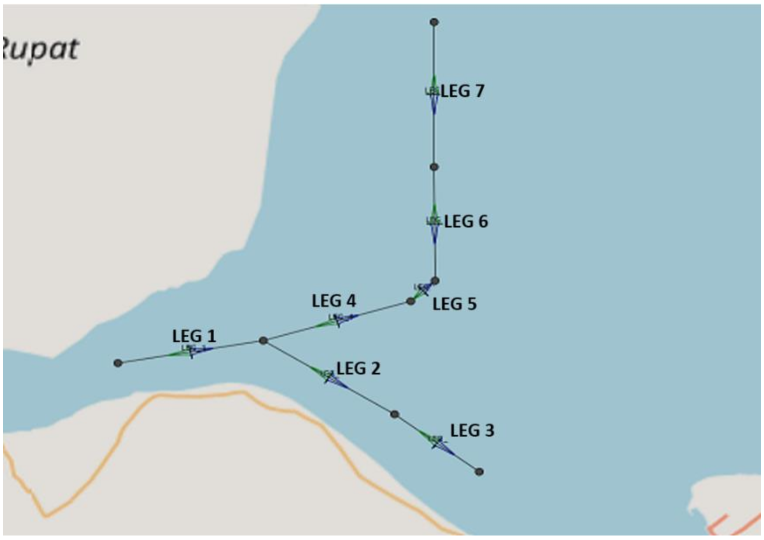


Figure 7. Design Leg

Figure 6 represents a density map of ship distribution, indicating the number of vessels passing through the route. In this density map, blue denotes areas with the lowest levels of ship traffic, whereas red signifies the routes that experience the highest frequency of vessel passage. The density map will be used as a reference for developing n legs, as illustrated in Figure 7. In this process, this research will focus on the routes that are most commonly used by vessels, particularly those highlighted in red in Figure 6, which indicate the busiest pathways, especially those leading to Dumai port.

From Figure 7, the following details about the planned leg:

- Leg 1 has a length of 9.926 meters.
- Leg 2 has a length of 10.437 meters and forms an angle of 121 degrees with Leg 1.
- Leg 3 has a length of 7.161 meters and forms an angle of 179 degrees with Leg 2.
- Leg 4 has a length of 12.045 meters and forms an angle of 74 degrees with Leg 2.
- Leg 5 has a length of 2.256 meters and forms an angle of 155 degrees with Leg 4.
- Leg 6 has a length of 9.809 meters and forms an angle of 127.5 degrees with Leg 5.
- Leg 7 has a length of 10.940 meters

The angular data will be utilized to determine the value of crossing collisions as well as collisions in bending. Furthermore, all of this data will be combined with other relevant information to assess the frequency of vessel collisions at Dumai Port for each type of collision.

3.1.2. Ship Traffic Data

The ship traffic data utilized is sourced from the AIS (Automatic Identification System) of Dumai Port for the year 2017. The existing data will be adjusted with an annual increase of 1.5% based on the ship arrival data to project the number of vessels through to the year 2027. Table 1 and Table 2 show the results of clustering the data based on vessel length and type. The clustering data is aligned with the inputs available in the IWRAP software. There are 16 size ranges for ships with intervals of 25 meters (ranging from 0-25 meters to 375-400 meters) and 14 types of ships. The breadth and speed data will be calculated by default using IWRAP. Additionally, the width of the navigation area will be set to 200 meters. This data will support the analysis of ship collisions within the designated navigation area.

Table 1. Ship Clustering Data (1/2)

	Crude Oil	Oil Product Tanker	Chemical Tanker	Gas Tanker	Container	General Cargo	Bulk Carrier
0-25	0	0	0	0	0	0	0
25-50	18	0	0	0	6	0	0
50-75	56	50	0	0	0	310	0
75-100	496	640	0	0	64	426	24
100-125	400	488	0	0	224	462	46
125-150	452	318	0	0	166	152	20
150-175	168	310	0	0	52	36	50
175-200	370	450	0	0	76	32	228
200-225	24	0	0	0	30	6	18

225-250	374	124	0	0	10	0	66
250-275	82	0	0	0	24	0	6
75-300	10	0	0	0	12	0	308
300-325	42	0	0	0	30	0	0
325-350	568	6	0	0	6	6	0
350-375	0	0	0	0	24	0	0
375-400	0	0	0	0	24	0	0

Table 2. Ship Clustering Data (2/2)

	Ro-Ro Cargo	**Passenger**	**Fast Ferry**	**Support Ship**	**Fishing Ship**	**Pleasure Boat**	**Other Ship**
0-25	0	10	0	0	0	0	174
25-50	0	1988	0	0	0	0	236
50-75	0	0	0	0	0	0	174
75-100	0	156	0	0	0	0	34
100-125	0	50	0	0	0	0	96
125-150	0	64	0	0	0	0	12
150-175	0	18	0	0	0	0	6
175-200	0	40	0	0	0	0	18
200-225	0	0	0	0	0	0	4
225-250	0	0	0	0	0	0	0
250-275	0	0	0	0	0	0	0
275-300	0	0	0	0	0	0	0
300-325	0	0	0	0	0	0	0
325-350	0	6	0	0	0	0	0
350-375	0	0	0	0	0	0	0
375-400	0	0	0	0	0	0	0

3.1.3. Frequency of Ship Collision

The frequency of vessel collisions will be calculated for each leg that has been established. In this calculation, the values for the causation factor will follow the default settings from IWRAP, as shown in Table 3:

Table 3. Causation Factor for each type of Collision

Condition	**Causation Factor**
Head-on Collision	0.5×10^{-4}
Overtaking Collision	1.1×10^{-4}
Crossing Collision	1.3×10^{-4}
Collision in bending	1.3×10^{-4}
Collision in merging	1.3×10^{-4}

The results of the simulation are presented in Table 4. The frequency values based on Equation 1, Equation 2, and Equation 3 for head-on collisions and overtaking collisions are 0.429641 and 0.105138, respectively. In contrast, the frequencies for the other three scenarios—crossing, bending, and merging—based on Equation 1, Equation 5 and Equation 6 are all below 0.1, with values of 0.0148296, 0.0360566, and 0.00410085, respectively. Consequently, the total frequency of ship collisions for the Dumai Port is 0.589766. This result remains below 1, which, according [22], is considered acceptable. However, given the total frequency and the increasing number of vessels each year, it is essential to implement mitigation measures, VTMS (Vessel Traffic Monitoring System) can be an option, especially since the shipping routes in the port area cannot be expanded.

Table 4. The Result for Frequency of Ship Collision

No	**Type of Collision**	**Frequency of Ship Collision**
1	Head-on Collision	0.429641
2	Overtaking Collision	0.105138
3	Crossing Collision	0.0148296
4	Collision in Bending	0.0360566
5	Collision in Merging	0.00410085
Total Frequency of Ship Collision		**0.589766**

3.2. Oil Spill Modelling Analysis

Oil spills have been selected as a consequence that may occur in the event of a ship collision. The frequency of ship collisions in Leg 1, Leg 2, and Leg 3 has the maximum frequency of collisions, which is why this point was chosen. Consequently, this study employs this point as a reference for potential oil spills that may occur as seen in Figure 8. The modelling involved two different types of oil spills: product oil and crude oil, which are the most common types of ship cargo passing through Dumai Port over two days. Wind data was utilized with varying speeds based on the water conditions, and the amount of oil spill was assumed to be 2,000 m³. The modelling was conducted with two wave heights: 0.5 meters (the minimum wave height) and 1.5 meters (the maximum wave height). The selection of wave heights is intended to simulate the highest wave conditions during high tide and the lowest wave conditions during low tide. This approach allows for estimating two types of dispersion patterns in the Dumai Port area.

Figure 8. The point of oil spill

The oil spill analysis will be divided into several categories:

- Evaporation: the condition when the oil evaporated, it turned into gas.
- Natural Dispersion: The condition occurs when the oil breaks down into small particles and is dispersed into water by wave and turbulence [23]
- Sedimentation: The process by which oil settles on the bottom of the sea [23]
- Beached: The condition when the oil spill reached the beach.
- Floating: The condition of oil spills still floating in the sea.

3.2.1. Oil Spill in wave height 0.5 meter

Figure 9 show the oil spill trajectory of crude oil in 0,5 meters over two days with the oil spill movement shown every 6 hours. Red dots represent the naturally dispersed and evaporated oil spill while black dots represent the oil that is still in the water/has reached land. In six hours, the oil spill begins to spread slowly, continuing to do so until 24 hours. Between 30 and 48 hours, the oil spread expands significantly, and oil is visibly reaching the shoreline. The difference between 6 hours and 48 hours is evident, as at 6 hours the oil is still concentrated at the spill point with many black dots clustered together, whereas at 48 hours, there is a greater number of black dots, which represents the amount of oil still floating, compared to the red dots. For more details, refer to Figure 11.

Figure 10 shows the oil spill trajectory of product oil in 0,5 meters over two days with the oil spill movement shown every 6 hours. Red dots represent the naturally dispersed and evaporated oil spill while black dots represent the oil that still in the water/has reached land. At 6 hours, the oil spill begins to spread slowly until 12 hours. Between 24 and 36 hours, the spread expands into the surrounding waters, and by 42 to 48 hours, the oil reaches the shoreline. The difference between the 6-hour and 48-hour marks is quite evident; at 6 hours, the spread is relatively concentrated around the spill point, while after 48 hours, the oil begins to disperse into the surrounding areas, with a dominance of red dots compared to the black dots. For more details, refer to Figure 12.

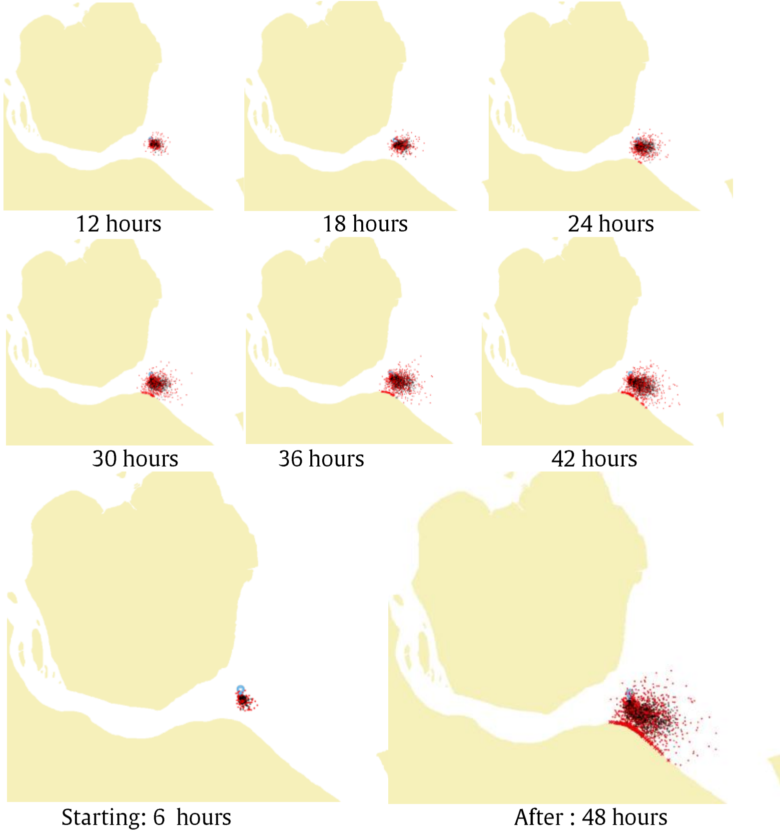


Figure 9. Trajectory of Crude Oil Spill in 0.5 Meters

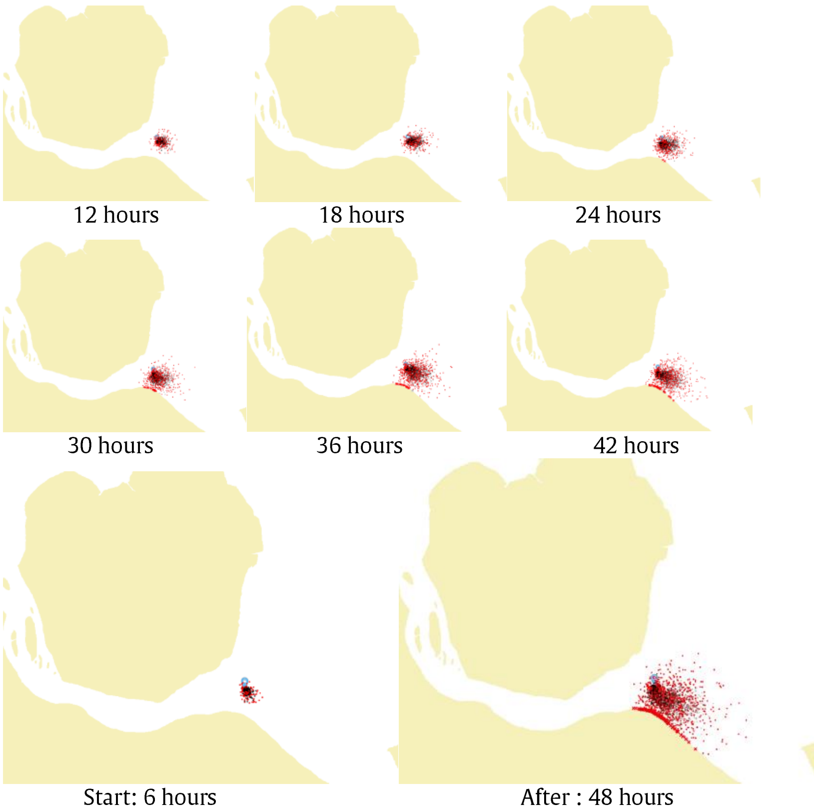


Figure 10. Trajectory of Product Oil Spill in 0.5 Meters

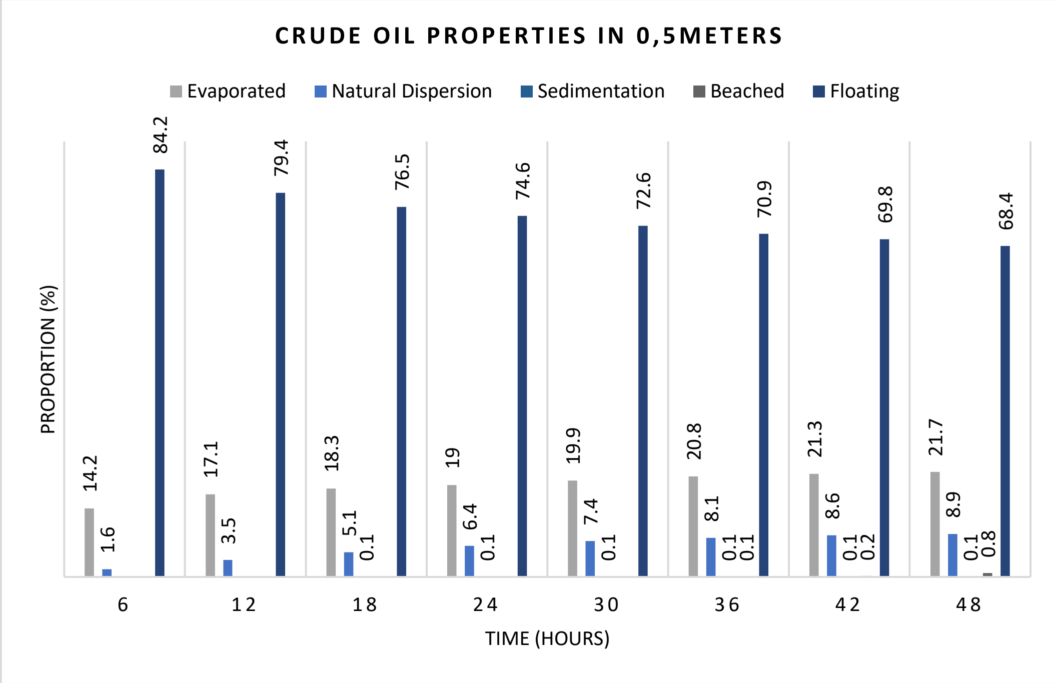


Figure 11. The Proportion of Crude Oil Spill in 0.5 Meters

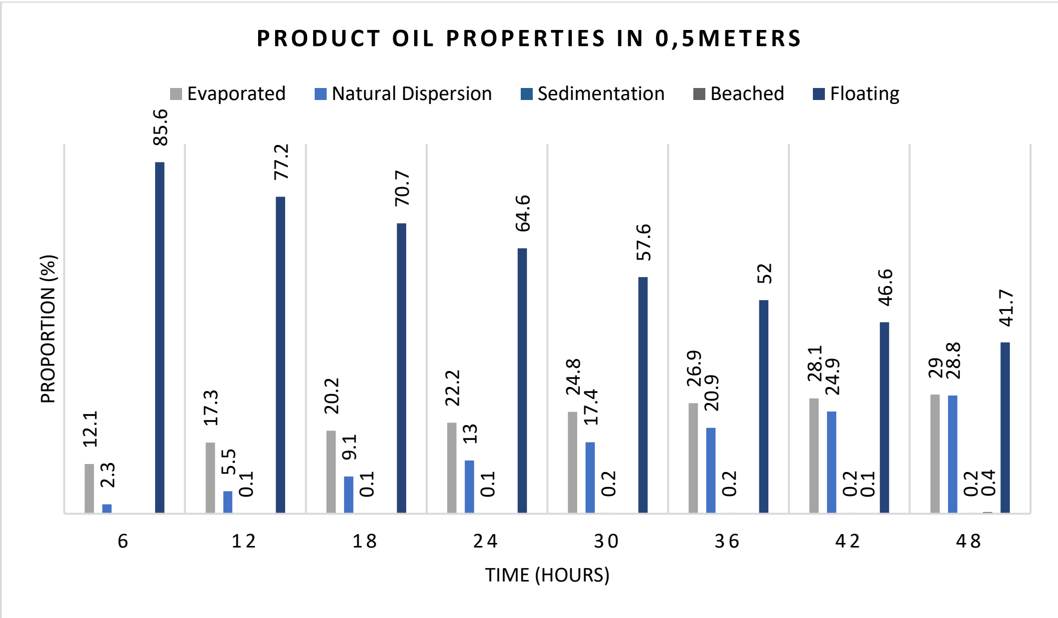


Figure 12. The Proportion of Product Oil Spill in 0.5 Meters

Figure 11 and Figure 12 show the proportion of the oil spill weathering as a percentage over 48 hours. Here is an explanation of each of the processes:

- Evaporated: In the crude oil model, the amount of oil that evaporates starts at 14.2% at 6 hours, experiencing an increase of about 3% at 12 hours and approximately 1.2% at 18 hours, reaching 18.3%. The subsequent increase does not exceed 1% until 48 hours when it reaches 21.7%. A similar trend occurs in the product oil model, where the highest increase happens from 6 to 12 hours, at around 4.8%. In the following periods, the increase ranges from 1% to 2%, reaching 29% at 48 hours
- Natural Dispersion: Natural dispersion in both models displays an upward trend throughout the time period. In the crude oil model, from 6 to 30 hours, the increase is approximately 1.5%, starting at 1.6% (6 hours) and reaching 7.4% (30 hours). From 30 to 48 hours, the rate of increase drops to approximately 0.4%, reaching 8.9% at 48 hours. The product oil model demonstrates a consistent increase of approximately 3-4%, beginning at 2.3% at 6 hours and resulting in 28.8% at 48 hours.
- Sedimentation: The amount of oil sedimentation in both models has the smallest proportion compared to other processes. The amount of oil that undergoes sedimentation in the crude oil model remains constant at 0.1% from 18 to 48 hours. In contrast, in the product oil model, sedimentation starts at 0.1% between 12 - 24 hours and increases to 0.2% from 30 to 48 hours

- Beached: In the crude oil model, the process begins at 36 hours, while in the product oil model, it starts at 42 hours, with both having the same initial proportion of 0.1 %. However, by the end of the time period, the proportion of crude oil increases to 0.8 %, while product oil reaches 0.4 %.
- Floating: During the 6 – 24 hours period, the disparity between crude oil and product oil was maintained at a maximum of approximately 10%. However, between 30 to 48 hours, the differences became more evident. The product oil model experienced a decrease around 5% in each time period, reaching 41.7% at 48 hours. In contrast, the crude oil model only experienced a decrease of 1-2%, resulting in a remaining amount of 68.4% at 48 hours.

3.2.2. Oil Spill in wave height 1.5 meter

Figure 13 shows the oil spill trajectory of crude oil in 1,5 meters over two days with the oil spill movement shown every 6 hours. Red dots represent the naturally dispersed and evaporated oil spill while black dots represent the oil that is still in the water/has reached land. At 6 hours, the oil spill begins to spread slowly around the spill point, with many black dots still visible in the water. Between 36 and 48 hours, the spread of the oil expands, with some reaching the land. Additionally, the difference between 6 hours and 48 hours is evident, as at 6 hours the black and red oil spots are still clustered around the spill point, whereas at 48 hours, the red spots dominate with a wider dispersion compared to the black spots, which are scattered around the spill area. For more details, refer to Figure 15.

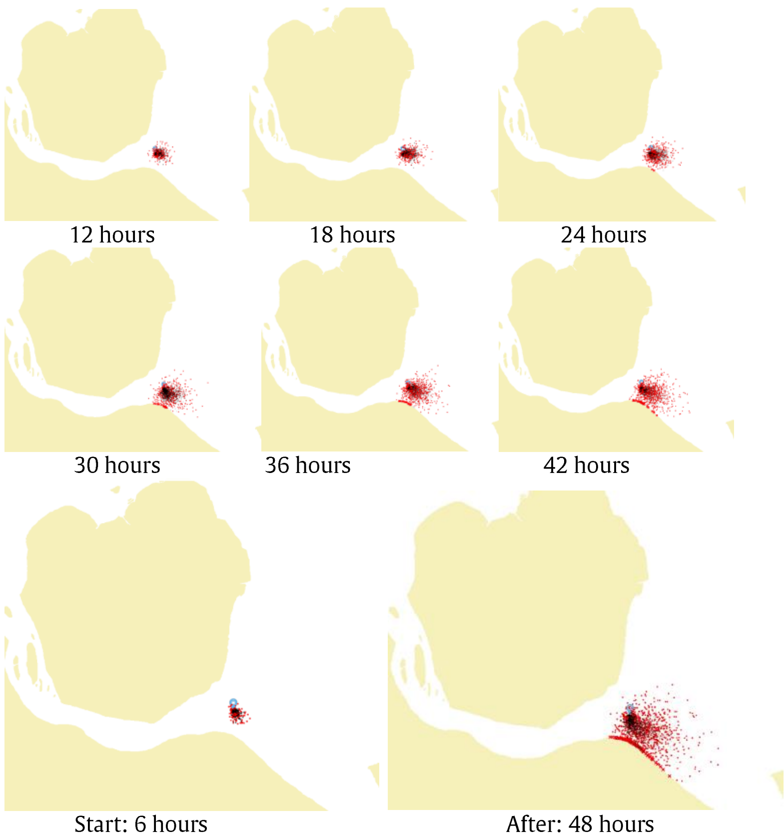
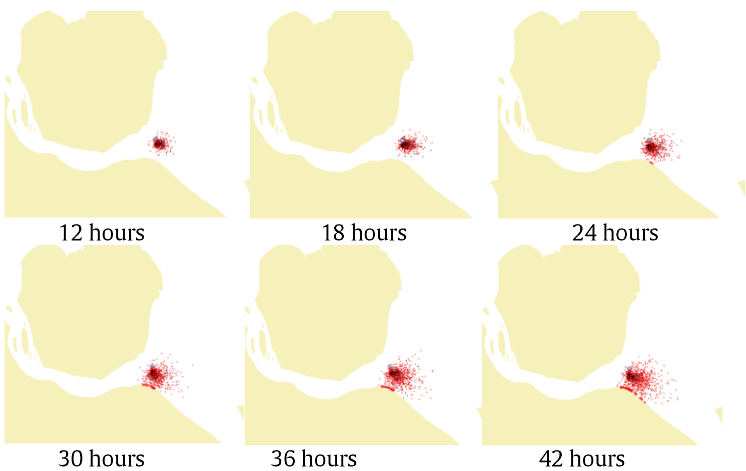


Figure 13. The Trajectory of Crude Oil Spill in 1.5 Meters



Start: 6 hours After: 48 hours

Figure 14. The Trajectory of Product Oil Spill in 1.5 Meters

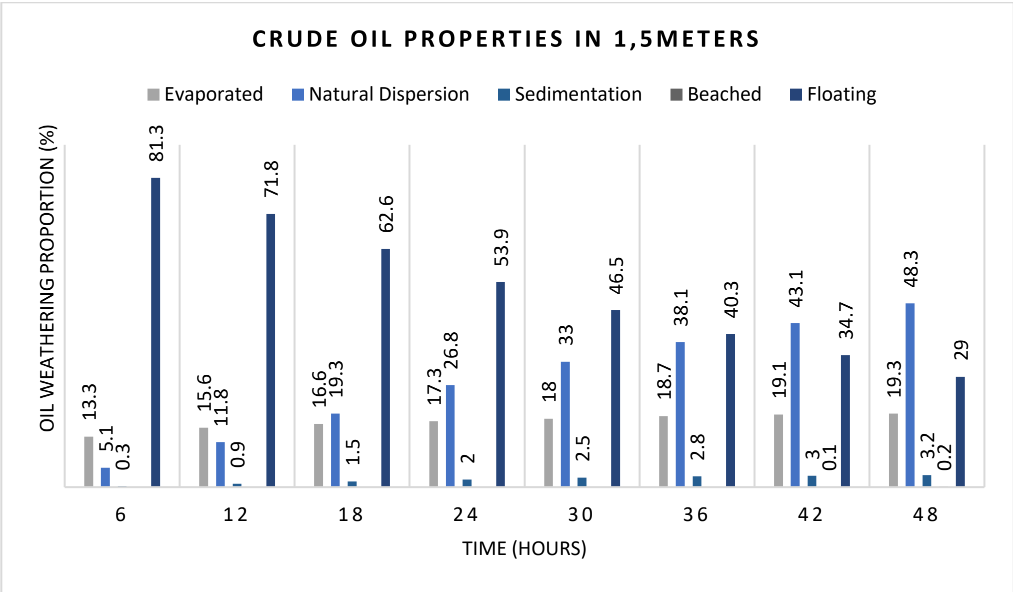


Figure 15. The Proportion of Crude Oil Spill in 1.5 Meters

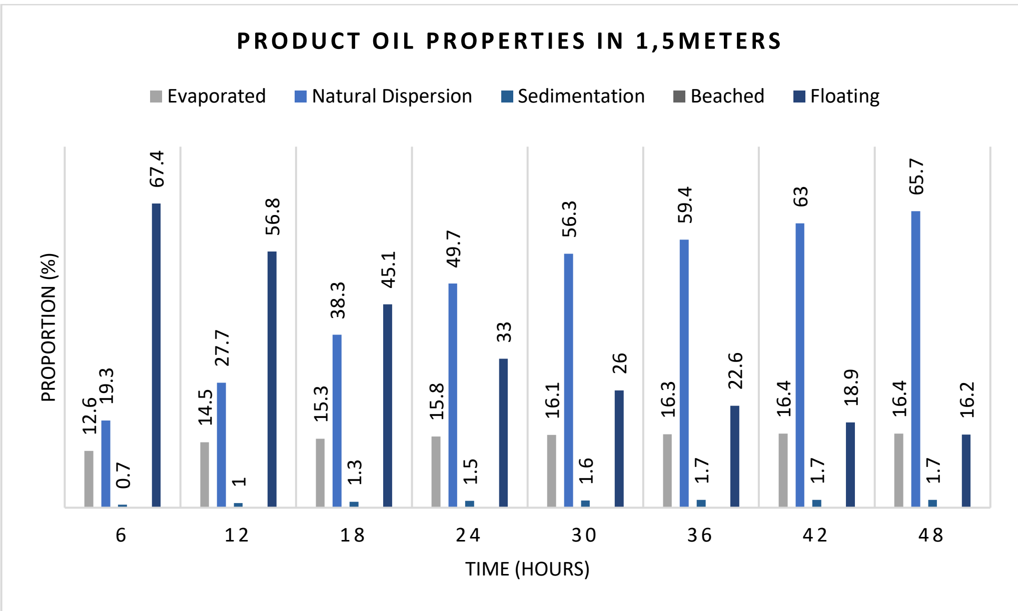


Figure 16. The Proportion of Product Oil Spill in 1.5 Meters

Figure 15 and Figure 16 show the proportion of the oil spill weathering as a percentage over 48 hours. Here is an explanation of each of the processes:

- Evaporated: In the crude oil model, the highest increase occurs between 6 to 12 hours, with a rise of 2.6%, from 12.6% to 15.6%. In contrast, between 18 to 48 hours, the increase does not exceed 1%, and is as low as 0.2% during the 42 to 48-hour period, resulting in 48.3%. In the product oil model, the largest increase is only 1.9%, rising from 12.6% to 14.5% during the first 12 hours. Subsequently, between 18 to 48 hours, the increase does not exceed 0.5%, resulting in 16.4% at 48 hours.

- Natural Dispersion: The crude oil model shows a twofold increase within the 6 to 12-hour interval, increasing from 5.1% to 11.8%. Between 18 to 48 hours, the increase is approximately 5-7%. Notably, during the 42 to 48-hour period, the proportion of natural dispersion surpasses the floating process, finishing at 48.3%. In the product oil model, at 24 hours, the proportion becomes the largest among other processes, reaching nearly 50%. The upward trend continues, resulting in a value of 65.7% at 48 hours, which is more than double the total of the other processes.
- Sedimentation: In the crude oil model, between 6 to 30 hours, there is a consistent increase of approximately 0.5% in each period, rising from 5.1% at 6 hours to 2.5% at 36 hours. Subsequently, the rate of increase declines to 0.3% during the 36 to 48-hour period, resulting in 3.2% at the end of the period. In the product oil model, an upward trend also occurs, with an increase of approximately 0.1-0.3% during the 6 to 36-hour period, reaching 1.7%. However, from 36 to 48 hours, that proportion remains unchanged.
- Beached: Beached process only happens in the crude oil model, with a value of 0.1% at 42 hours, increasing to 0.2% at 48 hours.
- Floating: In the crude oil model, the proportion at 6 hours remains the largest at 81.3%, but it continues to decline by approximately 10% in each period, reaching 53.9% at 24 hours. The decrease continues at a rate of 5% from 36 to 48 hours, resulting in 29% at 48 hours. A similar trend occurs in the product oil model, with a decrease of approximately 10% from 6 to 24 hours and 5% from 30 to 48 hours, resulting in a drop from 67.4% at 6 hours to only 16.2% at 48 hours, making it the third highest proportion.

From the modelling conducted at a wave height of 0.5 meters, floating predominates in both types of oil. However, during the modelling at 1.5 meters, natural dispersion becomes the highest by the end of the period. Natural dispersion is accelerated as wave height rises [23]. In the evaporation process, factors such as viscosity and density can have an impact [24]. The lighter the oil, the evaporation rate will increase [25]. This is evident in the modelling, where the evaporation value in the crude oil model is consistently lower compared to that of the product oil. From the weathering process, it is possible to predict the oil spill trajectory that would occur if an oil spill happened at Dumai Port. The results can serve as a consideration for an appropriate response plan because to safeguard sensitive resources and coastal areas, it is essential for spill response personnel to understand the trajectory of the oil spill [26]. The actions that can be taken for cleanup include the following:

- Oil Boom and Skimming: An oil boom is a barrier used to prevent the spread of oil spills (concentrating the oil slick with the boom), while skimming is the process of recovering oil or a mixture of oil and water using skimmers [27]. In all modeling conditions, this method can be utilized because it is a fundamental technique in oil spill cleanup. Booms will be deployed to prevent the spread of the oil, followed by the recovery process using skimmers
- Dispersant: Dispersants are a cleaning method for oil spills that work by reducing the bond between oil and water, allowing the oil to disperse on its own. The process takes longer compared to other methods, but it has the least impact on the environment compared to other techniques [28]. This method can be used on both models, especially for crude oil with lower viscosity, because the effectiveness of dispersants decreases as the viscosity of the oil increases [29].
- In-situ Burning: In situ burning (ISB) is recognized as a highly effective response technique for oil spills compared to other method, particularly when the oil is contained [30]. It involves the controlled combustion of spilled oil, which can significantly reduce the volume of oil. In both types of oil spills, the in situ burning method can be utilized. However, considering that the oil spread in both models reaches land and the negative effects of in situ burning (potential damage to aquaculture ecosystems and air pollution from the smoke produced). This method should be considered as a last resort if other methods prove ineffective.

Oil spills pose significant ecological, social, and economic challenges, necessitating coordinated responses from various stakeholders. Effective cleanup actions require support from government agencies (Local Government, Ministry of Marine Affairs and Fisheries, Ministry of Transportation, Ministry of Environment and Forestry, and Port Authority), Oil Industries, and civil society [30]. In oil spill cleanup, collaboration among various stakeholders is essential, along with the selection of cleanup methods that are appropriate for the dispersion of the oil spill, environmental conditions, and the type of oil involved. This ensures that the restoration of the water environment can be carried out accurately and efficiently.

4. Conclusion

Based on the risk analysis of ship collisions that occurred at Dumai Port, using vessel traffic data and scenarios such as head-on collision, overtaking collision, crossing collision, bending, and merging, a total frequency of ship collisions was obtained at 0.5. This result is considered acceptable, as it remains below the threshold of 1 incident per year. The Vessel Traffic Management System (VTMS) can be implemented as one of the mitigation plans. Additionally, modelling of the trajectory of ship collisions in areas with the highest frequency, specifically concerning oil spills, has been conducted. The modelling involved two types of oil, varying wind speeds, and two wave heights. The results showed that in the 2000 m^3 oil spill modelling at a height of 0.5 m, the crude oil model had 68.4% still floating, 0.1% sedimentation, and 0.8% beached, while the product oil model had 41.7% still floating, 0.2% sedimentation, and 0.4% beached. Furthermore, in the 1.5 m modelling, the crude oil model had 29% floating, 3.2% sedimentation, and 0.2% beached, whereas the product oil model had 16.2% floating and 1.7% sedimentation. In the 1.5 m oil modelling, a significant amount of oil was lost due to evaporation and natural dispersion. The results of trajectory modelling can serve as a reference for relevant personnel in determining the dispersion of oil spills, thereby facilitating an accurate response planning process. The oil cleanup methods that can be employed include oil booms, skimming, and dispersants, with considerations given to the spill's location and the type of oil involved. It is anticipated that collaboration among various stakeholders during the oil cleanup process will lead to a more effective and efficient response.

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