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SHIP COLLISION FREQUENCY DURING PIPELINE DECOMMISSIONING PROCESS ON SURABAYA WEST ACCESS CHANNEL (SWAC)

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Abstract

Surabaya West Access Channel (SWAC), which located in Madura Strait, is one of the busiest shipping channels in Indonesia with the depth about - 9m LWS and width 100 m. Due to the shallow and narrow waterways, the large vessels with deeper draft cannot pass the channel. Therefore, Indonesia Port Corporation plans to revitalize the channel to accommodate the larger vessels for passing the channel. Thus, the cost of logistics is reduced and the number of cargo increases. The shipping channel will be deepened to -13 m LWS and widened to 150 m. If dredging is done, the pipeline will be exposed to the seabed. Hence, the revitalization project cannot be conducted until subsea pipelines removal in the shipping channel is completed. Moreover, according to Minister of Energy and Mineral Resources Indonesia, if the off-shore installation included pipeline is not used anymore then they must be decommissioned. Pipeline decommissioning may cause unavoidable hazards such as ships collision between pipelay vessel and passing vessel. Hence, this study has two main objectives of selecting the best method of pipeline removal and determining the frequency of ships collision. The two alternative methods of pipeline removal offered are reverse S-lay and cut and lift. The selection was carried out using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) then verified by performing Analytic Hierarchy Process (AHP) method, while the collision frequency was calculated using CRASH Model and compared by using SAMSON Model. TOPSIS selected Reverse S-Lay as a better method for pipeline decommissioning. The result frequency assessment showed that the number is less than unity (1) for both collision scenarios in those two models, therefore, it can be concluded that the risks due to ship collisions are acceptable.

Keywords: CRASH model, Decommissioning, Pipeline SAMSON model, Ship Collision, TOPSIS.

1. Introduction

There are various ways to distribute natural gas, which conducted by the oil company in many countries. One of the most effective ways is using the gas pipeline to transport natural gas in very large quantities and long distances, whether by onshore or offshore pipeline.

In recent years, there are abandoned export gas pipeline transporting processed gas from the production platform to the power plant for fulfilling the electricity needs in Gresik area. The pipeline is crossing in Kilometre Point (KP) 44-46, Surabaya West Access Channel (SWAC) in Madura Straits as shown in Fig. 1, where the pipeline indicated by the red line is located in the crossing II as inside the box.

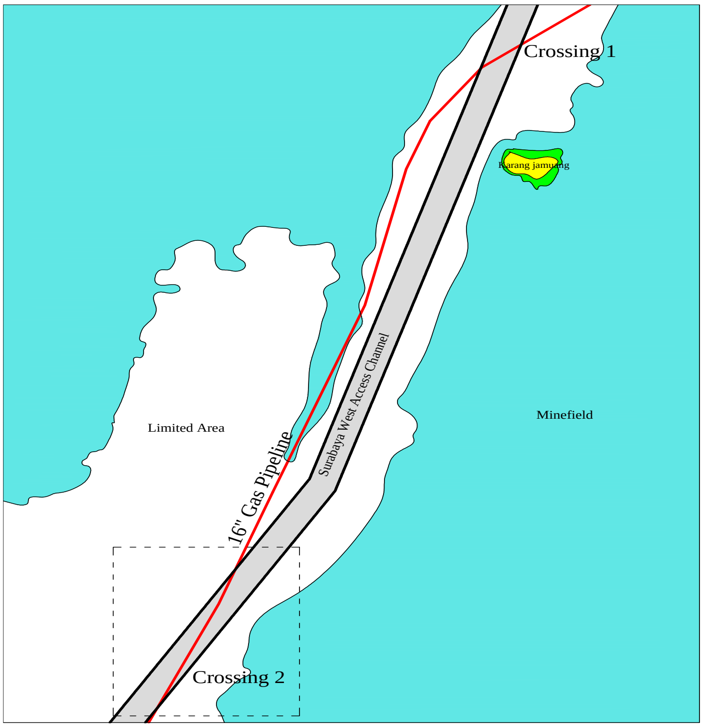

Fig. 1. Location of abandoned pipeline in Crossing II, Surabaya West Access Channel.

According to Minister of Energy and Mineral Resources Regulation of Indonesia in 2011, if the offshore installation included pipeline is not used anymore then they must be removed, or it called decommissioning.

In addition, due to Indonesia Port Corporation's revitalization plan in SWAC by deepening the lane become -13 m LWS and widen into 150 m, the pipeline should be removed. The pipeline has been buried at a depth of minus 2 - 2.3 meters below the seabed. According to the previous analysis, it stated that when the dredging process is conducted, the pipeline could arise to the seabed surface. Hence, the pipeline should be decommissioned.

The activity of pipeline decommissioning near the shipping lane with high traffic density could potentially arise the danger to safety against marine traffic. One of the potential hazards is ship collision between a vessel operated for pipeline decommissioning and passing vessel in the shipping lane. Therefore, the risk assessment should be performed to describe safety during the decommissioning process.

Safety describes the degree of freedom from danger. The safety of an activity or a system can be evaluated using the concept of risk. The risk is normally defined by two important parameters, namely the probability of occurrence of the undesired event, i.e., ship collision and consequence [1]. However, the definition of risk in a particular application can be categorised into several classifications. One category defines risk the probability of an undesirable event [2]. This study concerns about undesirable events that may arise due to pipeline decommissioning activity against ships traffic. Hence, the frequency that represents the likelihood of undesired events occur is used to evaluate the risk of ship collision during the activity of pipeline decommissioning in this study.

In this study, analysis for ship collision frequency during the pipeline decommissioning process is affected by selected pipeline removal method such as the duration of the working process, technical work, the position of operating ship and others. The selection of pipeline decommissioning should be conducted first, therefore, the scenario of ship collision during the process can be developed.

In choosing the best pipeline decommissioning method, it is necessary to utilize multi-criteria decision-making called Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP). As mentioned before that scenario of collision and the frequency assessment highly depend on the decommissioning method. TOPSIS and AHP are the MCDM method to determine the best alternative among available options. In addition, TOPSIS has a major weakness that TOPSIS does not provide the weight of elicitation and consistency checking for judgement [3], while AHP provides the pairwise comparison in calculating the weight and inconsistency checking of judgement in the ranking result. Hence, the utilization of TOPSIS and AHP can ensure that the chosen method is truly the most appropriate one.

The selected method effects the hazards that may occur during the decommissioning process and the duration for conducting the decommissioning process. The longer time to complete the activity, the greater number of vessels passing through the channel. The number of vessels is the most important variable in frequency assessment. In addition, the involved vessels in pipeline decommissioning process depend on the selected decommissioning method.

The rest of the article has arranged as follows: Section 3 presents the selection of pipeline decommissioning method using the TOPSIS method. AHP is also performed in this section as a comparative evaluation to reach a scientific and sufficiently justified solution. Section 4 describes scenario development for ship collision according to selected pipeline decommissioning methods. Section 5 shows the calculation of the ship collision frequency in the form of powered collision or ramming collision and drifting collision using CRASH model and SAMSON model. Lastly, Section 6 explains about analysis of comparative methods between those two models and finally, Section 7 presents the conclusion.

2. Previous Study

When a subsea pipeline is no longer needed for commercial purposed, it has to be made for its abandonment. The owner of the pipeline or other related parties has the responsibility to take an action, whether not taking any action or leaving the pipeline in place to decay, to fully removing, cleaning it or even recovering it to be reused [4]. This study is focused on the pipeline in accordance with Indonesia government regulations about offshore facilities that have not been used anymore should be decommissioned. The previous study presented comparative assessment methods to determine preferred options in pipeline decommissioning. The options offered commonly are reverse S-lay and cut and lift. The TOPSIS method will be applied to choose the best alternative for pipeline decommissioning between reverse S-lay and cut and lift.

3. Pipeline Decommissioning Methods

Two decommissioning options for the abandoned pipeline were reverse S-Lay and cut and lift. Reverse S-lay is a method that involves a pipeline S-lay vessel to pull the pipeline into the vessel deck. The pipeline will cut into the section in the vessel deck then it transports to onshore [5].

Another method is cut and lift, which the pipeline is fully cut into the section on the seabed using diver-operated cutting tools or using remotely operated cutting equipment. The shorter section pipelines are lifted to the water surface using a crane from the support vessel and stored in a cargo barge then they are brought to onshore [5, 6]. Selection of pipeline decommission methods conducted based on criteria as the most important component in the decision process [7]. Hierarchy of criteria consisting of sub-criteria is presented in Fig. 2. The criteria and sub-criteria are obtained and arranged from the previous relevant study. Decommissioning decisions involve considerations including safety, environment, societal, cost and technical feasibility.

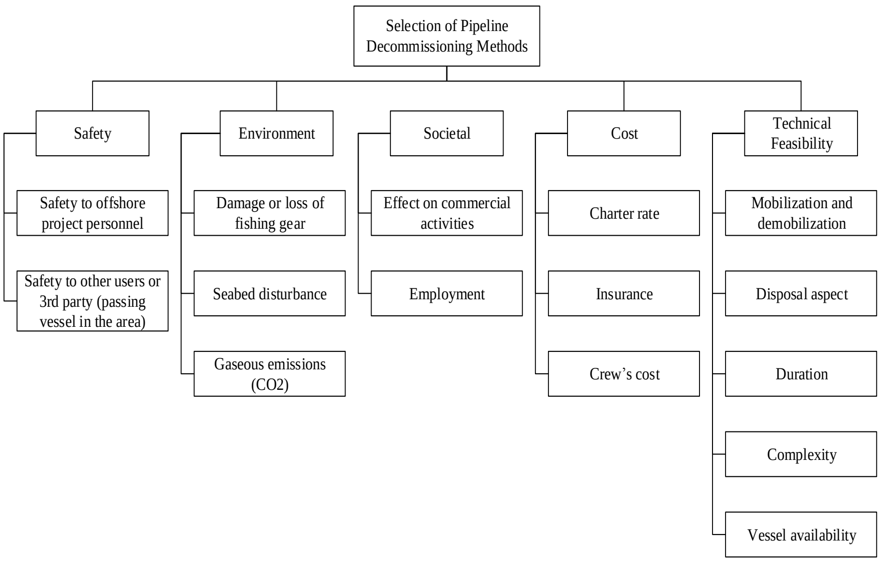

Fig. 2. Selection criteria for decommissioning decisions [8, 9].

4. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

The technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is known as one of the popular Multi-Criteria Decision Making (MCDM) method. Hwang and Yoon [10] first developed TOPSIS for solving an MCDM problem. There are the main advantages of TOPSIS method such that (1) Its simplicity, accuracy and it is relatively easy and fast, (2) It is useful for qualitative and quantitative data, (3) TOPSIS provides simple mathematical calculation to measure the relative performance for each alternative and (4) The output presents the preferential ranking based on both negative and positive criteria [3, 11].

Because of those numerous advantages, TOPSIS has been growing become the most satisfactory method to help select the best alternative with a finite number of criteria among numerous MCDM methods. TOPSIS is implemented in many different fields and specific sub-areas but the most popular topic in TOPSIS applications is Supply Chain Management and Logistics [12]. Behzadian et al. [12] present in their study about state-of-the-art literature on TOPSIS applications that TOPSIS is used to solve the supplier selection, transportation, and location problem in Supply chain and logistics management field.

In the field of risk assessment itself, TOPSIS has been adopted to identify the risk value of identified hazards and prioritize the potential risks [13]. TOPSIS is modified with a fuzzy approach that can be used to deal with the uncertainties including risk factors. The risk ranking of identified hazards from the proposed methods is expected to be more accurate and help assessors to prioritize the risky hazards in the industry [13]. In the maritime industry, the fuzzy TOPSIS is applied to evaluate the risk factors based on failure mode to obtain more accurate risk ranking of many risk component in international trade ports [14].

Moreover, TOPSIS help to solve decision problems in the shipping industry and marine transportation. Emovon [15] used TOPSIS to prioritize the maintenance strategy for ship systems by integrating with the Delphi method and AHP. The optimum solution can be given by the proposed method. It has also been validated by another hybrid MCDM called AHP-PROMETHEE and it presents less computationally intensive. The effectiveness of AHP-TOPSIS is also used for reliability assessment in Marine LNG-Diesel Dual Fuel Engine and select the best solution among all risk control options (RCOs) [16].

The main concept of TOPSIS is choosing the best alternative, which has the shortest distance from the positive ideal solution and the farthest distance of the negative ideal solution [17]. The procedure of TOPSIS is explained as following steps in Eqs. (1) to (7) [18]:

- Calculate the normalized decision matrix in Eq. (1):

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}, i = 1, 2, 3, ..., m; \; j = 1, 2, ..., n \quad (1)$$

- Compute the weighted normalized decision matrix. The weighted normalized value (z_{ij}) is calculated as:

$$z_{ij} = w_i y_{ij}, i = 1, 2, ..., m; \; j = 1, 2, ..., n \quad (2)$$

- Determine the positive ideal solution (PIS) and the negative ideal solution (NIS) as:

$$PIS = \left\{ z_1^+, .., z_2^+, .., z_n^+ \right\} = \underset{\forall i}{\min} z_{ij} \left| j \in j_2 \right\} \tag{3}$$

and

$$NIS = \left\{ z_1^-, .., z_2^-, .., z_n^- \right\} = \underset{\forall i}{\max} z_{ij} \left| j \in j_2 \right\} \tag{4}$$

Here, J_1 is the set of benefit criteria, and J_2 is the set of cost criteria.

- Calculate the separation measures using the n-dimensional Euclidean distance. The separation of an alternative a_i from the PIS and similarly, the separation of an alternative a_i from the NIS is given as:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} = \left(z_{ij} - z_j^+ \right)^2}, i = 1, 2, .., n \tag{5}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} = \left(z_{ij} - z_j^- \right)^2}, i = 1, 2, .., n \tag{6}$$

- Calculate the ranking index, namely the relative closeness of the alternative a_i with respect to the PIS. The ranking index of alternative a_i is defined as:

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{7}$$

Sometimes, RC_i is called the overall or composite performance score of alternative a_i. Here in after, this index is denoted as ranking index 0.

- Arrange the ranking indexes in *a* descending order to obtain the best alternative.

5. Collision Frequency Models

Collision frequency calculations carried out in this study are CRASH (Computerized Risk Assessment of Shipping Hazards) model then compared with SAMSON model. Spouge [19] proposed a CRASH model in which, is originally used to estimate collision frequency between ship and platform. However, this paper implemented the model to perform the number of collisions between passing vessel against the object that is a diving support vessel, not a platform. Here is a little modification is made.

Therefore, the comparison method between CRASH model and another method (SAMSON model) is required to verify that the proposed method provides the result that can describe the collision frequency during the concerned activity. Otherwise, the aim of the comparison method between CRASH model and SAMSON is to ensure that although the model used is different, but the value of collision frequency is less than one. It means that the collision risk still lays at an acceptable level. Those two models are described briefly in the following descriptions.

5.1. CRASH (computerized risk assessment of shipping hazards) model

The vessel collision frequency is greatly affected by shipping traffic in the area around the object (e.g., platform). The main elements of the model are:

- A database of shipping traffic data.
- A model of powered collisions.

• A model of drifting collisions.

5.1.1. Powered vessel collision

The CRASH model performed by DNV Technica originally estimates the expected frequency of collisions between ships and offshore installation. Then it is adopted in this study to calculate the frequency of ship collision between passing vessel and vessel that operated for decommissioning. The CRASH model uses a database of a merchant's vessel in shipping lanes to estimate the passing vessel traffic for a certain location in the study. Some aspects are considered in this model such as vessel type, watch keeping failure modes, visibility and weather distributions for the area, failure alerting of the standby vessel [19].

The CRASH models assume that the collision frequency is proportional to the number of ships passing the object. In CRASH, the number of collision frequency per year is calculated for each shipping lane, which passes the object as Eq. (8) [19]:

$$F_{CP} = N \times F_d \times P_1 \times P_2 \times P_3 \tag{8}$$

Frequency of powered passing vessel collisions (per year) is proportional to total traffic in the lane (*N*) and proportion of vessels that are in the part of the lane directed towards the object (*Fd*) as shown in Fig. 3. Accident will occur if three causation happens including probability that the passage planning stage of the voyage was not carried out successfully (P_1), probability that the vessel suffers a watchkeeping failure (P_2) and probability that the platform or stand-by vessel fails to alert the ship in time to prevent a collision (P_3) [19].

The collision diameter is defined as the width of that part of the shipping lane cross section from, which the ship would hit the platform unless it changed course [19].

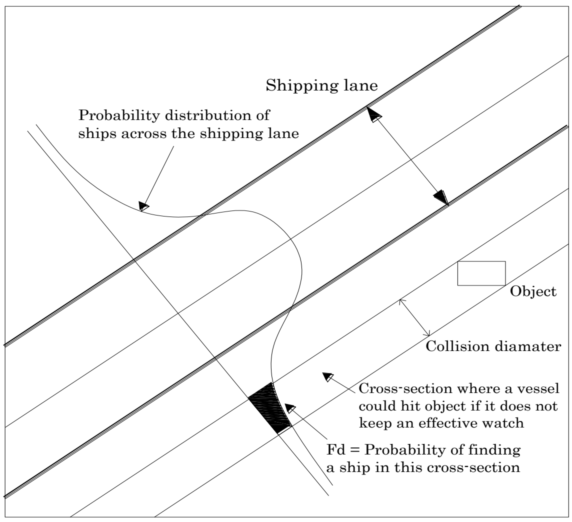

Fig. 3. Powered collision geometry [19].

5.1.2. Drifting vessel collision

A ship will start to drift and collide the object if the following conditions occur [19]:

- The vessel has a breakdown in its propulsion system (P_b).
- Wind direction leads to the object that makes the vessel drift towards it (P_w).
- Failed attempts to tow the vessel away
- The vessel is unsuccessful to repair itself before reaching the object

The frequency of the drifting collision can be calculated by dividing the parts of the shipping lanes, which close to the object into a small box (see Fig. 4).

The frequency can be calculated on each vessel in the box and drift to the object by Eq. (9):

$$F_{CD} = N \times P_b \times P_w \times D/BL \tag{9}$$

The number of drifting vessels is directly proportional due to a number of ships passing the shipping lane (*N*). *D* is the collision diameter, which means that it is the width to be considered for the vessel would hit the object by combining the size of the vessel and object. *BL* is box length perpendicular to the wind direction.

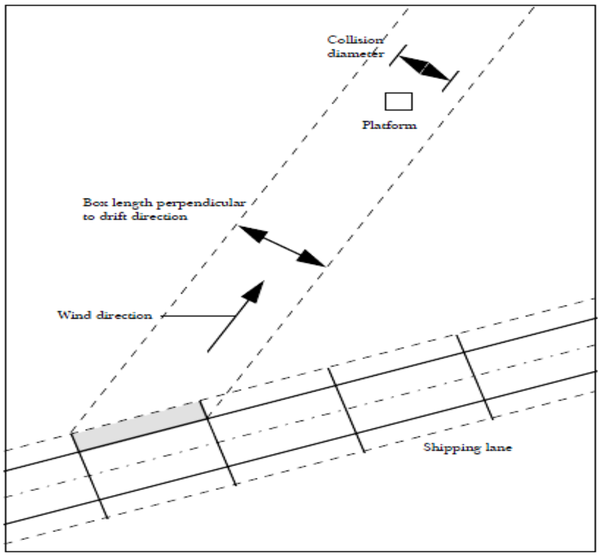

Fig. 4. Drifting collision geometry [19].

5.2. Safety assessment models for shipping and offshore in north sea (SAMSON)

Another model conducted in this study to assess the ship collision is based on Safety Assessment Models for Shipping and Offshore in the North Sea (SAMSON) by MARIN (Maritime Research Institute Netherlands). Two models are developed to determining the risk of ship collision, which describes different causes. Two models are:

5.2.1. Ramming Collision

Ramming collision involving the ships with an object occurs because of a navigational or human error. Here are the steps in determining ramming collision [20]:

- **Danger part**

The first step of this model is determining the danger part of a link. The danger part is the part of a link, which ship will ram an object due to a navigational error in different course angle. A ship whether will actually hit an object or not depends on the distance between the point of a link the errors occur and the object is called the ramming distance.

For ramming model, it is assumed that when a navigational error occurs, the ship will move in seven different course change angles, from -30^0 to 30^0 in every 10^0 difference angle. It is given in Fig. 5. Every course change angle has different probability, i.e., 0.05, 0.1, 0.2, 0.3, 0.2, 0.1 and 0.05.

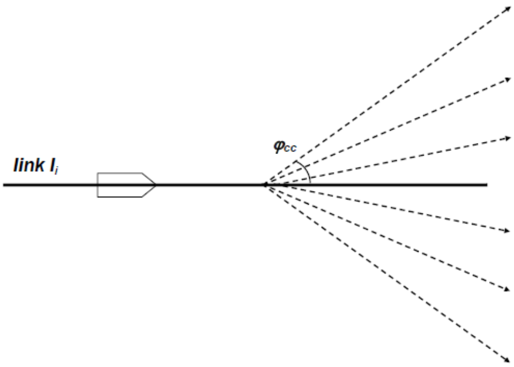

Fig. 5. Seven different ram-direction [20].

- **Avoidance function**

Avoidance function in ramming model is defined as the time that still possible for the ship to avoid the collision since the error is detected. Whether or not the ship can avoid the collision depends on the length of the ship (*L*) and the ramming distance (*r*). The probability of failed avoidance for the large ship will higher than smaller vessels because large ships need more time to change their course. The probability of hitting the object can be calculated as follow with *a* (dimensionless) is danger measure (default value 0.1).

$$P_{HIT}\left(r,L\right)=e^{-a\frac{r}{L}} \quad (10)$$

By multiplying P_{HIT} with a number of the ships (*N*) passing the lane and the probability of the ships hit the object due to a navigational error in φ direction (P_{RAM}), therefore, the ramming opportunities (*RO*) is:

$$RO=P_{RAM}\times N\times e^{-a\frac{r}{L}} \quad (11)$$

The last step for obtaining the number of ships ramming the object is calculated by multiplying the ramming opportunities (*RO*) and navigational error rate ($NER = 0.65 \times 10^{-4}$ for each ship).

$$N_{ram} = NER \times RO \tag{12}$$

5.2.2. Drifting collision

Drifting collision is an event that the crew on board cannot stop the ships when the ship loses power and starts drifting. The ship with engine failure can drifting in a direction with certain drift velocity depending on the environmental conditions (wind speed and current). The ship will drift against the object if the ship cannot repair the engine failure during the remaining drifting time. Here are several steps to determine the number of ship drift and hit the object [21]:

- **Determine the danger part of the link**

The first step is to determine in which, part of the link where the ship has an engine failure and starts to drift against the object according to wind direction (drift direction). The part of the link is called a danger part (see Fig. 6). The distance between the ship and the object ($r(x)$) is affected to drifting time after the drift velocity was obtained.

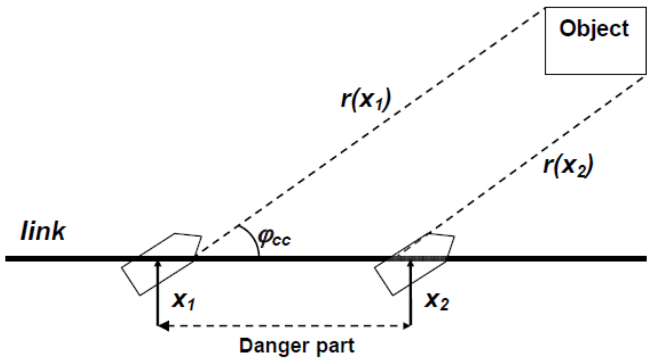

Fig. 6. Danger part [21].

- **Drifting distance and velocity**

Drifting distance is a distance from all positions on the danger part of the link to the object. A ship will only drift against the object if the time for repair the engine failure is longer than time for the ships to drift from the link to the object. Therefore, the drift velocity is needed to be determined by the following formula. The drift velocity depends on the wind, wave and current speed.

$$v_{drift} = \sqrt{\frac{\rho_{air}}{\rho_w}\frac{A_{Lin}}{L_i T_{in}}\frac{c_{dwind}}{c_d}v_b^{\,2} + \frac{1}{8}\frac{\zeta_b^{\,2}}{T_{in}}\frac{R^2}{c_d}} \tag{13}$$

When the drifting distance and the velocity are obtained, the time for ships against the object can be determined.

- **Repair function**

The third step is to determine the probability of the ship takes larger time for repairing the engine failure than its drifting time. The repair function is a probability function for the duration of an engine failure. The repair function is defined as:

$$P_{EF}\left(t > t_s\right) = 1 \text{ for } t < 0.25 \tag{14}$$

$$P_{EF}\left(t > t_s\right) = \frac{1}{1.5\left(t_s - 0.25\right) + 1} \text{ for } t > 0.25 \tag{15}$$

When the duration of repairing the engine failure is longer, the ship will hit the object. The probability of the ship drift to the object is:

$$P_{DRIFT} = P_{EF}\left(t > t\left(x\right)\right) \tag{16}$$

- **Number of ships drift against object**

Finally, the number of ships will drift against the object is determined by multiplying the number of ships passing the lane (*N*), emergency anchor failure (P_{AF}), the probability of the ship drift to the object (P_{DRIFT}) and the probability of engine breakdown.

$$N_{DRIFT} = \sum_{l_i} N_{ship} \times P_{DRIFT} \times P_{AF} P_{enginebreakdown} \tag{17}$$

6. Result and Discussion

After performing the research methods, the results of pipeline decommissioning method selection and the calculation of collision frequency are obtained as follows:

6.1. Selected pipeline decommissioning method

In the TOPSIS method, there are criteria that each criterion consists of several sub-criteria. Assessment of relative importance and preference values between criteria and sub-criteria obtained from questionnaires filled by respondents who expert in the related field. The weighting of criteria and sub-criteria are assessed using pairwise comparison. Fig**. 7** shows the result of weights for all criteria.

By performing TOPSIS calculation steps, the selected method is reverse S-Lay with a value of 0.61 while cut and lift is only 0.39. The results of this calculation can be seen in Fig. 8. To verify the results obtained from TOPSIS, the selection of pipeline decommissioning methods is also performed by AHP (Analytical Hierarchy Process) using Expert Choice software. Fig. **9** shows that based on AHP, the selected pipeline removal method is Reverse S-Lay with the value of 0.5452 (54.5%). The results of TOPSIS and AHP give the same result namely reverse S-Lay as the chosen method through the given value is different.

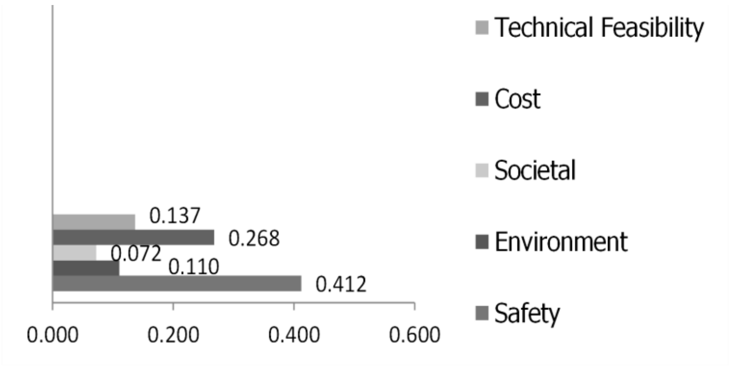

Fig. 7. Weight of all criteria.

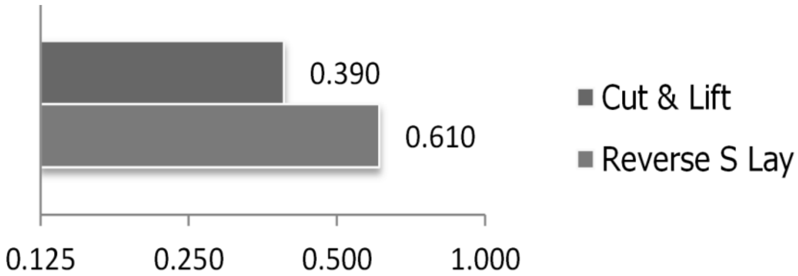

Fig. 8. Selection result of pipeline decommissioning method by TOPSIS.

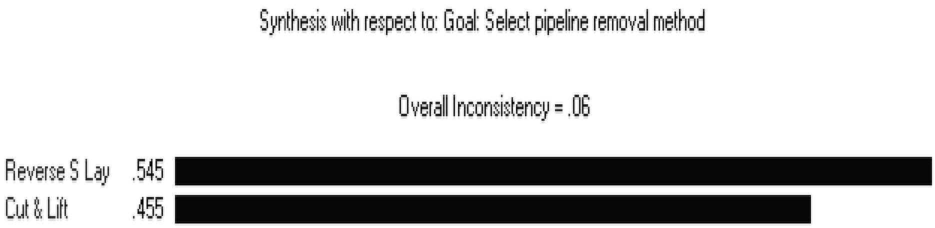

Fig. 9. Selection result of pipeline decommissioning method by AHP.

6.2. Development of pipeline decommissioning scenarios

The selected pipeline removal method based on TOPSIS and AHP is reverse S-lay. Reverse S-lay method involved diving support vessel (DSV) to pull and cut the pipeline section, and pipelay barge to transport it to shore. Based on several options, pipelay vessel and DSV, which used in this study have specifications as in Table 1.

The scenario for the pipeline decommissioning process can be seen in Fig. 10, where the DSV will cut the pipe in every 200 meters, while pipelay barge remains near the shipping lane during the process such as for pipeline cutting, preparation decommissioning and exposing the pipeline.

The estimated duration of working for pipeline decommissioning process of 2900 meters length is approximately 215 hours. If the work only needs 10 hours per day then it takes 22 days until the whole pipeline is finished to be moved [22].

Table 1. Pipelay barge and diving support vessel specifications.

Pipelay barge		**Diving support vessel**	
Length	= 85.34 m	**Length**	= 77 m
Breadth	= 24.38 m	**Breadth**	= 20.4 m
Draught	= 5.5 m	**Draught**	= 8 m
Tension capacity	= 30 ton	**DP 2 dynamic positioning system**	
Class/flag	= GL/Indonesia		

6.3. Frequency of powered vessel collision with CRASH model

As shown in Fig. 10, the potential hazard of passing vessel collision may towards to DSV in the lane or pipelay barge near the outer of the lane. The assessment of ship collision frequency is applied for those two objects.

The frequency of ship collisions with DSV on all segments will be calculated for all ships entering and leaving the lane, while pipelay vessel in this scenario only in one position.

Based on DSV position segmentation and location of pipelay vessel, the number of vessels, the proportion of vessels in the shipping lane leading to the object are included in the calculation as shown in Table 2.

Causation probability for powered vessel collision in the CRASH model is conducted by using Fault Tree Analysis with three main major causes; human error, failure voyage and failure alerting (Fig. 11).

Collision will happen when all causation factors occurred. The probability of all causations is obtained from the literature. By summing the cumulative frequency calculation results of ship collision powered collision for DSV and pipelay then the cumulative frequency is obtained, with the value of 0.1996.

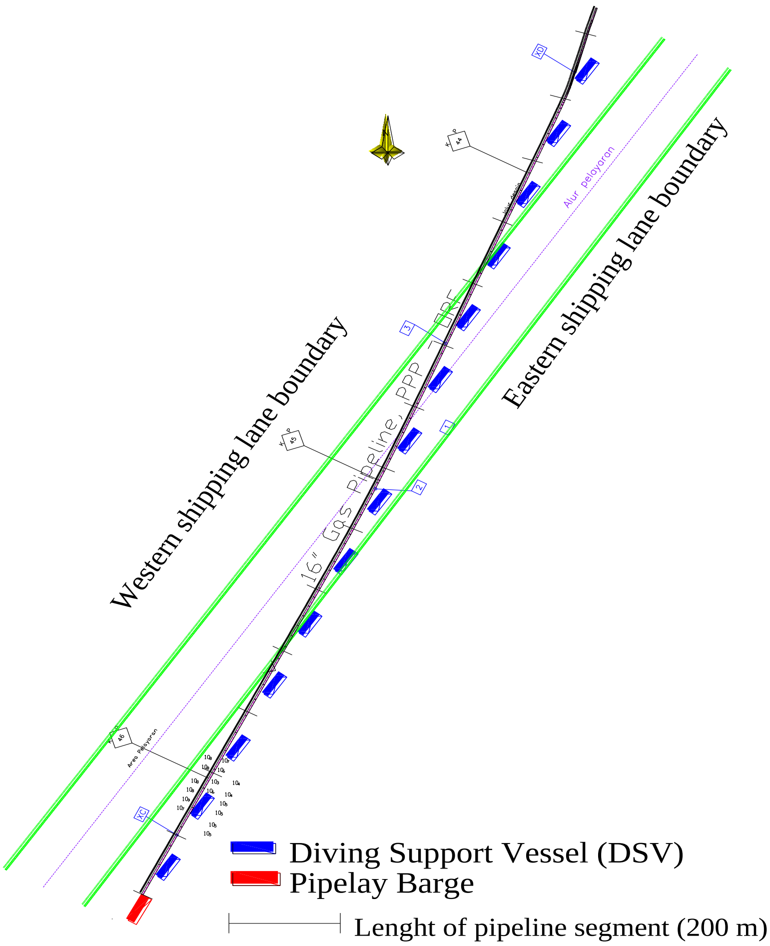

Fig. 10. Pipeline decommissioning scenarios.

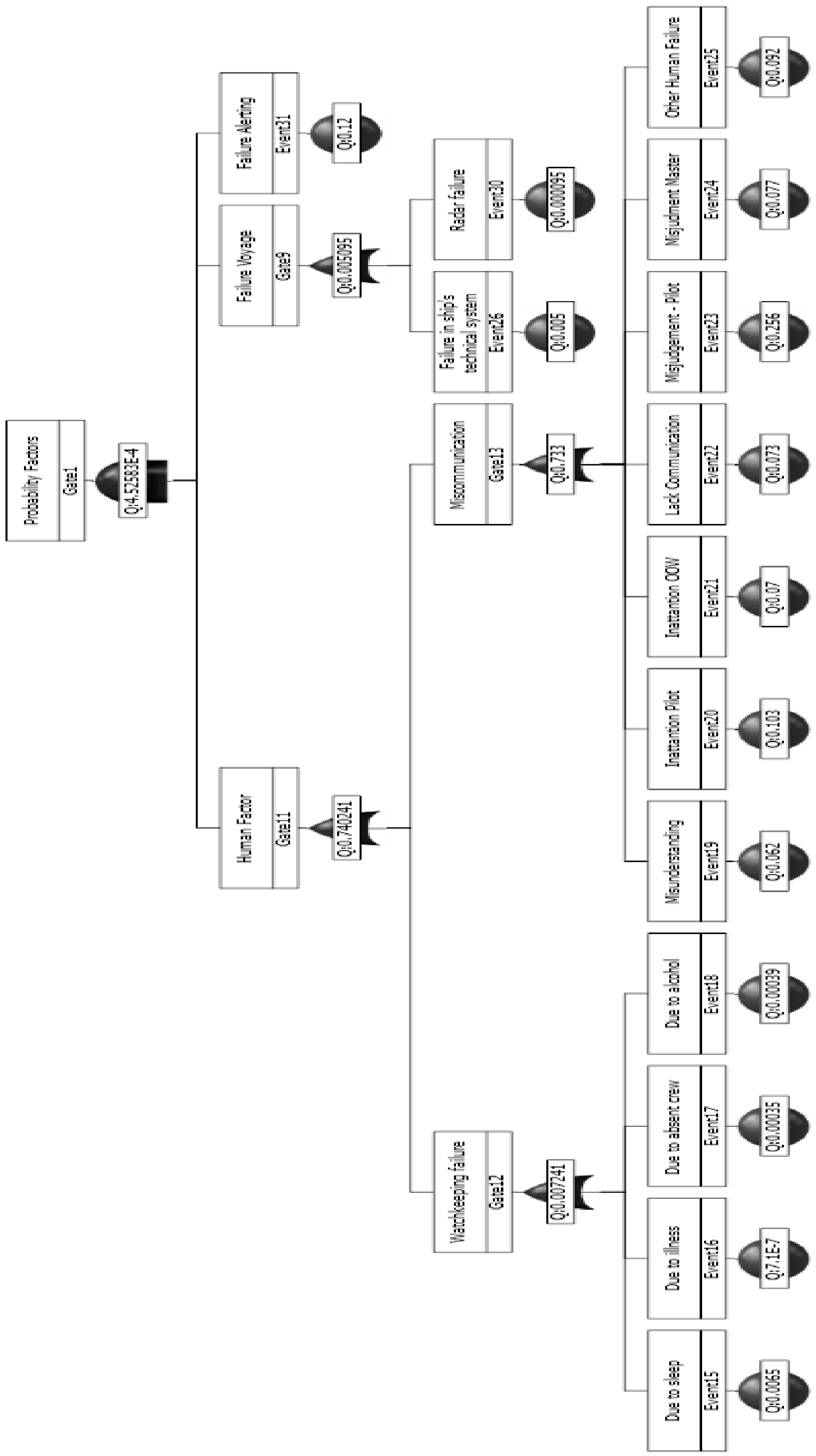

Fig. 11. Causation probability for powered vessel collision [1, 19, 23].

Table 2. Summary of frequency collision with DSV in all segmentations and pipelay barge.

Segment	Number of vessels (N)	F_d	F_d	$P1 \times P2 \times P3$	Collision frequency	Collision frequency
Segment 1	6	0.000	0.007	0.000453	0.000000	0.000020
Segment 2	6	0.000	0.054	0.000453	0.000000	0.000146
Segment 3	6	0.000	0.202	0.000453	0.000000	0.000548
Segment 4	6	0.002	0.817	0.000453	0.000004	0.002216
Segment 5	6	0.013	2.406	0.000453	0.000036	0.006526
Segment 6	6	0.087	5.170	0.000453	0.000235	0.014024
Segment 7	6	0.430	8.577	0.000453	0.001165	0.023268
Segment 8	6	2.215	9.652	0.000453	0.006010	0.026183
Segment 9	6	6.204	6.014	0.000453	0.016830	0.016314
Segment 10	6	9.382	1.622	0.000453	0.025451	0.004401
Segment 11	6	7.528	0.246	0.000453	0.020421	0.000667
Segment 12	6	3.049	0.021	0.000453	0.008270	0.000056
Segment 13	6	0.712	0.001	0.000453	0.001932	0.000003
Segment 14	6	0.061	0.000	0.000453	0.000167	0.000000
Segment 15	6	0.001	0.000	0.000453	0.000004	0.000000
Pipelay barge	420	0.008	0.122	0.000453	0.001538	0.023179
Frequency of powered passing collision with DSV =					0.1749	
Frequency of powered passing collision with pipelay barge =					0.0247	
Total frequency of powered passing collision =					0.1996	

6.4. Frequency of powered vessel collision with CRASH model.

Frequency drifting collision for each ship position passing in the box will be calculated entirely like in powered vessel collision calculation. The number of vessels in the box depends on the duration of the DSV and the lay barge located in a particular segment. When the ship has an engine failure, the ship will start drift in the direction 60° with the drifting speed of 3 knots. The drifting speed of 3 knots is based on several literatures, which stated that the ship drifting velocity is 3 knots for some weather conditions. Probability of breakdown in each box depends on the distance between the ship and the object that will be reached, or it's called the length of the box.

Based on calculations, the frequency of ship collisions in the form of a drifting collision on each box is different. The largest frequency is in box 1 about 0.00010589 because when there is a ship that suffered failure to the engine in that position then the ship may starts drifting and crashing into pipe lay and DSV. The cumulative frequency of ship collision with DSV and pipelay barge due to the drifting collision is 0.00011985. This result is much smaller than the frequency of a powered vessel collision.

6.5. Frequency of ramming collision with SAMSON model

Basically, the model used by MARIN and CRASH model to estimate the number of collisions is relatively the same. If in the CRASH model, the collision frequency is obtained by estimating the number of crash candidates multiplied by the causation factors, while MARIN estimated the number of collision probability is multiplied by Navigational Error Rate (NER). These models differ from one another in terms of assumptions for determining collision candidates and collision probability.

Collisions with objects (DSV or pipelay vessel) caused by navigational error can occur in every position. In this model, ship collisions due to navigation errors can cause the ship to change the direction into 7 direction ranging from -30° to 30°. After calculating the probability of the ship failed to avoid the objects, then this value multiplied by probability for the different course change angles and the number of passing vessels. A number of ramming collisions are obtained after ramming opportunity multiplied by breakdown frequency.

Based on the calculation of frequency ramming collision, the largest collision frequency occurs on the ship that changes the direction of 10^0 with a frequency value of 0.00169 for ships with DSV and 0.0058 for the ship with pipelay barge. This is due to the probability of changing direction 10^0 has the highest probability.

6.6. Frequency of drifting collision with SAMSON model

SAMSON Model and CRASH Model have many similarities, except for the assumptions of several factors such as speed drifting and emergency anchoring. The vessel will begin drifting in case of failure in the engine and there is no emergency propulsion of the main engine. The drifting speed is affected by wind, current, waves and ship characteristics such as ship size. There are several probabilities to stop the drifting vessel as if repairing the main engine with a time less than the time needed by ship to hit the object, or by successfully performing an emergency anchoring. In this SAMSON model, the speed of the ship's drift is influenced by Beaufort classes.

Based on calculations, the largest drifting frequency is in segments 3 through 11 for outgoing lane and segments 8 and 9 for the oncoming lane with the same collision frequency value of 0.0000174. This same value is due to the time required to reach the DSV less than 0.25 hours, hence, the probability of the ship failed to repair and hit the object is the same namely 1. By summing the frequency of the ship collision with DSV on all segments, the cumulative frequency is about 0.0003035. Collision frequency of pipelay barge is larger because of the duration of pipelay barge near the lane is longer. The frequency of drifting collision with pipelay is 0.001157.

In order to provide a more clear description of the result of collision frequency assessment performed by two models as presented in Table 3.

In this study, the calculation of the frequency of ship collisions during pipeline decommissioning process is performed by using two different models. Both models show the same result of collision frequency for powered collision and drifting collision, i.e., less than 1. However, it can be seen in Table 3 that powered vessel collision frequency based on the CRASH model is greater than compared to the SAMSON model. Basically, these two models have different assumptions. DNV uses causation factors that cause vessels sailing deviate from the lane.

While SAMSON model uses a value called NER (Navigational Error Rate). In addition, in SAMSON model also influenced by the opportunity of angle change. This is also affecting the results of the frequency calculation of powered vessel collision from SAMSON model becomes smaller when compared with the CRASH Model. On the other hand, the calculation of DNV is very sensitive to centreline and standard deviation. The farther the object from the centre of the lane, the frequency will be smaller. Whereas, if in MARIN, regardless of the standard deviation value does not give very different results for the frequency calculation results.

The opposite result occurs for drifting collision calculations where SAMSON frequency becomes larger when compared to the CRASH model. If in SAMSON, the assumption of drifting speeds based on Beaufort classes is greater than the assumption of drift velocity in CRASH. It does affect the time to reach the object to be faster, therefore, the possibility of collision is greater if there is engine failure on SAMSON model.

Based on the performed analysis, for making frequency assessment of powered collision, the CRASH model gives more detail in analysing the collision scenario and causation factors while the assessment process in SAMSON is only determined by navigational error rate only. Otherwise, the CRASH model has a more simple calculation than SAMSON model.

The result obtained from SAMSON model for drifting collision is assumed to have more accuracy than the CRASH model because, in the process of assessment, the environmental aspect is more considered. It can be concluded that the drift velocity depends on the wind, wave and current speed. The scenario since the ship loses power starts the drift, try to repair the engine until the ship drifts against the object are clearly described in more systematic procedures. Hence, it is expected that the assessment of collision frequency based on SAMSON model provides more accurate.

Table 3. Result of ship collision frequency performed by CRASH model and SAMSON model.

Collision frequency	QRASH model (DNV)			SAMSON model (MARIN)		
	DSV	Pipe lay vessel	F_{cum}	DSV	Pipe lay vessel	F_{cum}
Powered collision	0.175	0.025	0.1996	0.0037	0.0122	0.0159
Drifting collision		0.0001198		0.00030	0.00116	0.00146

7. Conclusions

As a risky activity, the risk of ship collision during pipeline decommissioning should be evaluated by performing the frequency assessment. Before calculating the number of ship collision frequency, the selection of the best pipeline decommissioning method is applied by using TOPSIS and AHP. The best method of pipeline decommissioning that is obtained by utilizing TOPSIS and AHP is reverse S-Lay. The scenario during the process is developed and it is obtained that the duration required during the decommissioning pipeline process is about 22 days with 15 segment pipelines. This duration affects the number of ship collision frequency. The longer duration, the greater number of vessels passing the shipping lane, therefore, the collision frequency may be higher. Based on frequency assessment both CRASH and SAMSON model, the value of collision frequency is less than 1. The results of both models indicate that the frequency is at a safe level, therefore, during the pipeline removal process does not interfere with the safety of the voyage. It is expected that the study can provide the application of multi-criteria decision-making for choosing the best pipeline decommissioning method and risk assessment model for ship collision in the case of pipeline decommissioning. Moreover, this study may contribute to the field of marine safety to decrease the risk of ship collision.

Nomenclatures

a	Default value (0.1)
BL	Box length perpendicular, m
D	Collision diameter, m
D_i^+	Separation of an alternative from PIS
D_i^-	Separation of an alternative from NIS
F_{CD}	Frequency of drifting collision
F_{CP}	Frequency of powered passing vessel collisions (per year)
F_{cum}	Cumulative frequency
g	Gravity constant (9.8 m/s^2)
L	Ship length, m
L_i	Lateral air surface of ship in full load
N	Total traffic in lane
NER	Navigational error rate
N_{ram}	Number of ships ramming object
P	Causation probability
P_{AF}	Probability of emergency anchor failure
P_{EF}	Probability of repair failure
P_{RAM}	Probability of ships hit object
P_b	Probability of vessel has engine breakdown
P_w	Probability of wind direction leads to object that make vessel drift towards it
RC_i	Overall or composite performance score of alternatives
RO	Ramming opportunities
r	Ramming distance, m
t	Duration of repairing engine failure, s
v_{drift}	Drift velocity, m/s
x_{ij}	Weight of alternative for each criterion
y_{ij}	Weighted normalized decision matrix
z_{ij}	Weighted normalized value

Greek Symbols

ζ_b	Significant wave amplitude, m
ρ_{air}	Air density (1.225 kg/m^3)
ρ_w	Water density (997 kg/m^3)
φ	Angle of ram direction, deg
φ_{cc}	Course change angle, deg

Abbreviations

AHP	Analytic Hierarchy Process
CRASH	Computerized Risk Assessment of Shipping Hazards
DSV	Diving Support Vessel

MCDM	Multi-Criteria Decision Making
NIS	Negative Ideal Solution
PIS	Positive Ideal Solution
SAMSON	Safety Assessment Models for Shipping and Offshore in North Sea
SWAC	Surabaya West Access Channel
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

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