Application of Formal Safety Assessment for Ship Collision Risk Analysis in Surabaya West Access Channel

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Abstract. In 2019, ship density of Surabaya West Access Channel reached 28,112 ships. The high number of vessel densities that exist in Surabaya West Access Channel (APBS), it is possible for ship collisions to occur. In this study, Formal Safety Assessment used for ship collision Risk Analysis in Surabaya West Access Channel (APBS). Formal Safety Assessment is a structured and systematic methodology developed by the International Maritime Organization (IMO) used to conduct risk assessments and also evaluates cost-benefit assessments to get some recommendations to improve safety in the maritime world, including protection of life, health, the marine environment, and property. To achieve the above objectives, IMO’s guidelines on the application should comprise the following steps; First step, Hazard Identification using Event Tree Analysis based on historical accident data. The second step, risk analysis is composed of two main activities: frequency calculating and consequence modeling. The frequency of ship collision was calculated using Traffic Based Model and for the consequence, Ansys software was used to model the structural damage of hull caused by the incident. The third step, Risk Control Option is used to get some options to prevent collisions. The fourth step, Cost-Benefit Assessment is used to identify and compare benefits and costs associated with the implementation of each RCO using Net Cost of Averting a Fatality (NCAF) and Gross Cost of Averting a Fatality (GCAF) Criteria. The last step of Formal Safety Assessment (FSA) is Recommendations for Decision-Making to get some options for mitigation.

1. Introduction

Surabaya West Access Channel (SWAC) is located between eastern part of Java and Madura Islands. Surabaya West Access Channel serves 17 Greater Metropolitan ports, including Port of Tanjung Perak in Surabaya that serves several types of ships and one of the main ports in Indonesia. According to data from PT. APBS, Surabaya West Access Channel (SWAC) which had a revitalization from 24.2 NM in length, 100 meters in width and -8.5 meters in depth to 150 meters in width and -13 meters in depth. In 2019, ship density in Surabaya West Access Channel (SWAC) reached 28,112 ships reported by Vessel Traffic Service (VTS) Surabaya. High ship density through the Surabaya West Access Channel (SWAC) led to an increased the risk of ship collision. The study area of this research is shown in figure 1.
Figure 1. Study Area

Figure 2 shows that the highest number of ships per month in 2019 is in December with 2768 ships. Based on the total number of ships passing through Surabaya West Access Channel, the arrival frequency of meeting ships \( \left( N_m \right) \) in Surabaya West Access Channel is 3.2 ships/hour. Surabaya West Access Channel can be said as the busiest shipping access channel in Indonesia. Besides being the busiest shipping access channel in Indonesia, Surabaya West Access Channel become one of the economic boosters because of its vital strategic region for seaborne trade. Based on Vessel Traffic Service (VTS) Surabaya data, the ship population passing through Surabaya West Access Channel in 2019: cargo ships 51.7%, passenger ships 18.1%, tanker ships 13.8%, tugs 8.8%, high-speed craft 0.7%, and another vessel 6.9%.

![Number of Ship](image)

**Figure 2.** Number of ships per month in 2019

2. **Methodology**
Formal Safety Assessment is a structured and systematic methodology developed by the International Maritime Organization (IMO) used to conduct risk assessments and also evaluates cost-benefit assessments to get some recommendations to improve safety in the maritime world, including
protection of life, health, the marine environment, and property [1]. The FSA can be used as a tool to assist in evaluating new regulations regarding safety in the maritime world and also in the comparison between existing regulations and regulations to be updated. To achieve the above objectives, IMO’s guidelines on the application should comprise the following steps:

1. Hazard Identification
2. Risk Analysis
3. Risk Control Option
4. Cost-benefit Assessment
5. Recommendation.

2.1. Hazard Identification

The goal of FSA's first step as stated above is that all possible hazards can be identified. Hazard identification can be done with two methods, using historical data and brainstorming. Most of the research has been done using historical data, so it does not consider unprecedented events but has the potential to occur. Historical data can be used, as far as vigilance is carried out, especially in the cause of the accident to identify correctly. Based on the historical data, ship collision in Surabaya West Access Channel caused by main engine overheating, ship control error, technical failure, external factor, other ship errors occur in the process of navigation, environmental conditions, and human error. [2]

| Overheat | Technical Failure | Human Error | External Factor | Other Ship | Head On |
|----------|-------------------|-------------|----------------|------------|---------|
| Y        | Y                 | Y           | Y              | 0.133      | 1.76E-07 |
| Y        | 0.00444           | N           | 0.000171       | 0.00395    | 0.00385 |
| N        | 0.99556           | 0.996       |                |            |         |

Table 1. Hazard identification of head-on collision in SWAC.

| Ship Speed Control Error | Technical Failure | External Failure | Other Ship | Overtaking |
|-------------------------|-------------------|------------------|------------|------------|
| Y                       | Y                 | Y                | 0.133      | 3.93E-06   |
| Y                       | 0.0667            | N                | 0.019      | 0.044      |
| N                       | 0.9333            | 0.933            |            |            |

Table 2. Hazard identification of overtaking collision in SWAC.
2.2. Risk Analysis

Risk analysis of ship collision is affected by frequency and consequences are carried out to determine the risk of each scenario with variations carried out to obtain variations in the results to be assessed [3]. In this thesis, the calculation of frequency of ship collision using Traffic Based Model to find out the variation of results from three scenarios, namely head-on, crossing, and overtaking [4]. To determine the consequence of ship collision, the damage using Ansys.

The risk of ship collision can be determined as:

\[ R = N_a \times C \]

Where,
- \( N_a \) = Frequency
- \( C \) = Consequence

2.2.1. Frequency of Ship Collision

The first step in calculating the frequency of collision is to determine the number of accident’s probability \( P_a \) that is multiplied by the arrival frequency of meeting ships \( N_m \). The concept of frequency calculation using Traffic Based model can be expressed as:

\[ N_a = P_a \times N_m \]

Where,
- \( P_a \) = Probability of accident
- \( N_m \) = Arrival frequency of meeting ships (ships/hour)

Head-on is a conflict between two or more ships that sail in the same route but have different direction with course differences between 157.5° and 202.5°. Overtaking is a conflict between two vessels that sail in the same direction and route, but have different velocity and also the angel of two vessels involved should not exceed 22.5°. Crossing is a conflict when some ships sail but have a different direction, in the different route and the difference between two vessels’ courses falls in the range 22.5° - 90° or 270° – 337.5° [5]. The ship collision probability \( P_a \) can be expressed as:

\[ P_a = N_i \times P_r \]

Where,
- \( N_i \) = Probability number of collisions per passage
- \( P_r \) = Causation factor

The probability number of head-on and overtaking collisions per passage can be determined as:

\[ N_i = \frac{B_1 + B_2}{W} \times \frac{V_1 + V_2}{V_1 \times V_2} \times D \times N_{mil} \]

Where,
- \( B_1 \) = Beam of ship 1 (m)
The probability number of crossing collisions per passage can be determined as:

\[
N_i = \frac{N_m}{V_i \times V_p} + \left[ (B_1 + L_2) \times V_1 + (B_2 + L_1) \times V_2 \right]
\]  

(5)

Where,

- \(B_1\) = Beam of ship 1 (m)
- \(B_2\) = Beam of ship 2 (m)
- \(W\) = Width of channel (m)
- \(V_1\) = Mean speed of ship 1 (m/s)
- \(V_2\) = Mean speed of ship 2 (m/s)
- \(D\) = Relative sailing distance (m)
- \(N_m\) = Arrival frequency of meeting ships (ships/hour)

### Table 4. Frequency of ship collision

| Scenario   | Nm (Ship/hr) | W (m) | D (m)           | Pe          | Ni            | Pa          | Na            |
|------------|--------------|-------|-----------------|-------------|---------------|-------------|---------------|
| Head-on    | 3.2          | 150   | 45600           | 1.76E-07    | 17684.3317    | 0.031124    | 0.09959816    |
| Overtaking | 3.2          | 150   | 45600           | 3.9289E-06  | 20502.5966    | 0.080553    | 0.2578        |
| Crossing   | 3.2          | 150   | 45600           | 1.32E-05    | 270.098348    | 0.003565    | 0.01140895    |

From the explanation of the frequency of collisions with three types of collisions, namely: head-on, overtaking, and crossing, the total collision frequency can be calculated by:

\[
N_a = N_{a\text{ Head on}} + N_{a\text{ Overtaking}} + N_{a\text{ Crossing}}
\]  

(6)

Where,

- \(N_a\) = Total frequency of collision
- \(N_{a\text{ Head on}}\) = Frequency of head-on
- \(N_{a\text{ Overtaking}}\) = Frequency of overtaking
- \(N_{a\text{ Crossing}}\) = Frequency of crossing

\[
N_a = 0.099598156 \text{ acc/year} + 0.257769798 \text{ acc/year} + 0.011408954 \text{ acc/year} + 0.368776908 \text{ accident/year}
\]

### Table 5. Probability Index

| Probability Index | Frequency | Definition                              |
|-------------------|-----------|-----------------------------------------|
| Frequent          | > 0.5     | Will occur frequently                   |
| Probable          | 0.5-0.05  | May occur several times                 |
| Occasional        | 0.05-0.005| Likely to occur during lifetime         |
| Remote            | 0.005-0.0005| Unlikely to occur during lifetime    |
| Improbable        | < 0.0005  | Event so unlikely, may never be experience |

Based on the probability index, the frequency of ship collision in Surabaya West Access Channel is classified as probable.
2.2.2. Consequence of Ship Collision

The consequences of ship collisions can be classified into three groups, namely: loss of life or injuries, damage to property, environmental [6]. In determining the consequences of a ship collision (C), this paper focuses on the consequences of damage to property that is ships involved in the incident. Ansys software was used to model the structural damage of hull caused by the incident. A critical factor of structure damage is the transferred energy that depends on lost of kinetic energy and mass of two ships involved.

The transferred energy can be expressed as:

\[ E_{t2} = E_t \cdot \left( \frac{1}{1 + m_1/m_2} \right) \]  
\[ E_t = \frac{m_1 \cdot m_2 (1 + C_h)}{2(m_1 + m_2(1 + C_h))} \cdot (v_1 \cdot \sin \alpha)^2 \]

Where,
- \( E_{t2} \) = Transferred energy
- \( E_t \) = Lost of kinetic energy
- \( m_1 \) = The striking ship’s mass
- \( m_2 \) = The struck ship’s mass
- \( v_1 \) = The striking ship’s speed
- \( \sin \alpha \) = Angle to the struck ship
- \( C_h \) = Mass coefficient

Zhang has made a reassessment of the added mass coefficient \((C_h)\) in the basis of recent investigation and proposes. In this paper, assuming that struck ship subject to yaw condition and we can assume an added mass coefficient \((C_h)\) of 0.21.

Table 6. Added Mass Coefficient

| Motion mode | Added mass coefficient \((Ch)\) Range | Proposed |
|-------------|--------------------------------------|-----------|
| Surge       | 0.02-0.07                            | 0.05      |
| Sway        | 0.4-1.3                              | 0.85      |
| Yaw         | 0.21                                 | 0.21      |

Table 7. The Scenario of Overtaking Collision

| Striking Ship  | Struck Ship  |
|----------------|--------------|
| BELAJA         | EVER BLINK   |
| L = 200 m     | L = 211 m    |
| B = 32 m      | B = 33 m     |
| D = 8.3 m     | D = 9.4 m    |
| V = 11.8 knot | V = 12.4 knot|
| Type = Bulk Carrier | Type = Container |
| IMO = 9873280 | IMO = 9790098 |

2.2.2.1. Transferred Energy

\[ E_t = \frac{61352 \cdot 36972(1 + 0.21)}{2(61352 + 36972(1 + 0.21))} \cdot (5.97 \cdot \sin 10)^2 \]
\[ = 13.9 MJ \]  
\[ E_{t2} = E_t \times \left( \frac{1}{1 + m_1/m_2} \right) \]
2.2.2.2. Finite Element Analysis of Ship Collision
Structure damage is analyzed by using Ansys explicit dynamics analysis. The initial condition is determined to analyze the consequence of ship collision. Overtaking ship collision scenario is chosen because has the highest frequency. Overtaking is a conflict between two vessels that sail in the same direction and route, but have different velocity and also the angel of two vessels involved should not exceed 22.5° [5]. The initial condition with velocity is 6.070444 m/s and for hydrostatic pressure: acceleration is 9.81 m/s² and density is 1.025 kg/m³.

\[
\begin{align*}
\text{energy} & = 13.9 \times 0.38 \\
& = 5.23 \text{ MJ}
\end{align*}
\]

Figure 3. Total Deformation of Striking Ship

Figure 3 shows the results of total deformation of the striking ship using Ansys explicit dynamics analysis produces the following data: deformation maximum is 4.7439 m and deformation minimum is 4.2497 m.

Figure 4. Total Deformation of Struck Ship

Figure 4 shows the results of total deformation of the struck ship using Ansys explicit dynamics analysis produces the following data: deformation maximum is 1.6801 m and deformation minimum is 0 m.

2.2.2.3. Repair Cost Calculation
Total area of hull damage of the ships that involved in overtaking scenario according to simulation using Ansys is about 21.98 m². The repair cost must be calculated to determine total loss cost caused by ship collision because it gives impact for company’s profit and operational time. The total repair cost can be expressed as:

\[
\text{Total Repair Cost} = \text{Material Cost} + \text{Employment Cost}
\]
In this paper, material cost is including the cost for replating, sandblasting, and coating. Material cost for repair is about IDR 42,384,715.00 and employment cost is about IDR 8,627,837.00, so total cost for repair is IDR 51,012,553.00. Based on table 8, the consequence of ship collision in Surabaya West Access Channel (SWAC) is classified as minor.

**Table 8. Consequence Index**

| Consequence categories | Loss Cost  |
|------------------------|------------|
| Insignificant          | < $ 1,000  |
| Minor                  | < $ 10,000 |
| Moderate               | < $ 100,000|
| Major                  | < $ 1,000,000|
| Catastrophic           | >= $ 1,000,000|

2.2.3. Risk Representative

To rank in the risk index, we then needed to define frequency and consequences through a logarithmic scale. In this research, the risk index obtained based on AN/NZS 4360:1999 risk matrix.

**Table 9.** The conclusion for this risk representative, the frequency which is classified as probable, and the consequence which is classified as minor, the risk for ship collision in Surabaya West Access Channel is high. The high-risk area must be mitigating to prevent the accident.

| Risk Matrix | Consequence |
|-------------|-------------|
| Insignificant | Minor | Moderate | Major | Catastrophic |
| Frequent     | H     | H     | E     | E     | E     |
| Probable     | M     | H     | H     | E     | E     |
| Occasional   | L     | M     | H     | E     | E     |
| Remote       | L     | L     | M     | H     | E     |
| Improbable   | L     | L     | M     | H     | H     |

Where:
- L: Low
- M: Moderate
- H: High
- E: Extreme

2.3. Risk Control Option

In essence, the purpose of the RCO is to obtain the most effective solution for all sides, effective for the most frequent accidents, and effective for other parts of the incident. The RCO can then be considered based on the reduced chances of a series of accident events that most often occur, and increases the chance of zero accidents in maritime world program.
Table 10. Risk Control Options are made from factors that influence the frequency of ship collision. These factors are here separated into three main groups: waterway system, vessel, and human factor.[7]

| RCO | Factor            | Causes                  | Safety Measure to reduce risk                                      |
|-----|-------------------|-------------------------|---------------------------------------------------------------------|
| 1   | Waterway System   | High ship density       | Width revitalization of Surabaya West Access Channel from 150 m to 200 m |
| 2   | Vessel            | Unsafe speed            | Speed limit                                                         |
| 3   | Human Factor      | Fatigue and unfit condition | Medical check for all crews on board before unmooring operation     |
|     |                   | Alcohol                 | Breath alcohol test for all crews on board before unmooring operation |

2.4. Cost-Benefit Assessment
Based on the guidelines for Formal Safety Assessment from IMO, estimating the cost-effectiveness of risk reduction measures are NCAF and GCAF.[1]

Gross Cost of Averting a Fatality (Gross CAF):

\[
GCAF = \frac{\Delta C}{\Delta R}
\]  \hspace{1cm} (12)

Net Cost of Averting a Fatality (Net CAF):

\[
NCAF = \frac{\Delta C - \Delta B}{\Delta R}
\]  \hspace{1cm} (13)

Where:

\[\Delta C\] = Expected cost of the RCO

\[\Delta B\] = Expected benefit of the RCO

\[\Delta R\] = Reduces the risk

Table 11. Cost Benefit Assessment

| RCO | \(\Delta R\) | \(\Delta C\) (Sm) | \(\Delta B\) (Sm) | \(\Delta C - \Delta B\) (Sm) | GCAF (Sm) | NCAF (Sm) |
|-----|--------------|------------------|------------------|-----------------------------|-----------|-----------|
| 1   | 0.089377     | 963.36           | 984.77           | -21.412                     | 10778.6   | -239,565829 |
| 2   | 0.244015     | 0.0065           | 0.0079           | -0.0014                     | 0.02678   | -0.00579395 |
| 3   | 0.118009     | 0.0457           | 0.0100           | 0.0357                      | 0.38729   | 0.302553  |

2.5. Recommendation
The final step of formal safety assessment is giving recommendations based on analysis of formal safety assessment from steps 1–4 to the stakeholder for safety improvement. From Cost-Benefit Assessment criteria, there are some recommendations as follows:

1. Width revitalization of Surabaya West Access Channel from 150 m to 200 m. The benefit from revitalization is not only to reduce ship collision frequency of 0.089377 accident/year but also can increase the profit from pilotage of 33%.

2. Implementation of speed limit can reduce frequency 0.244015 accident/year. The benefit from speed limit is not only to reduce the frequency of ship collision but also reduce ship’s fuel oil consumption and \(\text{SO}_x\), \(\text{NO}_x\) emissions from exhaust.
3. Conclusion

Based on historical accident data, hazard analysis of ship collision in Surabaya West Access Channel are problems in main engine overheating, ship control error, technical failure, external factor, other ship errors occur in the process of navigation, environmental conditions, and human error [2]. The scenario used to calculate the collision frequency of ships is head-on, overtaking, and crossing with the total frequency of all scenarios is 0.368776908 accident/year. The estimated loss cost for repair caused by the accident is IDR 51,012,553.00. Risk representative from frequency and consequence of ship collision is classified at high risk. The high-risk area must be mitigating to prevent the accident. Risk Control Options are made from factors that influence the frequency of ship collision. These factors are here separated into three main groups: waterway system, vessel, and human factor. After estimating the cost-effectiveness of risk reduction, the results of Cost-Benefit Assessment are RCO 1 can reduce ship collision frequency of 0.089377 accident/year with Net Cost of Averting a Fatality (NCAF) about -239,565829 ($m), RCO 2 can reduce ship collision frequency 0.244015 accident/year with Net Cost of Averting a Fatality (NCAF) about -0.00579395, RCO 3 can reduce ship collision frequency 0.118009 accident/year with Net Cost of Averting a Fatality (NCAF) about 0.302553 ($m). The final step of formal safety assessment is giving recommendations for safety measures to reduce risk. From Cost-benefit Assessment criteria, the chosen RCOs are width revitalization of from 150 m to 200 m and implementation of speed limit.

Acknowledgments

We want to thank to Vessel Traffic Service (VTS) Surabaya, Kesyaibandaran Kelas Utama Tanjung Perak Surabaya, who helped, supported, and guided during the making of this research.

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