Risk Assessment of Balikpapan-Samarinda Oil Distribution Pipeline Using Kent Muhlbauer Method

S C Gyarino¹, D W Handani¹,², E Pratiwi¹, F I Prastyasari¹,², I M Ariana¹,²

¹ Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia
² Center of Excellence for Maritime Safety and Marine Installation, Institut Teknologi Sepuluh Nopener, Surabaya, 60111, Indonesia

e-mail: gyarino@gmail.com

Abstract. The planned relocation of the Indonesian capital city to East Kalimantan can lead to an increase in fuel consumption in the area, and to meet all these needs, a pipeline is planned to be built, to transport oil from the Balikpapan BBM Terminal to Samarinda and Palaran. The pipeline system is used for fluid transfer processes that are prone to damage where there are several potential hazards to pipelines and high costs for construction and maintenance, so it takes a lot of consideration in choosing the path to be built and risk assessment of the selected path. This study aims to select an alternative oil distribution pipeline, then identify hazards, analyze frequency, consequences, then represent risks and analyze mitigation efforts in overcoming the damage to the oil distribution pipeline. On alternative pipeline selection, the Analytical Network Process method is used. Alternative 5 was chosen, with combines of segment 1A (onshore), toll segment, Palaran segment, and Samarinda C segment. Then, for risk assessment, Kent Muhlbauer's model indexing method is used, and based on the results of risk representation by looking at the average relative risk score, which is 19 points when flowing gasoline, and 41 points when flowing gasoil, it is found that segments 3, 4, 2B, 1B, 1D, and 2A are the most vulnerable segments with a relative score below the average. After carrying out risk mitigation actions, it's found that the segments that are in a vulnerable condition exceed the average value of the previous relative risk score.

1. Introduction
The planned relocation of the Indonesian capital city to East Kalimantan, it could lead to a possible increase in fuel consumption in the area. This happens because there will be production, distribution, and consumption activities from the community and government that will go to the area.

To meet all these petroleum needs, it is planned to build a fluid transfer system that is useful for moving fluids from the Balikpapan Fuel Oil Terminal (TBBM) to Samarinda and Palaran, such as a pipeline system. A pipeline system used for the fluid transfer process is quite susceptible to damage. Several things that can cause leakage or damage to the pipe are corrosion, fracture, crack due to an earthquake or landslide, design errors, operational errors, and others.

With several potential hazards to pipelines, as well as the high costs that need to be incurred for construction and maintenance, many considerations are needed in choosing the pipeline to be built. Some of the criteria that need to be considered include construction, operational, maintenance costs, and
so on. In addition, an analysis of the risks that may result in leaks or pipe damage that can occur is also needed, so that they can be mitigated and possibly as early as possible.

In considering some of these aspects, it can be done with an approach based on existing data. One solution that can be offered is the use of Multi Criteria Decision Making (MCDM). MCDM is a decision-making technique from several existing alternatives based on certain criteria [1]. The commonly used MCDM methods are Analytical Hierarchy Process (AHP) and Analytic Network Process (ANP) [2]. With a review of the weaknesses of the AHP method that had previously been carried out by [3], where ANP was also developed from the weaknesses of AHP by [4], in this study a pipeline route was selected using the ANP method.

Furthermore, after the alternative pipeline route has been selected, in this study a risk assessment of the pipeline will be carried out. The Kent Muhlbauer method [5] can be used to carry out pipe risk assessments both offshore and onshore. Kent Muhlbauer's indexing models method was used in this study because it is able to provide direct answers, is a low-cost, comprehensive analysis (allows incomplete knowledge and is easily modified when new information becomes available), can act as a decision support tool for resource allocation modeling and can provide direct answers to the level of risk in each pipeline segment.

When we carry out a pipeline risk assessment using the Kent Muhlbauer method, the pipeline is divided into several parts or segments so that calculations can be carried out more accurately [5]. This risk assessment is carried out by calculating the relative risk score. The relative risk score is the comparison between the value on the probability index (representing the frequency value) and the Leak Impact Factor (LIF) value (representing the consequence value).

2. Method
The methodological procedures used in this study are described in this section. Regarding the formulation of the problem and review of the literature, several alternative pipeline routes will be developed along with the criteria, followed by the creation and collection of questionnaire data, and finally the processing of questionnaire data to obtain the selected alternative using the ANP method.

Following that, a pipeline risk assessment begins with hazard identification, followed by an assessment of the frequency and consequences of potential hazards that may occur in the selected pipeline, followed by risk evaluation, where when the risk is unacceptable, proposed mitigation action is made to reduce the risk so that it is acceptable. When the risk is acceptable, the process of compiling conclusions and suggestions for this research begins.

2.1. Preparation of Criteria and Alternative Design of Pipelines
After obtaining the necessary data related to the alternative pipeline design, the data is processed to be used as several criteria and alternatives that may be selected. The next step is the creation and collection of questionnaire data to relevant stakeholders.

2.2. Questionnaire Creation and Questionnaire Data Collection
From several existing design alternatives along with the criteria being reviewed, then we make a questionnaire to get the value of pairwise comparisons on each criterion, as well as the available alternative designs. The questionnaire will be filled in by the relevant stakeholders for further data processing using the ANP method that developed by Saaty [4].

2.3. Questionnaire Data Processing
After obtaining the appropriate CR value, then the preparation and completion of the supermatrix using the ANP method is carried out, to obtain a priority ranking of each criterion, sub-criteria to obtain the selected alternative. At this stage the ANP method has been completed.
2.4. Sensitivity Analysis
Sensitivity analysis is used to see the level of sensitivity of the alternative rankings to changes in the preferences of decision makers. Changes in priority rankings that occur are expected to be used to see the level of consistency of alternative rankings if at any time there is a significant change from decision makers.

2.5. Hazard Identification
Hazard identification is carried out on the selected alternative pipeline design. The results of the hazard identification will then be processed for an assessment of the frequency and consequences.

2.6. Frequency Assessment
Frequency assessment is an assessment of the possibility of failure in a system or in this case a pipeline. The assessment of the probability of this failure is carried out by calculating the four indexes in the indexing model that developed by Muhlbauer [5].

2.7. Consequence Assessment
This consequence assessment aims to determine the impact that can occur caused by the hazard or potential hazards that exist. In this final project, the consequence assessment is carried out by calculating the value of the LIF in the indexing model that developed by Muhlbauer [5].

2.8. Relative Risk Calculation
This relative risk calculation aims to calculate the total value of the relative risk on the pipeline. This relative risk calculation uses the value of the probability index and LIF. Calculation of this relative risk is carried out on each pipe segment. A low relative risk value indicates that the pipeline segment has a higher level of risk.

2.9. Risk Evaluation
The risk evaluation stage is the stage of assessing which pipeline segment has a higher risk level. Pipeline segments that have a higher level of risk should be prioritized for mitigation actions first.

3. Results and Discussion

3.1. Preparation of Criteria and Alternative Design of Pipelines
After obtaining the necessary data related to the alternative pipeline design, the data is processed to be used as several criteria and alternatives that may be selected. The following Figure 1 shows all of the pipeline segment options that can be constructed.

![Figure 1. All of the Pipeline Segment Option](image-url)
There are 7 available segments, which consist of segment 1A (orange line), segment 1B (maroon line), toll segment (red line), Samarinda A segment (dark blue line), Samarinda B segment (light blue line), and segment Samarinda C (pink line). From all the existing pipeline segment options, six alternative pipelines are formed with the following details on Table 1.

| Alternatives | Segments Combinations                                      |
|-------------|------------------------------------------------------------|
| 1           | Segment 1A - Toll Segment - Palaran Segment - Samarinda A Segment |
| 2           | Segment 1B - Toll Segment - Palaran Segment - Samarinda A Segment |
| 3           | Segment 1A - Toll Segment - Palaran Segment - Samarinda B Segment |
| 4           | Segment 1B - Toll Segment - Palaran Segment - Samarinda B Segment |
| 5           | Segment 1A - Toll Segment - Palaran Segment - Samarinda C Segment |
| 6           | Segment 1B - Toll Segment - Palaran Segment - Samarinda C Segment |

According to Setyorini [6], the making of criteria and sub-criteria in the AHP and ANP methods can be more adapted to the latest and growing conditions. Therefore, the criteria for alternative pipeline designs in one case with other cases may be different. However, the criteria and alternatives that exist in other cases can be used as references to be adapted to the cases to be studied. After reviewing several studies that have been conducted previously by Thomaidis [7], Balogun [8], and Yildirim [9], the criteria and sub-criteria used in this study can be seen in Table 2. Figure 2 shows the interdependence of alternatives, criteria and sub-criteria in the ANP network model.

Table 2. Criteria And Sub-Criteria for The Selection of The Balikpapan-Samarinda Oil Distribution Pipeline Route

| No. | Criteria                          | Sub-Criteria                                  |
|-----|-----------------------------------|-----------------------------------------------|
| 1   | Economic                          | Investment Costs                             |
|     |                                   | Operating Costs                              |
| 2   | Safety                            | Environmental Safety                          |
|     |                                   | Facility Security                             |
| 3   | Operational Technical Aspect      | Operational Complexity                        |
|     |                                   | Accessibility                                 |
| 4   | Construction Technical Aspect     | Complexity of Construction                    |
|     |                                   | Duration of Construction                      |
| 5   | Social                            | Operational-social Issues                     |
|     |                                   | Construction-social Issues                    |

Figure 2. The ANP Network Formed
3.2. Creation and Distribution of Questionnaires
In the ANP method, to get a weight assessment of the existing criteria, sub-criteria, and alternatives, a questionnaire is used as a means so that later the highest alternative value is obtained according to the value given by the respondent. Respondents who fill out this questionnaire are parties who have been / are currently involved in work or studies related to the pipeline and oil and gas fields. The sample size of the targeted respondents is around 15-30 people, in which the size range of the collected data is considered to be able to identify patterns from all data [10]. This questionnaire is used to determine how much influence or assessment between criteria, sub-criteria, alternatives, and sub-criteria in terms of an alternative.

3.3. Calculation of ANP Method
The calculation of the questionnaire data using the ANP method was carried out with the help of SuperDecision software, with data from 15 respondents who had been obtained. The input data used is a combined opinion matrix that has previously been calculated from the respondents' assessments. Next, the supermatrix and limit matrix were formed in the SuperDecision software, and the consistency ratio was checked, whether it was below 0.1 or not. An example of a combined opinion matrix from comparisons between criteria with respect to goal can be seen in Table 3.

| Name  | Normalized By Cluster | Limiting | Rank |
|-------|------------------------|----------|------|
| Economic | 0.198 | 0.049 | 2 |
| Safety | 0.100 | 0.025 | 5 |
| Social | 0.153 | 0.038 | 3 |
| Operational Technical Aspect | 0.093 | 0.023 | 6 |
| Construction Technical Aspect | 0.318 | 0.080 | 1 |
| Alternative 6 | 0.138 | 0.035 | 4 |

Table 3. Combined Opinion Matrix from Comparisons between Criteria with Respect to Goal

After calculating the ANP with the help of SuperDecision to get the best alternative for the pipeline design, the chosen alternative is the 5th alternative with the highest priority weight. Where the 5th alternative is a combination of the 1A (onshore) segment, the toll segment, the Palaran segment, and the Samarinda C segment. respondents can be said to be consistent and valid. The overall order of alternatives along with the weights of the super matrix and also the limit matrix can be seen in the Table 4 below.
3.4. Sensitivity Analysis
Sensitivity analysis was conducted to determine the level of consistency of alternative rankings to changes in the preferences of decision makers. Sensitivity analysis was carried out with the help of SuperDecision software, and the changes in the selected weights were carried out on the largest sub-criteria, namely the facility security sub-criteria. This is done to see the effect resulting from changes in the weight of the sub-criteria on the chosen alternative.

From the sensitivity analysis carried out, it was found that ranking changes began to occur when the weight changed by +60%, where there was a change in ranking in the third and fourth-order. The overall results of weight changes can be seen in the Figure 3. From the sensitivity analysis that has been carried out, it can be concluded that the first priority ranking order is stable to changes in the preferences of decision makers.

Figure 3. Graph of Change in Weight to Change in Value of Alternatives (Facility Security Subcriteria)

3.5. Pipeline Specifications and Segmentation
The fluid flowing in the pipeline is divided into gasoline and gasoil. The specifications of the pipelines used can be seen in Table 5, 6 and 7.

| Table 5. Pipe Specifications for Charging Pump |
|-----------------------------------------------|
| Material Specification | API 5L, PSL 2 Grade B |
| SMYS (psi) | 35000 |
| Internal Design Pressure (psi) | 8.237 |
| Outer Diameter (inch) | 12.75 |
| Wall Thickness Calculation (inch) | 0.002 |
| Allowance for Corrosion (inch) | 0.118 |
| t + A (inch) | 0.120 |
| Nominal Wall Thickness (inch) | 0.172 |
| Maximum Operating Pressure (psi) | 679.905 |
Table 6. Pipe Specifications for Main Pump

| Material Specification                  | API 5L, PSL 2 Grade B |
|----------------------------------------|------------------------|
| SMYS (psi)                              | 35000                  |
| Internal Design Pressure (psi)          | 594.129                |
| Outer Diameter (inch)                   | 12.75                  |
| Wall Thickness Calculation (inch)        | 0.150                  |
| Allowance for Corrosion (inch)          | 0.118                  |
| t + A (inch)                            | 0.268                  |
| Nominal Wall Thickness (inch)           | 0.375                  |
| Maximum Operating Pressure (psi)        | 1482.352               |

Table 7. Pipe Specifications for Booster Pump

| Material Specification                  | API 5L, PSL 2 Grade X52 |
|----------------------------------------|-------------------------|
| SMYS (psi)                              | 52000                   |
| Internal Design Pressure (psi)          | 1221.340                |
| Outer Diameter (inch)                   | 12.75                   |
| Wall Thickness Calculation (inch)        | 0.208                   |
| Allowance for Corrosion (inch)          | 0.118                   |
| t + A (inch)                            | 0.326                   |
| Nominal Wall Thickness (inch)           | 0.375                   |
| Maximum Operating Pressure (psi)        | 2202.352                |

Then, it is generally accepted that pipelines, unlike other objects of risk assessment, such as generating facilities, usually do not have constant hazard potential in each part. This happens because of the different conditions along the route, as well as the treatment of the pipe as an adaptation to existing conditions. Thus, the risk picture of the entire pipeline may differ according to the existing conditions. Therefore, it is necessary to do segmentation so that risk assessment of the entire pipeline can be carried out more accurately. Table 8 shows the result of pipeline segmentation based on the dynamic segmentation approach method from the [5]. Then, the pipeline risk assessment is carried out with the assumption that the condition of the new pipeline has been completed and will be operational.

Table 8. Pipeline Segmentation Results

| Segment | Initial km | Final km | Class Location | Length (km) | Notes                                      |
|---------|------------|----------|----------------|-------------|--------------------------------------------|
| 1A      | 0          | 5        | 1              | 5           | Empty land                                 |
| 1B      | 5          | 8.4      | 3              | 3.4         | Residential and company areas              |
| 1C      | 8.4        | 13       | 1              | 4.6         | Empty land                                 |
| 1D      | 13         | 18.5     | 3              | 5.5         | Residential and company areas              |
| 2A      | 0          | 50       | 3              | 50          | Toll road (assuming that in 1.6 km there are 10 cars with 2 passengers) |
| 2B      | 50         | 85.2     | 3              | 35.2        | Toll road (assuming that in 1.6 km there are 10 cars with 2 passengers) |
| 3       | 0          | 6.62     | 4              | 6.62        | Residential area                           |
| 4       | 0          | 6.69     | 4              | 6.69        | Residential area                           |

3.6. Frequency Assessment Based on Index Sum
The frequency assessment in the Kent Muhlbauer method is carried out by calculating the scores on the following four indices: third party damage index, corrosion index, design index, and incorrect operation
index. Each of the above indexes has several variables that have different portions or value weights for the index. The size of the portion or weight of this value depends on how much influence this variable has on the potential for failure of the pipeline itself.

3.7. Third Party Damage Index

Third Party Damage Index is a pipe safety risk factor originating from the activities of personnel/parties who are not related to the pipeline. In Table 9, it can be seen the recapitulation of the third party damage index for all pipeline segments. From the calculations that have been carried out, it is found that the score in each segment is worth between 33 to 48 with an average of 36.4, where the variables that can reduce the score include the level of activity in the pipeline area including high-level activity areas, the frequency of patrols that have never been carried out and public outreach that has never been done.

| No   | Index Sum               | Weight Max | Score Max | Segment 1A | 1B | 1C | 1D | 2A | 2B | 3 | 4 | Average Score |
|------|-------------------------|------------|-----------|------------|----|----|----|----|----|---|----|---------------|
| 1.1  | Minimum Depth Cover     | 20%        | 20        | 20         | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20            |
| 1.2  | Activity Level          | 20%        | 20        | 15         | 15 | 0  | 0  | 0  | 0  | 0  | 4             |
| 1.3  | Aboveground Facilities  | 10%        | 10        | 1           | 1  | 1  | 1  | 1  | 1  | 1  | 1             |
| 1.4  | Line Locating           | 15%        | 15        | 6           | 6  | 6  | 6  | 6  | 6  | 6  | 6             |
| 1.5  | Public Education Program| 15%        | 15        | 1           | 1  | 1  | 1  | 1  | 1  | 1  | 1             |
| 1.6  | Right-of-way Condition  | 5%         | 5         | 5           | 5  | 5  | 5  | 5  | 5  | 5  | 5             |
| 1.7  | Patrol Frequency        | 15%        | 15        | 0           | 0  | 0  | 0  | 0  | 0  | 0  | 0             |
|      | Total Third-Party Damage| 100%       | 100       | 48          | 33 | 48 | 33 | 33 | 33 | 33 | 36            |

3.8. Corrosion Index

The potential for pipe damage caused by corrosion is perhaps the best known hazard associated with steel pipes. Corrosion is always a concern, because any loss of pipe wall thickness means a decrease in structural integrity and therefore an increased risk of failure. The corrosion index score obtained is presented in Table 10. From the calculations that have been done, the average score of the corrosion index is 40.6, where the biggest variable that reduces the score is corrosion on the external pipe.

| No   | Index Sum              | Weight Max | Score Max | Segment 1A | 1B | 1C | 1D | 2A | 2B | 3 | 4 | Average Score |
|------|------------------------|------------|-----------|------------|----|----|----|----|----|---|----|---------------|
| 2.1  | Atmospheric Corrosion   | 10%        | 10        | 6.5        | 6.5| 6.5| 6.5| 6.5| 6.5| 6.5| 6.5           |
| 2.1.1| Atmospheric Exposure    | 50%        | 5         | 3           | 3  | 3  | 3  | 3  | 3  | 3  | 3             |
| 2.1.2| Atmospheric Type        | 20%        | 2         | 2           | 2  | 2  | 2  | 2  | 2  | 2  | 2             |
| 2.1.3| Atmospheric Coating     | 30%        | 3         | 1.5         | 1.5| 1.5| 1.5| 1.5| 1.5| 1.5| 1.5           |
|      | - Coating quality       | 25%        | 3         | 3           | 3  | 3  | 3  | 3  | 3  | 3  | 3             |
|      | - Applicant             | 25%        | 3         | 3           | 3  | 3  | 3  | 3  | 3  | 3  | 3             |
|      | - Inspection            | 25%        | 3         | 0           | 0  | 0  | 0  | 0  | 0  | 0  | 0             |
|      | - Correction of Defects | 25%        | 3         | 0           | 0  | 0  | 0  | 0  | 0  | 0  | 0             |
| 2.2  | Internal Corrosion      | 20%        | 20        | 11          | 11 | 11 | 11 | 11 | 11 | 11 | 11.0          |
| 2.2.1| Product Corrosivity     | 50%        | 10        | 3           | 3  | 3  | 3  | 3  | 3  | 3  | 3             |
| 2.2.2| Prevention              | 50%        | 10        | 8           | 8  | 8  | 8  | 8  | 8  | 8  | 8             |

8
the score assessment is the error variable related to operational and maintenance activities. out, the average score of the incorrect operation index is 56, where the largest variable that decreases the operation index score obtained is presented in the pipeline personnel in designing, constructing, operating, or maintaining pipelines. The incorrect operation index assesses the potential for pipeline failure caused by errors made by pipeline personnel in designing, constructing, operating, or maintaining pipelines. The incorrect operation index score obtained is presented in Table 11. From the calculations that have been done, the average score from the design index is 60, where the biggest variable that reduces the score is the possibility of spikes in pipe pressure and ground movement.

3.9. Design Index
In the design index, the assessment not only looks at the potential of the active failure mechanism, but also the pipeline's ability to withstand the failure mechanism. The design index score obtained is presented in Table 11. From the calculations that have been done, the average score from the design index is 60, where the biggest variable that reduces the score is the possibility of spikes in pipe pressure and ground movement.

| No | Index Sum          | Weight Max | Score Max  | Segments | Average Score |
|----|--------------------|------------|------------|----------|---------------|
| 3.1| Safety Factor      | 35%        | 35         | 35 35 35 35 35 28 28 28 | 32.4          |
| 3.2| Fatigue            | 15%        | 15         | 3 3 3 3 3 2 2 2          | 2.6           |
| 3.3| Surge Potential    | 10%        | 10         | 5 5 5 5 5 5 5 5          | 5.0           |
| 3.4| Integrity Verification | 25%       | 25         | 15 15 15 15 15 15 15 15 | 15.0          |
| 3.5| Land Movement      | 15%        | 15         | 5 5 5 5 5 5 5 5          | 5.0           |
|    | Total Design Index | 100%       | 100 | 63 63 63 63 63 55 55 55 55 | 60.0          |

3.10. Incorrect Operation Index
The Incorrect operation index assesses the potential for pipeline failure caused by errors made by pipeline personnel in designing, constructing, operating, or maintaining pipelines. The incorrect operation index score obtained is presented in Table 12. From the calculations that have been carried out, the average score of the incorrect operation index is 56, where the largest variable that decreases the score assessment is the error variable related to operational and maintenance activities.

| No | Index Sum       | Weight Max | Score Max  | Segments | Average Score |
|----|-----------------|------------|------------|----------|---------------|
| 4.1| Design          | 30%        | 30         | 24 24 24 24 24 24 24 24 | 24            |
| 4.1.1| Hazard Indentification | 13.30%     | 4          | 4 4 4 4 4 4 4 4 4 4 | 4             |
| 4.1.2| MOP Potential   | 40%        | 12         | 10 10 10 10 10 10 10 10 | 10            |
| 4.1.3| Safety System   | 33.30%     | 10         | 6 6 6 6 6 6 6 6 6 6 6 | 6             |
| 4.1.4| Material Selection | 6.70%     | 2          | 2 2 2 2 2 2 2 2 2 2 | 2             |
| 4.1.5| Checks          | 6.70%      | 2          | 2 2 2 2 2 2 2 2 2 2 | 2             |
| 4.2| Construction    | 20%        | 20         | 20 20 20 20 20 20 20 20 | 20            |
| 4.2.1| Inspection      | 50%        | 10         | 10 10 10 10 10 10 10 10 10 | 10            |
| 4.2.2| Materials       | 10%        | 2          | 2 2 2 2 2 2 2 2 2 2 | 2             |
The probability of failure per segment can be seen in Table 13. Recapitulation of the Index Sum and Probability of Failure

| Index Sum                  | Segments | Average |
|----------------------------|----------|---------|
|                           | 1A  | 1B  | 1C  | 1D  | 2A  | 2B  | 3   | 4   |
| Third-Party Damage         | 48  | 33  | 48  | 33  | 33  | 33  | 33  | 33  | 36.4 |
| Corrosion Index            | 41  | 41  | 41  | 41  | 39  | 39  | 39  | 39  | 40.6 |
| Design Index               | 63  | 63  | 63  | 63  | 55  | 55  | 55  | 55  | 60.0 |
| Incorrect Operation Index  | 56  | 56  | 56  | 56  | 56  | 56  | 56  | 56  | 56.0 |
| Total Index Sum            | 208 | 193 | 208 | 193 | 193 | 183 | 183 | 183 | 193.0|
| Probability of Survival    | 7%  | 5%  | 7%  | 5%  | 5%  | 4%  | 4%  | 4%  | 5%  |
| Probability of Failure     | 93% | 95% | 95% | 95% | 95% | 96% | 96% | 96% | 95% |

Where TPD, C, D, and IO are scores of each index in percent that have an AND relationship. The probability of failure is generated by subtracting 1 from the multiplication of survival probability, so that by using the calculation results of the total existing index values, the results of the calculation of the average probability of failure of the entire oil distribution pipeline are 95%. The results of the calculation of the probability of failure per segment can be seen in Table 13.

3.11. Index Sum and Calculation of Probability of Failure Score

After the four indexes have known the total number of points, the total points from the four indexes are accumulated. In this scoring system, it is important to note that the number of scores is directly proportional to the level of safety, so that when the score increases, the level of safety also increases. From the results of calculations carried out, the average total index value is 193, the smallest total index value is 183, and the largest total index value is 208. In addition, it is concluded that the smallest average index value in the third party damage index of 36.4 and a corrosion index of 40.6, requiring more handling so that the level of safety can be increased.

The total index value obtained can then be converted into the form of failure probability using probability theory. Assuming that each index represents a survival probability, which means that the greater the index value, the greater the level of safety, and indicates the lower the threat. Muhlauer [5] explains this relationship in the equation below:

\[
\text{Probability of Failure Score} = 1 - \left( \frac{\text{TPD}}{100} \times \frac{\text{C}}{100} \times \frac{\text{D}}{100} \times \frac{\text{IO}}{100} \right)
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\text{Probability of Failure Score} = 1 - \left( \frac{\text{TPD}}{100} \times \frac{\text{C}}{100} \times \frac{\text{D}}{100} \times \frac{\text{IO}}{100} \right)
\]
3.12. Consequence Assessment Based on Leak Impact Factor
To obtain the value of the consequences of the Kent Muhlbauer method, the LIF calculation is used. The greater the value of the Leak Impact Factor, the greater the value of consequences and risks that may be accepted. Where there are several variables that need to be calculated, namely: product hazard, leak volume, dispersion, and receptors. From these variables, it is used to obtain the LIF by equation (2).

\[
\text{LIF} = \text{product hazard} \times \text{leak} \times \text{dispersion} \times \text{receptors}
\]

The leak impact factor score obtained is presented in Table 14 and Table 15. From the calculations that have been carried out, the average score of the leak impact factor is 10.57 for gasoline products and 4.90 for gasoil products, where the largest variable that reduces the score is the product hazard variable and the receptors variable.

| No. | Leak Impact Factor | Poin Max | Segments | Average |
|-----|--------------------|----------|----------|---------|
|     |                    | 1A 1B 1C 1D 2A 2B 3 4 |          |         |
| 1.  | Product Hazard     | 22 10 10 10 10 10 10 10 |          | 10      |
| 2.  | Leak Volume        | 1 0.4 0.4 0.4 0.4 0.4 0.4 0.4 | 0.4     | 0.4     |
| 3.  | Dispersion         | 1 0.4 0.4 0.4 0.4 0.4 0.4 0.4 | 0.4     | 0.4     |
| 4.  | Receptors          | 8.5 5 7 5 7 7 8 8 | 6.8     |         |
|     | LIF                | 187 7.8 11 7.8 11 11 11 13 13 | 10.57   |         |

3.13. Relative Risk Score
The relative risk score is the result of dividing the total index by the leak impact factor. The relative risk score is an illustration of the risk of the Balikpapan-Samarinda oil distribution pipeline, where it can be seen which segment has the lowest score, so that it can be seen what actions must be taken to improve the safety of the pipeline. The overall results of the relative risk score on the pipeline can be seen in the Table 16 and Table 17.

| No. | Leak Impact Factor | Poin Max | Segments | Average |
|-----|--------------------|----------|----------|---------|
|     |                    | 1A 1B 1C 1D 2A 2B 3 4 |          |         |
| 1.  | Product Hazard     | 22 10 10 10 10 10 10 10 10 10 10 |          | 10      |
| 2.  | Leak Volume        | 1 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 | 0.4     | 0.4     |
| 3.  | Dispersion         | 1 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 | 0.4     | 0.4     |
| 4.  | Receptors          | 8.5 5 7 5 7 7 8 8 | 6.8     |         |
|     | LIF                | 187 7.8 11 7.8 11 11 11 13 13 | 10.57   |         |

| Segment Gasoline | 1A | 1B | 1C | 1D | 2A | 2B | 3  | 4  |
|------------------|----|----|----|----|----|----|----|----|
| Index Sum        | 208| 193| 208| 193| 193| 183| 183| 183|
| LIF              | 7.8| 11 | 7.8| 11 | 11 | 11 | 13 | 13 |
| RR               | 27 | 18 | 27 | 18 | 18 | 17 | 15 | 15 |
Table 17. Recapitulation of the Relative Risk Score when Flowing Gasoil

| Segment Gasoil | 1A | 1B | 1C | 1D | 2A | 2B | 3  | 4  |
|----------------|----|----|----|----|----|----|----|----|
| Index Sum      | 208| 193| 208| 193| 183| 183| 183| 183|
| LIF            | 3.6| 5.1| 3.6| 5.1| 5.1| 5.1| 5.8| 5.8|
| RR             | 57 | 38 | 57 | 38 | 38 | 36 | 32 | 32 |

3.14. Risk Representation

In this study, a limited risk representation was carried out in accordance with other studies that have been published in the journal by Subagyo [11], namely by using the average value of the relative risk score that has been calculated to be a reference in assessing which segment is the most vulnerable compared to other segments, and which aspects contributed the most to the failure of that segment. The calculations that have been done can be seen in the Table 18 and Table 19.

Based on Table 18 and Table 19, it can be said that with reference to the average value of the relative risk score, which is 19 points when draining gasolin, and 41 points when draining gasoil, the segment that is most vulnerable or has the highest risk of successive failures are segments 3, 4, 2B, 1B, 1D, and 2A, with relative scores below the average. This can happen because the segment is in an area with a high level of activity, which causes the value of the third party damage index to be. In addition, in segments 2B, 3, and 4, it was also found that the booster pump was operational, which caused the operating pressure in both segments to be higher than the segment before the booster pump, which could lead to a higher possibility of corrosion and fatigue.

Table 18. Evaluation of the Relative Risk Score when Flowing Gasoline

| Segments          | 1A | 1B | 1C | 1D | 2A | 2B | 3  | 4  |
|-------------------|----|----|----|----|----|----|----|----|
| Third-Party Damage| 48 | 33 | 48 | 33 | 33 | 33 | 33 | 33 |
| Corrosion Index   | 41 | 41 | 41 | 41 | 39 | 39 | 39 | 39 |
| Design Index      | 63 | 63 | 63 | 63 | 55 | 55 | 55 | 55 |
| Incorrect Operation Index | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| **Total Index Sum** | **208** | **193** | **208** | **193** | **183** | **183** | **183** | **183** |
| Probability of Survival | 7% | 5% | 7% | 5% | 5% | 4% | 4% | 4% |
| Probability of Failure | 93% | 95% | 93% | 95% | 96% | 96% | 96% | 95% |
| LIF (gasoline)    | 7.8| 11.0| 7.8| 11.0| 11.0| 11.0| 12.5| 12.5|
| RR (gasoline)     | 26.6| 17.6| 26.6| 17.6| 17.6| 16.7| 14.6| 14.6|

Table 19. Evaluation of the Relative Risk Score when Flowing Gasoil

| Segments          | 1A | 1B | 1C | 1D | 2A | 2B | 3  | 4  |
|-------------------|----|----|----|----|----|----|----|----|
| Third-Party Damage| 48 | 33 | 48 | 33 | 33 | 33 | 33 | 33 |
| Corrosion Index   | 41 | 41 | 41 | 41 | 39 | 39 | 39 | 39 |
| Design Index      | 63 | 63 | 63 | 63 | 55 | 55 | 55 | 55 |
| Incorrect Operation Index | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| **Total Index Sum** | **208** | **193** | **208** | **193** | **183** | **183** | **183** | **183** |
| Probability of Survival | 7% | 5% | 7% | 5% | 5% | 4% | 4% | 4% |
| Probability of Failure | 93% | 95% | 93% | 95% | 96% | 96% | 96% | 95% |
| LIF (gasoline)    | 3.6| 5.1| 3.6| 5.1| 5.1| 5.8| 5.8| 4.9|
| RR (gasoline)     | 57.4| 38.0| 57.4| 38.0| 38.0| 36.0| 31.5| 31.5|
3.15. Risk Mitigation

Based on the results of the risk representation by looking at the relative risk score, it was found that segments 3, 4, 2B, 1B, 1D, and 2A were the most vulnerable segments, with a relative score value below the average, both when draining gasoline, as well as gasoil. Mitigation actions must be prioritized in these segments in order to increase the level of safety. Based on the analysis of the index sum value, it was found that the third party damage index and corrosion index are the factors with the worst safety level, which increases the chance of pipeline failure. Therefore, to improve the safety of pipelines, risk mitigation measures that can be recommended are carried out on all indices as an effort to reduce the frequency level, including:

- Conduct regular patrols along the pipeline.
- Conduct community outreach activities about the location and facilities of the pipeline, as well as hold meetings with local contractors and excavators once a year.
- To test the corrosiveness of the soil around the pipeline, to determine the level of corrosiveness.
- Assess the effectiveness of cathodic corrosion protection.
- Conduct a survey on the presence of DC current sources that may be in contact with pipelines.
- Inspect and repair defects in coatings on a regular basis on pipelines in accordance with applicable standards.
- Record all activities that can cause an increase in operational pressure on the pipeline.

From the mitigation recommendations that can be done, the new index sum value and the new relative risk value are calculated, to find out changes in the new risk level, where it is found that the relative risk value of few segments that were previously below the average calculation, which is 19 points when flowing gasoline, and 41 points when flowing gasoil, after mitigation measures have passed the average value. The results obtained can be seen in the Table 20 and Table 21.

| Segments | 1A | 1B | 1C | 1D | 2A | 2B | 3 | 4 |
|----------|----|----|----|----|----|----|---|---|
| Third-Party Damage | 48 | 54 | 48 | 54 | 54 | 54 | 54 | 54 |
| Corrosion Index | 41 | 62 | 41 | 62 | 62 | 68 | 68 | 68 |
| Design Index | 63 | 63 | 63 | 63 | 65 | 65 | 65 | 65 |
| Incorrect Operation Index | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| **Total Index Sum** | 208 | 235 | 208 | 235 | 235 | 243 | 243 | 243 |
| Probability of Survival | 7% | 12% | 7% | 12% | 12% | 13% | 13% | 13% |
| Probability of Failure | 93% | 88% | 93% | 88% | 88% | 87% | 87% | 87% |
| LIF (gasoline) | 7.8 | 11.0 | 7.8 | 11.0 | 11.0 | 11.0 | 12.5 | 12.5 |
| RR (gasoline) | 26.6 | 21.4 | 26.6 | 21.4 | 21.4 | 22.1 | 19.4 | 19.4 |

| Segments | 1A | 1B | 1C | 1D | 2A | 2B | 3 | 4 |
|----------|----|----|----|----|----|----|---|---|
| Third-Party Damage | 48 | 54 | 48 | 54 | 54 | 54 | 54 | 54 |
| Corrosion Index | 41 | 62 | 41 | 62 | 62 | 68 | 68 | 68 |
| Design Index | 63 | 63 | 63 | 63 | 65 | 65 | 65 | 65 |
| Incorrect Operation Index | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| **Total Index Sum** | 208 | 235 | 208 | 235 | 235 | 243 | 243 | 243 |
| Probability of Survival | 7% | 12% | 7% | 12% | 12% | 13% | 13% | 13% |
| Probability of Failure | 93% | 88% | 93% | 88% | 88% | 87% | 87% | 87% |
| LIF (gasoline) | 3.6 | 5.1 | 3.6 | 5.1 | 5.1 | 5.1 | 5.8 | 5.8 |
| RR (gasoline) | 57.4 | 46.3 | 57.4 | 46.3 | 46.3 | 47.8 | 41.8 | 41.8 |
4. Conclusion
Based on the analysis and discussion that has been done, the following conclusions can be drawn in this research:

- In selecting the route for the oil distribution pipeline from Balikpapan to Samarinda and Palaran using the ANP method, the selected alternative results are alternative 5, with a combination of segment 1A (onshore), toll segment, Palaran segment, and Samarinda C segment. Alternative 5 is selected by the weight value is 31.8%. After a sensitivity analysis has been carried out with changes in the weight of the facility security sub-criteria with a value variation of -100% to +100%, the chosen alternative can be declared quite strong and stable, because the chosen alternative is consistent with alternative 5.

- In the assessment of the frequency of failure based on the index sum, the results of the calculation of the average probability of failure are 95%, with the third party damage index and the corrosion index with an average value of 36.4 and 40.6 as the index with the smallest average value, which means that the level of safety is lower than the other indices.

- In assessing the consequences of failure based on the leak impact factor, the results of the calculation of the average leak impact factor are 10.57 when draining gasoline products, and 4.9 when draining gasoil products.

- Based on the results of risk representation by looking at the average relative risk score, which is 19 points when draining gasoline, and 41 points when draining gasoil, it is found that segments 3, 4, 2B, 1B, 1D, and 2A are the most vulnerable segment with a relative score below the average. Mitigation actions must be prioritized in these segments in order to increase the level of safety.

- To improve the safety of pipelines, risk mitigation measures that can be recommended are carried out on all indices as an effort to reduce the frequency level.

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