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Determination of the Risk of Oil and Gas Offshore Pipelines in Indonesia: A Risk-Based Analysis Approach for Developing Inspection Strategy Policy

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Article History

Abstract

Indonesia has a target of producing 1 million BOPD of oil and 12 BSCFD of natural gas in 2030. The strategy for achieving the production target in 2030 is transformation from resources to production, accelerating chemical EOR, massive connectivity for finding large wells, and optimizing field production. In optimizing existing field production, one of the supporting factors is production facilities, so production facilities with good integrity are needed to minimize upplanned shutdowns. One of the oil and gas installations that pose a high risk is the installation of oil and gas pipelines. The existing pipeline installation in the Java Sea, from North Cirebon to the Seribu Islands, has an area of 8300 km2 and is operated by PT XYZ. Therefore, it requires complete and accurate inspection data to find out. This research method uses a modification of the Kent Mulhbauer scoring index. The risk level of the three subsea pipelines at Company XYZ, namely 4 in Gas Line Mike Mike, 8 in Gas Line Echo pipeline, and 8 in Gas Line Mike Mike pipeline, is found to be in the very highrisk category. The inspection strategy carried out for the third pipe with a very high risk category is visual inspection (ROV), freespan assessment, cathodic protection check (CP), UT thickness inspection on the riser and elbow (topside and subsea), and UT thickness inspection on the bottom pipe sea using the NACE ICDA method for thickness taking points and inspection periods once every 4 years or based on risk-based inspection (RBI). The cost and effort of examining the strategy will be assessed directly with the level of the risk category. Because of this, so that the inspection of the strategy can be optimal, effective, and efficient, it is divided into 3 (three) risk categories, namely low, medium, and high/very high, where the selection of strategy inspection is appropriate with the level of risk. The results of this study are expected to be a reference in making a policy or regulation to carry out regular inspections of underwater pipelines by using the risk analysis method to determine the inspection strategy.

Keywords: Corrosion, Inspection, Index Scoring, Pipelines

1. INTRODUCTION

The energy sector, particularly oil and natural gas (oil and gas), continues to be a major contributor to state revenue. Additionally, the oil and gas sub-sector has a multiplier effect on various related industries. These natural resources play a crucial role in daily activities, providing numerous benefits. In Indonesia, oil and gas energy remains a cornerstone of the economy, serving as both a foreign exchange earner and a supplier of domestic energy needs. Therefore, optimal, effective, and efficient efforts must be undertaken in the management of oil and gas [1].

Oil and gas management must adhere to good engineering principles with a focus on safety aspects. Oil and gas safety encompasses worker, general, installation, and environmental safety. The importance of oil and gas safety is underscored in Law no. 22 of 2001 concerning Oil and Natural Gas, which mandates that Business Entities and/or Permanent Establishments ensure adherence to standards and quality, application of good engineering principles, occupational safety and health, environmental management, and prioritization of local labor and domestic products [1].

In the seas surrounding Indonesia, there are 43 distribution pipe segments or approximately ±1,400 distribution pipes off the coast. Of these, 69% are more than 25 years old, indicating aging, while 31% are under 25 years old. Notably, the Java Sea area has the highest percentage (40%) of distribution pipes that have experienced aging [2].

One significant distribution pipe installation in the waters of the Java Sea, spanning from North Cirebon to the Thousand Islands, covers an area of 8300 km2 and is operated by PT XYZ. Many of these distribution pipes have been in operation for over 20 years. Over the course of their operation, some distribution pipes have experienced failures, including leaks, with negative impacts on both the state and the operator. This underscores the importance of optimizing existing installations and giving greater attention to the integrity of distribution pipes during operation [2].

To determine optimal, effective, and efficient inspection strategy policies, a Risk Based Analysis approach is employed. This analysis is based on the probability and consequences of failure in distribution pipes, with the probability of failure calculated using the Kent Muhlbauer (2004) scoring index. This method is chosen due to the inherent difficulty and cost associated with inspecting offshore distribution pipes [3].

In this research, a Risk Based Analysis will be conducted on oil and gas distribution pipeline installations at PT to comprehensively assess distribution pipe integrity. The goal is to minimize the occurrence of failures or leaks in distribution pipes, thereby ensuring the achievement of the national oil and gas production target.

2. Theoretical Review

2.1 Offshore Distribution Pipe (Offshore)

The distribution pipe is a cylindrical conduit used for conveying fluids, maintaining fluid pressure, directing fluid, and regulating fluid flow speed. The oil and gas industry employs distribution pipes as a medium for fluid transportation, whether it be petroleum, water, gas, or a mixture of these. In offshore upstream industries, distribution pipes are commonly utilized to transport oil and gas from production well platforms to process platforms, and subsequently from process platforms to production terminals on land. The fluids are then distributed again to consumers, either through loading tankers for exports or to gas purchasing companies for their internal fuel needs [4].

2.2 Oil and Gas Production Targets in Indonesia

Given Indonesia's high demand for petroleum, crude oil or fuel imports are necessary to meet these needs. Consequently, the Government has set a target to increase oil production to 1 million barrels by 2030 through various efforts and support from KKKS (Contractor Cooperation Contract). As depicted in Figure 2.3, Indonesia aims to produce 1 million BOPD (barrels of oil per day) and 12 BSCFD (billion standard cubic feet per day) of natural gas by 2030. As of March 2022, the realized oil production is 651.70 MBOPD, and natural gas production is 5510.87 thousand MMBTUD (thousand million British thermal units per day). The strategy to achieve the 2030 production target involves transforming resources to production, accelerating chemical Enhanced Oil Recovery (EOR), massive exploration to discover large wells, and optimizing existing field production [1].

2.3 PT XYZ's Subsea Distribution Pipeline Network

PT XYZ operates a distribution pipeline network stretching from North Cirebon to the Thousand Islands, covering an area of 8,300 km2. Most of these distribution pipes have been in operation for over 20 years, with a total length of 2115 km [2].

2.4 Piping System Risk Assessment

Risk management, a scientific approach addressing risk issues, aims to eliminate or reduce risks faced by companies and organizations. Formerly confined to the insurance sector, risk management has become recognized and applied across various business and organizational aspects globally [5]. The rapid expansion of hydrocarbon transportation from offshore to onshore has driven the development of undersea pipeline networks. In offshore production facilities, undesirable events like dents or ruptures in the underwater distribution pipeline network, caused by the impact of foreign objects, are highly probable. Incidents such as dents or scratches can compromise the distribution pipe's durability, leading to potential rupture due to insufficient strength to withstand operational pressure loads [6].

2.5 Risk Assessment based on W. Kent Muhlbauer

Risk is often defined as the probability of an event causing a loss and the potential magnitude of that loss. Risk increases when either the probability of an event or the magnitude of potential loss rises. Transporting products via pipelines entails risk due to the possibility of pipeline failure, release of contents, and consequential damage. The commonly accepted definition of risk is often expressed mathematically, as in Equation 2.7 [7].

Risk = (event likelihood) x (event consequence) ……… (2.7)

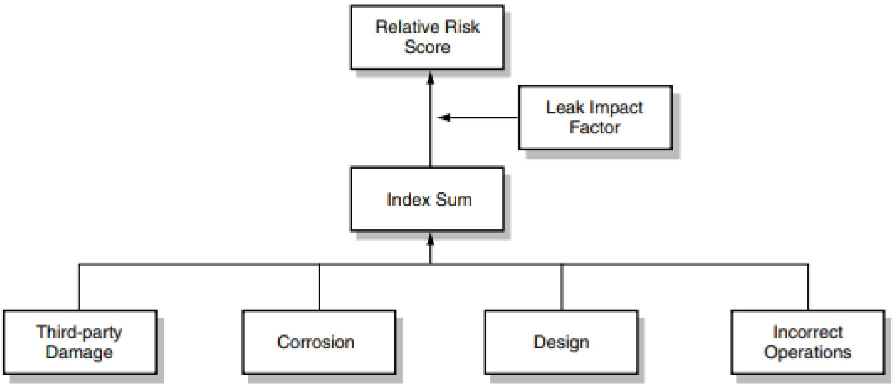

Figure 1. 9 Risk Assessment Model Flowchart [7]

In modeling Figure 2.9, W. Kent Muhlbauer explains that there are 5 points that influence risk assessment in distribution pipes, namely Leak Impact Factor, Third-Party Damage, Corrosion, Design, and Incorrect Operation [7].

3. METHODS

The data collection method for this research is primary data and secondary data. Secondary data, which will use data from the PT XYZ report owned by the Directorate General of Oil and Gas, consisting of:

1. Pipe design & specifications
2. Standard Operating Procedure (SOP) for the operation of distribution pipes
3. Documents for maintenance and supervision of pipeline safety
4. Data on shipping route plans & ship specifications
5. Offshore platform operating data
6. Data supporting other research needs (weather conditions, geographic & community conditions, fishermen's fishing schedules and so on).

Furthermore, the primary data used is the results of interviews that will be conducted in connection with the results of secondary data analysis obtained in the research.

3.1 Risk Analysis

Risk analysis in this study used a modification of the Kent Muhlbauer scoring index. Risk analysis on distribution pipeline networks can be used as a reference for maintaining the reliability and integrity of distribution pipeline network facilities, as well as accommodating safety factors and increasing confidence levels in the implementation of operational activities throughout the design life of the distribution pipeline network and beyond by reviewing the probability of failure (PoF) as in Table 3.1 and consequence of failure

(CoF) as in Table 3.2. The weighting in the assessment considers the failure index based on references that correspond to actual conditions in the field.

Table 3. 1 Parameter Probability of Failure (PoF) [7]

Parameter *Probability of Failure* (PoF)	
	Score
Third Party Damage Index	100
Corrosion Index	100
Design Index	100
Operational Nonconformity Index	100
Maximum Score	400

Table 3. 2 Parameter Consequence of Failure (CoF) [7]

Parameter *Consequence of Failure* (CoF)
Leak Impact Factor (LIF) = PH x LV x D x R
Product Hazard (PH)
- *Acute Hazard*
- *Cronic Hazard*
Leak/Spill Volume (LV)
Dispersion (D)
Receptor (R)

4. RESULT

This research focuses on the distribution pipe owned by PT XYZ and used to transport crude oil from offshore production fields. The specifications of the distribution pipe studied can be seen in Table 4.1 as follows:

Table 4. 1 Data and Specifications for Offshore Pipelines Researched [2]

Pipeline ID Name		4 in Gas Line Mike Mike	8 in Gas Line Echo	8 in Gas Line Mike Mike
Area		Mike	Lima	Mike-Mike
Service content	(MSCFD)	1676	1337	3962
OD (in)		4,5	8,625	8,625
WT (in)		0,337	0,5	0,5
Material		API 5L X-52	API 5L X-60	API 5L X-52
Manufacture Type		Longitudinal Seam	ERW	Longitudinal Seam
Corrosion Coating		N/A	5/32" D&W	5/32" D&W
Concrete Weight		N/A	N/A	N/A
Design Press. (psig)		1315	1350	1350
Design Temp. (F)		300	100	200
Max Oper. Pres. (psig)		N/A	N/A	N/A
Oper. Press. (psig)		600	700	90
Oper. Temp. (F)		N/A	85	70
Length (km)		1,61	4,40	1,69
Depth (m)		0 – 7	39 – 41	23 – 29
Patrol Frequency		-	-	-
Yearbuilt		1986	1984	1983
ILI Inspection Date		-	-	-
Last Inspection Date		31 Oktober 2018	15 Oktober 2019	3 April 2019
Age		34	39	40
Max CO2 (%vol)	(%)	7,5	2	7
	Period	2019-2020	2020	2016
Max H2S (ppm)	(ppm)	20	12	7
	Period	2019-2020	2020	2016
Max SRB (colony/ml)	(colony)	NFW	NFW	NFW
	Period	2019-2020	2020	2016
Chemical Injection	Yes/No	No	Yes	Yes
	(%)	-	100	N/A
	update	2019	2020	N/A
	Remarks	-	Gas Corrosion Inhibitor	N/A
Cleaning pigging	Yes/No	No	No	Yes

4.1Calculation and Analysis of Probability of Failure

Probability of Failure (PoF) assessment of the four category indexes is carried out by giving points to each variable using the criteria explained in Chapter 3. Each category index has a maximum value of 100 points, so the maximum score on the total index is 400. The PoF calculation is carried out according to the methodology described in Chapter 3. The methodology is described by Kent Muhlbauer [7].

4.2Calculation of the Third Party Index

Based on research data obtained through interviews with experts, practitioners and workers involved, as well as company documents relating to these pipes, an evaluation was carried out to determine the risk of the Third Party Damage Index on three pipes, namely 4 in Gas Line Mike Mike , 8 in Gas Line Echo, and 8 in Gas Line Mike Mike. This evaluation uses a scoring system developed by Kent Muhlbauer [7]. The evaluation results are then presented in Table 4.2, Table 4.3, and Table 4.4. as follows:

Table 4. 2 Third Party Damage Index Pipa 4 in Gas Line Mike Mike

Factor	Variable	Max Score	Actual Score	Change of Failure
Third Party Damage Index	Depth of Cover	20	13	10%
	Activity Level	25	8	17%
	Abovegound Facilities	10	10	0%
	Damage Prevention	20	3	14%
	Rigth-of-Way Condition	5	5	0%
	Patrol Frequency	20	0	20%
Total Score		100	39	61%

Table 4. 3 Third Party Damage Index Pipa 8 in Gas Line Echo

Factor	Variable	Max Score	Actual Score	Change of Failure
Third Party Damage Index	Depth of Cover	20	13	10%
	Activity Level	25	8	17%
	Aboveground Facilities	10	10	0%
	Damage Prevention	20	3	14%
	Right-of-Way Condition	5	5	0%
	Patrol Frequency	20	0	20%
Total Score		100	39	61%

Table 4. 4 Third Party Damage Index Pipa 8 in Gas Line Mike Mike

Factor	Variable	Max Score	Change of Success	Change of Failure
Third Party Damage Index	Depth of Cover	20	13	10%
	Activity Level	25	8	17%
	Aboveground Facilities	10	10	0%
	Damage Prevention	20	3	14%
	Right-of-Way Condition	5	5	0%
	Patrol Frequency	20	0	20%
Total Score		100	39	61%

The assessment results in Tables 4.2, 4.3 and 4.4 show that the Third Party Damage Index variable score for each distribution pipe reaches a maximum scale of 100 points, with the assessment results as follows:

1. Mike Mike's 4 in Gas Line Distribution Pipe with a score of 39 points
2. 8 in Gas Line Echo Distribution Pipe with a score of 39 points
3. Mike Mike's 8 in Gas Line Distribution Pipe with a score of 39 points

It can be seen that the three distribution pipes have the same rating, namely 39 points, this is because the three distribution pipes are in the same environmental characteristics. In the Third Party Damage Index, the parameter that has the highest probability of failure value is Patrol Frequency. This is caused by not carrying out routine patrols, so the possibility of failure due to third parties increases. Kolaei, et al [8] also calculated the risk of third party damage using the Kent Muhlbauer index scoring method [7], where in the research of Correlation, et al [8] the distribution pipe studied transported gas fluid, this is relevant to the fluid transported in the pipe samples in this research.

4.3 Corrosion Index Assessment

Based on research data obtained through interviews with experts, practitioners and workers involved, as well as company documents relating to these pipes, an evaluation was carried out to determine the Corrosion Index risk assessment for three pipes, namely 4 in Gas Line Mike Mike, 8 in Gas Line Echo, and 8 in Gas Line Mike Mike as listed in Table 4.5, Table 4.6 and Table 4.7.

Table 4. 5 Corrosion Index Pipa 4 in Gas Line Mike Mike

Factor	Variable	Max Score	Average Score	Change of Failure
Corrosion Index	Product Corrosivity	10	0	10%
	Internal Protection	10	4	6%
	Water Corrosivity	15	0	15%
	Mechanical Corrosion	5	2	3%
	Service Age	10	0	10%
	Cathodic Protection Effectiveness	25	0	25%
	Coating Fitness	10	7	10%
	Coating Condition	15	10	3%
Total Score		100	23	77%

Table 4. 6 Corrosion Index Pipe 8 in Gas Line Echo

Factor	Variable	Max Score	Average Score	Change of Failure
Corrosion Index	Product Corrosivity	10	0	10%
	Internal Protection	10	4	6%
	Water Corrosivity	15	0	15%
	Mechanical Corrosion	5	2	3%
	Service Age	10	0	10%
	Cathodic Protection Effectiveness	25	0	25%
	Coating Fitness	10	7	10%
	Coating Condition	15	10	3%
Total Score		100	23	77%

Table 4. 7 Corrosion Index Pipa 8 in Gas Line Mike Mike

Factor	Variable	Max Score	Average Score	Change of Failure
Corrosion Index	Product Corrosivity	10	0	10%
	Internal Protection	10	4	6%
	Water Corrosivity	15	0	15%
	Mechanical Corrosion	5	2	3%
	Service Age	10	0	10%
	Cathodic Protection Effectiveness	25	0	25%
	Coating Fitness	10	7	10%
	Coating Condition	15	10	3%
Total Score		100	23	77%

4.4Design Index Assessment

Based on the results of data processing, the Design Index assessment obtained an overview of the risks for the Design Index for the 4 in Gas Line Mike Mike, 8 in Gas Line Echo, and 8 in Gas Line Mike Mike distribution pipes using the Kent Muhlbauer method [7] as shown in Table 4.8, Table 4.9 and Table 4.10.

Table 4. 8 Design Index for 4 in Gas Line Mike Mike Distribution Pipe

Factor	Variable	Max Score	Average Score	Change of Failure
Design Index	Safety Factor	35	21	14%
	Fatigue	15	3	12%

	Surge Potential	10	10	0%
	Integrity Verification	25	5	20%
	Stability	15	0	15%
Total Score		100	39	61%

Table 4. 9 Design Index for 8 in Gas Line Echo Distribution Pipe

Factor	**Variable**	**Max Score**	**Average Score**	**Change of Failure**
Design Index	Safety Factor	35	28	7%
	Fatigue	15	3	12%
	Surge Potential	10	10	0%
	Integrity Verification	25	5	20%
	Stability	15	0	15%
Total Score		100	46	54%

Table 4. 10 Design Index for 8 in Gas Line Mike Mike Distribution Pipe

Factor	**Variable**	**Max Score**	**Average Score**	**Change of Failure**
Design Index	Safety Factor	35	28	7%
	Fatigue	15	3	12%
	Surge Potential	10	10	0%
	Integrity Verification	25	5	20%
	Stability	15	0	15%
Total Score		100	46	54%

4.5Incorrect Operation Index assessment

Assessing the incorrect operation index based on the results of data processing, we obtained a risk picture for the design index for the 4 in Gas Line Mike Mike, 8 in Gas Line Echo, and 8 in Gas Line Mike Mike distribution pipes using the Kent Muhlbauer method [7] which was modified to the index The construction factor scoring is because the assessment is no longer relevant because the distribution pipe has passed its design period. Assessment of the incorrect operation index using the modified Kent Muhlbauer method [7] as shown in Table 4.11, Table 4.12, Table 4.13.

Table 4. 11 Incorrect Operation Index 4 in Gas Line Mike Mike Distribution Pipe

Factor	**Variable**	**Max Score**	**Average Score**	**Change of Failure**
Incorrect Operation Index	**Design**			
	Hazard Identification	5,3	5,3	0%
	MOP Potential	13,3	13,3	0%
	Safety System	11,3	6.17	5%
	Material Selection	3,3	3,3	0%
	Checks	3,3	3,3	0%
	Operation			
	Procedures	8,3	8,3	0%
	SCADA/Communication	4,3	0	4%
	Drug Testing	3,3	3,3	0%
	Safety Programs	3,3	3,3	0%
	Surveys/Maps/record	6,3	0	6.3%
	Training	11,3	7,91	3%
	Mechanical error preventers	7,3	1.26	6%
	Maintenance			
	Documentation	3,3	3,3	0%
	Schedule	4,3	4,3	0%
	Procedures	11,3	11,3	0%
Total Score		100	74.34	25.66%

Table 4. 12 Incorrect Operation Index 8 in Gas Line Echo Pipeline

Factor	**Variable**	**Max Score**	**Average Score**	**Change of Failure**
Incorrect Operation Index	**Design**			
	Hazard Identification	5,3	5,3	0%
	MOP Potential	13,3	13,3	0%
	Safety System	11,3	6.17	5%
	Material Selection	3,3	3,3	0%
	Checks	3,3	3,3	0%
	Operation			
	Procedures	8,3	8,3	0%
	SCADA/Communication	4,3	0	4%
	Drug Testing	3,3	3,3	0%
	Safety Programs	3,3	3,3	0%
	Surveys/Maps/record	6,3	0	6.3%
	Training	11,3	7,91	3%
	Mechanical error preventers	7,3	1.26	6%
	Maintenance			
	Documentation	3,3	3,3	0%
	Schedule	4,3	4,3	0%
	Procedures	11,3	11,3	0%
Total Score		100	74.34	25.66%

Table 4. 13 Incorrect Operation Index Distribution Pipe 8 in Gas Line Mike Mike

Factor	**Variable**	**Max Score**	**Average Score**	**Change of Failure**
Incorrect Operation Index	**Design**			
	Hazard Identification	5,3	5,3	0%
	MOP Potential	13,3	13,3	0%
	Safety System	11,3	6.17	5%
	Material Selection	3,3	3,3	0%
	Checks	3,3	3,3	0%
	Operation			
	Procedures	8,3	8,3	0%
	SCADA/Communication	4,3	0	4%
	Drug Testing	3,3	3,3	0%
	Safety Programs	3,3	3,3	0%
	Surveys/Maps/record	6,3	0	6.3%
	Training	11,3	7,91	3%
	Mechanical error preventers	7,3	1.26	6%
	Maintenance			
	Documentation	3,3	3,3	0%
	Schedule	4,3	4,3	0%
	Procedures	11,3	11,3	0%
Total Score		100	74.34	25.66%

4.6Analisis Consequence of Failure

Analysis of the Consequence of Failure (CoF) calculation using the Kent Muhlbauer method [7], namely calculating the impact of leaks which aims to state the magnitude of the consequences that will arise if a pipe failure or leak occurs. There are 4 factors that influence the magnitude of the impact if a pipeline leak occurs, namely:.

1. Product Hazard (product danger)
- Acute Hazard
- Chronic Hazard
2. Leak/ Spill Volume

3. Dispersion (spreading)

4. Receptor

Based on the results of calculations using the Kent Muhlbauer method [7], the Consequence of Failure results are obtained in Table 4.14 below:

Table 4. 14 Overview Consequence of Failure (CoF)

No	**Leak Impact Factor**	**Range Score**	**Section Pipeline**		
			4 in Gas Line Mike Mike	**8 in Gas Line Echo**	**8 in Gas Line Mike Mike**
A	**Product Hazard (PH)**	**0-22**	**9**	**9**	**9**
	Acute Hazard				
	Flammability (Nf)	0-4	4	4	4
	Toxicity (Nh)	0-4	1	1	1
	Reactivity (Nr) OP > 200 psi	0-4	2	2	2
	Chronic Hazard	**0-10**	**2**	**2**	**2**
	Reportable Quantity (RQ)				
	Fluid : Natural Gas RQ 5000 : 2 point				
B	**Leak Volume Factor (LV)** Table 7.12 Kent Muhlbauer		**1**	**1**	**1**
C	**Dispersion Factor (D)**		**3**	**3**	**3**
	Product : Flammable (natural gas)				
	Hazard Nature : Thermal				
	Hazard Model : Thermal radiation, vapor cloud, jet fire				
D	**Receptors (R)**		**2,4**	**2,4**	**2,4**
	Population Density		**1**	**1**	**1**
	High Value Area		**0,7**	**0,7**	**0,7**
	Environment		**0,7**	**0,7**	**0,7**
Total Score Leak Impact Factor			**64,8**	**64,8**	**64,8**

4.7Relative Risk

According to Kent Muhlbauer [7] the relative risk score is the division of the total index by the leak factor. The relative risk score is a score of the initial assumptions of the risk management process. To obtain an absolute risk score, it is necessary to calculate it based on pipe operations over several years. Calculation of relative risk using the Kent Muhlbauer method [7] for the three distribution pipes can be seen in Table 4.15 below:

Table 4. 15 Relative Risk

Section	**Third Party Damage**	**Corrosion**	**Design**	**Incorrect Operation**	**Index Sum**	**Leak Impact Factor**	**Relative Risk Score**
4 in Gas Line Mike Mike	39	23	39	74,34	175,34	50,4	3,48
8 in Gas Line Echo	39	23	46	74,34	182,34	50,4	3,62
8 in Gas Line Mike Mike	39	23	46	74,34	182,34	50,4	3,62

The relative risk score value according to Kolaei, et al [8] is divided into 4 (four) risk level categories as shown in Table 4.16 below:

Table 4. 16 Risk Criteria Tables [8]

No	Risk Score	Risk Level
1	6-7	**Very high**
2	7-8	**High**
3	8-9	**Medium**
4	9-10	**Low**

In determining the risk level for the three distribution pipes, risk criteria from Kolase, et al [8] are also used. These risk criteria are relevant to the sample of distribution pipes studied because in Correlation, et al. s research [8] it was also gas distribution pipes. The risk level results for the three distribution pipes can be seen in table 4.17 below:

Table 4. 17 Risk Criteria for the Three Distribution Pipes

Pipe Section	Risk Score	Risk Assessment
4 in Gas Line Mike Mike	2,71	**Very high**
8 in Gas Line Echo	2,81	**Very high**
8 in Gas Line Mike Mike	2,81	**Very high**

The results of the relative risk score recapitulation above show that the three distribution pipes received very high risk scores. A low relative risk score is influenced by the leak impact factor value. Population density and flow rate carried by pipes are the main factors that influence differences in leak impact factor values. Based on the results of the relative risk score, it is necessary to carry out a more comprehensive inspection of the distribution pipe in order to obtain appropriate mitigation steps to reduce the risk.

5 DISCUSSION

In this study, a modification of the Kent Muhlbauer method [7] was conducted, incorporating the service age factor into the assessment of the Corrosion Index of distribution pipes. According to Ke Shan et al. [9], the service age significantly impacts the integrity of distribution pipes, necessitating the inclusion of this factor in the corrosion index evaluation. The age of the distribution pipe plays a crucial role in its integrity, as the bathtub failure rate curve theoretically elongates with increasing pipe age, thereby raising the likelihood of failure. Consequently, the service age or age of the pipeline was incorporated in the assessment of the corrosion index. Based on the assessment results presented in Tables 4.6, 4.7, and 4.8, it can be inferred that the Corrosion Index variable for the Gas Line Mike Mike (4), Gas Line Echo (8), and Gas Line Mike Mike (8) distribution pipes has an average score of 23 points out of a maximum scale of 100 points. This indicates an average probability of 77% for the distribution pipes to fail. In this index, the atmospheric corrosion variable is not applicable, as all assessed pipe sections are located below sea level. Consequently, the variables of water corrosivity, service age, and cathodic protection pose the highest risk factors in this index. This is attributed to the highly corrosive seawater environment with low resistivity in which the three pipes are installed. According to Kent Muhlbauer [7], variables related to seawater corrosion, distribution pipe age, and the cathodic protection system can contribute to a high-risk value.

All three distribution pipes exhibit a high-risk value since they have never been internally monitored for corrosion, which could mitigate potential issues. Additionally, surveys on the effectiveness of cathodic protection and the potential for interference from other metal materials have not been conducted in the last 5 years. The last recorded CP measurement value was 774-785 mV, which remains below the permitted value, influencing the assessment results. Considering that the transported fluid is gas, including corrosive elements such as H2S and CO2, there is an increased risk of corrosion. To counteract this, chemical injection with a C surfactant as a water corrosion inhibitor is generally performed on the three pipes. Monitoring activities involving corrosion coupons/probes are conducted to monitor the rate of internal corrosion. These pipes are protected by coating to prevent external corrosion, and additional measures such as Cathodic Protection (CP) are installed to offer supplementary protection in case of pipe coating failure resulting from mechanical damage, disbondment, or the incorrect choice of coating type. Particularly for underwater pipes, installing CP over a specific distance range is crucial.

Based on the assessment, the average probability of failure for the Gas Line Mike Mike (4), Gas Line Echo (8), and Gas Line Mike Mike (8) distribution pipes is determined to be 61%, 54%, and 54%, respectively. Tables 4.8, 4.9, and 4.10 reveal that integrity verification is the most critical variable in these distribution pipes. To detect early anomalies, pressure tests and in-line inspection (ILI) activities are essential. Distribution pipe inspections can be conducted both internally and externally using a pig or Remote Operating Vehicle (ROV). However, ILI cannot be performed on these three distribution pipelines due to the absence of Pig Launcher and Pig Receiver facilities. The fatigue variable is considerably high due to the age of the pipes reaching 34 years, 39 years, and 40 years. Piping is prone to leaks as it is susceptible to vibration loads, mechanical loads, and thermal fatigue. The safety factor variable is satisfactory, considering that the operating pressure of the pipes is well below the specified design pressure. The stability variable in the design index also contributes to the elevated risk level at the distribution pipe location, which is an area prone to landslides. In a similar study on gas distribution pipes, Kolaei et al. [8] utilized the Kent Muhlbauer [7] index scoring method to calculate the risk design index, demonstrating relevance to the current research, where the three distribution pipes studied are also gas distribution pipes.

In the assessment of incorrect operations, the most risky factor is the operating system due to the lack of survey activities on the distribution pipe. Maintenance also influences the assessment of incorrect operations, despite yielding low risk results. In practice, maintenance is carried out using the run-to-fail method, repairing activities only when a leak occurs in the pipe. The run-to-fail method is typically employed in offshore oil and gas installations, as it is simpler than the preventive maintenance approach, where the actual condition of the distribution pipe cannot be ascertained by ILI. The consequences of a leaking gas pipe under the sea include environmental pollution, fires, property damage, and loss of production. Therefore, an appropriate inspection strategy is imperative, aligning with the identified level of risk.

In the scoring system, an increase in score signifies an increase in the level of security. Recalling the concept of the probability of failure (index sum), where a higher score corresponds to increased security levels. Conversely, the concept of the consequences of failure (leak impact factor) is inversely proportional, meaning that a higher score indicates a greater risk of occurrence. The relative risk score is calculated by dividing the index sum by the leak impact factor, representing the system's ability to withstand the consequences that may arise.

Internal corrosion damage mechanisms in subsea distribution pipes at PT are evident from the leak history data, aligning with the risk analysis results on the three distribution pipe samples, where the corrosion variable had the highest damage factor.

The implementation of internal corrosion inspection methods typically utilizes in-line inspection (ILI). Since ILI cannot be conducted on the three distribution pipe samples, conventional data collection to measure the wall thickness of the distribution pipe is performed using the NDT inspection method, specifically Ultrasonic Testing (UT). The UT method has its limitations, requiring appropriate surface preparation before data collection. Considering the operational conditions of the three distribution pipes at PT, it becomes crucial to prioritize determining inspection points deemed critical and representative of the internal condition of subsea pipelines. In determining these inspection points, the NACE Internal Corrosion Direct Assessment (ICDA) reference is utilized [10].

NACE conducted a study before releasing the standard, developing the ICDA methodology based on characteristics, conditions, and flow assurance studies on distribution pipes. According to Jaragh et al. [11], ICDA simulation results demonstrate the validity and suitability of the comparison data with intelligent pigging results. The use of the ICDA method can reduce uncertainty in determining the rate of corrosion, metal loss, and inspection location of distribution pipes, thereby increasing confidence in determining the integrity and remaining life of distribution pipes. In conclusion, the NACE ICDA can serve as a method for determining internal inspection points, potentially replacing ILI.

External corrosion damage mechanisms, usually attributed to low cathodic protection (CP) values, do not significantly occur on distribution pipes in the PT XYZ environment. Interviews and reports from PT indicate less than 10 points for external corrosion when compared to the hundreds or thousands of points of internal corrosion, depending on the length of each distribution pipe [2]. This external corrosion approach was applied to ILI results of other distribution pipes since the three distribution pipe samples lacked ILI data.

Pipe failures related to free spans generally occur due to local buckling or vortex-induced vibration in the distribution pipe. Vortex-induced vibration, causing fatigue, results from the free span length exceeding its maximum allowable length. However, based on interviews and free span inspection reports, free spans at PT

can be identified through surveys using a diver or remotely operated vehicle (ROV). Floerl et al. [12] mention that inspection surveys using divers or ROVs can be expensive.
According to Floerl, et al [12] the cost and effort of an inspection strategy will be directly proportional to the level of risk category. This was also confirmed by Steenvoorde [3] who said that inspection of offshore distribution pipes is not easy and requires quite a lot of money. Therefore, so that the inspection strategy can be optimal, effective and efficient, it is divided into 3 (three) risk categories, namely low, medium and high/very high, where the selection of the inspection strategy is according to the level of risk. So it can be concluded that the appropriate inspection policy strategy plan according to the risk category is as follows:

1. Low Risk Category, inspections that need to be carried out are:
a. Visual inspection (ROV)
b. Free Span assessment
c. Cathodic protection (CP) check
d. UT thickness inspection on riser and elbow (topside)
e. Inspection period every 4 years or based on Risk Based Inspection (RBI)
2. Medium Risk Category, inspections that need to be carried out are:
a. Visual inspection (ROV)
b. Free Span assessment
c. Cathodic protection (CP) check
d. UT thickness inspection on riser and elbow (topside and subsea)
e. Inspection period is once every 4 years or based on Risk Based Inspection (RBI)
3. High/Very High Risk category, the inspections that need to be carried out are:
a. Visual inspection (ROV)
b. Free Span assessment
c. Checking cathodic protection
d. UT thickness inspection on riser and elbow (topside and subsea)
e. UT thickness inspection on pipe sections using the NACE ICDA method for thickness taking points
Inspection period every 4 years or based on Risk Based Inspection (RBI)

6. CONCLUSION

The level of risk for the three subsea distribution pipes at Company

7. SUGGESTION

In order to realize an optimal, effective and efficient strategic plan, it is recommended that the inspection strategy policy be divided into 3 categories based on the level of risk, namely low, medium and high/very high

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