Proceedings of the ASME 2024 43rd International Conference on Ocean, Offshore and Arctic Engineering
OMAE2024
June 9-14, 2024, Singapore, Singapore

OMAE2024-124032

PETRO-AIMS: IMPLEMENTATION OF MUHLBAUER AND EL REEDY METHOD FOR INTEGRATED SUBSEA PIPELINE AND OFFSHORE PLATFORM INTEGRITY MANAGEMENT SYSTEM

Maulidiyah Pravi[1], Farid Putra Bakti[1,2], Frederick Gavin Surjadi[1]

[1]Mineering Energi Internasional, Indonesia
[2]Institut Teknologi Bandung, Indonesia

ABSTRACT

This study investigates the implementation of combining two risk assessment methods that was developed for two distinct types of assets: the Muhlbauer and El Reedy techniques. The Muhlbauer method was developed for pipeline assets, while the El Reedy method was developed for offshore jacket platform assets. Even though they were developed for different type of assets, both Muhlbauer and El Reedy method uses the same straight-forward semi-quantitative risk assessment framework. The implementation of combining the two method is done within a web-based asset integrity management system: Petro-AIMS environment. To demonstrate a real-world case application of the proposed method, the data from four offshore platforms that are connected to ~70 km offshore subsea pipeline is investigated. By implementing the same Likelihood of Failure (LoF) and Consequence of Failure (CoF) assessment framework for two different asset type, it is shown that Petro-AIMS is projected to be a practical and effective tool to perform asset integrity management function.

Keywords: *Asset Integrity Management System, Pipeline Risk Analysis, Offshore Platform Risk Analysis*

1. INTRODUCTION

Nowadays, many offshore platforms and pipeline in Indonesia is reaching or exceeding their original anticipated design life. Therefore, there is a particular need to evaluate the structural integrity and to ascertain their safety and operability. The risk of asset failure should be mitigated by lowering the risk factor as low as reasonably possible. Therefore, it is imperative that the inspection, repair, and maintenance works are done based on the asset's relative risk values. To do that, a reliable, versatile, and effective risk-based Asset Integrity Management System (AIMS) need to be adopted.

In this study, Petro-AIMS that was developed by PT Mineering Energi International is investigated. The objective of the system is to capture, analyze and report the Asset Integrity of the offshore platforms and its associated costs. Petro-AIMS gather all of the AIM information and documentation in one large manageable database while at the same time being able to analyze the results to help key decision making. It also manages and tracks proposed recommendations for improvements accompanying documentation (drawings, photographs, and assessments).

One of the most integral aspects of the Petro-AIMS system is the Structural Integrity Management. In Petro-AIMS, The Structural Integrity are defined as the ability of a structure to perform its required function effectively and efficiently over a defined time period whilst protecting health, safety, and the environment. The structural integrity module covers not only the jacket itself but also the topsides, process equipment, risers, conductors, and pipelines.

There are various methods to determine the risk in offshore platform and subsea pipeline assets. For example Tawekal R.L. [1-2] and Tawekal J.R. [3] discussed a quantitative risk analysis for platform assets, while Tanujaya [4], Dwikowski [5], and De Stefani [6] discussed quantitative risk assessment methods for pipeline assets. The present study focused on the platform and subsea pipeline semi-quantitative risk analysis implementation in Petro-AIMS. In the semi-quantitative method, the risk categorization is done by qualitatively defining the scoring rules of each risk factors, and then quantitatively evaluate the risk by using those pre-determined score matrices. The overview of the semi-quantitative risk analysis used in this study might be found in figure 1 below.

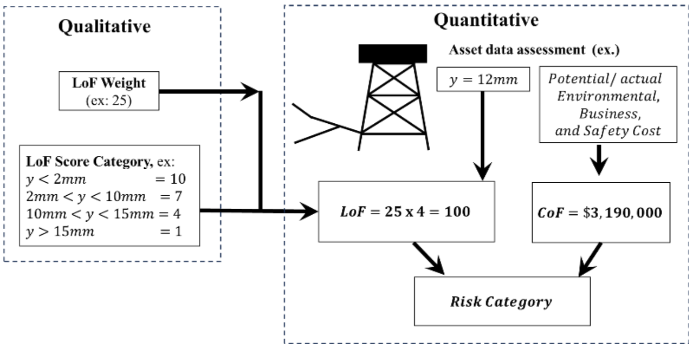

FIGURE 1: SEMI QUANTITATIVE RISK ANALYSIS ILLUSTRATION, USED IN BOTH EL REEDY [7] AND MUHLBAUER [8]

The semi-quantitative risk analysis method implemented in Petro-AIMS was comprehensively discussed by El Reedy [7] for jacket type platform assets and by Muhlbauer [8] and Akbarinia [9] for pipeline assets. However, there is still lack of AIM systems that exploit the framework similarity between El Reedy and Muhlbauer method. Petro-AIMS combine the El-Reedy and Muhlbauer method in its system, effectively opening up many possibilities for new decision-making tool developments. This study will show how both El Reedy and Muhlbauer method are compatible with each other, what are the most sensitive risk factor in both methods, cross-implementation case study, and the benefit of implementing semi-quantitative risk analysis approach.

2. PLATFORM LIKELIHOOD OF FAILURE (LoF^{PL})

Structural platform assessment techniques are based on El Reedy [7], the likelihood of failure that leads to structural collapse are identified into two main factors, the platform strength (or capacity) and loads. Note that in the semi-quantitative method, a maximum LoF score (100% score from max) does not necessarily means that the platform has the probability of failure of one (100%).

There are several factors that affect the platform strength capacity. For example, different number of legs and different framing schemes will contribute different strength capacity. Other factors that are also affect the platform strength are years of construction (design practice), pile system, number of risers and conductors, number of boat landings, pile system, number of damaged, missing, and cut members, number of flooded members, splash zone, record of CP Survey and anode depletion, inspection story, and remaining thickness.

The loads may come from loadings that are already considered in the initial designs, or changes in the platform condition that might affect the loading. The latter may come in various forms, such as additional boat landings and marine growths. In overall, the load factors that are considered to increase the platform likelihood of failure are marine growth, scour, topside weight change, additional risers, caissons, and conductors, wave-in deck, and earthquake. Considering all of the LoF factors, the platform Likelihood of Failure can be found from:

$$LoF^{PL} = \sum_{\substack{\text{Asset Data} \\ i= \text{Strength} \\ \text{Load}}} [Weight_i \text{ x } Score_i] \quad (1)$$

To accommodate the relative influence of each factor, each factor has different weight based on El Reedy techniques [7], each of the factor weight and score to obtain the Platform LoF show in table 1. Based on this data, damage members & missing or cut members contribute the most significantly to LoF score, while marine growth contribute the least.

TABLE 1: PLATFORM LIKELIHOOD OF FAILURE (LOF) SCORE AND WEIGHT

Platform LoF (LoF^{PL})	Weight	Score
Asset Data		
Design Practice	6.00	0 - 10
Bracing Configuration and Number of Legs	10.00	0 - 10
Additional Boat Landings	5.00	0 - 10
Pile Strength and Disturbance	10.00	0 - 10
Risers and Conductors	7.00	0 - 10
Grouted Piles	3.00	0 - 10
Strength Factor		
Damaged Members & Missing or Cut Members	21.00	0 - 10
Inspection History	6.00	0 - 10
Flooded Member Effect	8.00	0 - 10
Splash-Zone Corrosion and Damage	8.00	0 - 10
Cathodic Protection	6.00	0 - 10
Remaining Wall Thickness	8.00	0 - 10
Load Factor		
Topside Weight Change	10.00	0 - 10
Year of Design (Another Location)	6.00	0 - 10
Additional Risers or Conductors	10.00	0 - 10
Marine Growth	5.00	0 - 10
Scour	6.00	0 - 10
Seismic Load	8.00	0 - 10
Wave in Deck	25.00	0 - 10

3. PIPELINE LIKELIHOOD OF FAILURE (LoF^{SP})

Pipeline likelihood of failure factors are assessed using the Muhlbauer [8] approach. Just like the platform LoF determination, the Muhlbauer approach also divided the LoF into several main failure categories (or factors), which is then divided into their sub-categories. Note that a maximum LoF score (100% score from max) does not directly translate to a probability of failure of one (100%).

In the Muhlbauer method, LoF of pipeline assets are divided into four main factors: third party factors, design factors, operation & construction factors, and corrosion factors. For Pipeline, the score weight of these factors can be adjusted by users, providing the users to calculate LoF based on most representative historical pipeline failure data. For example, if the pipeline is located in the recreational area or shipping lanes, the third-party factors will play bigger role in for the LoF score, rather than in secluded area (see ref. DNV RP-F116 Integrity Management of Submarine Pipeline Systems, Figure A-3 as example). The Pipeline Likelihood of Failure can be found from:

$$LoF^{SP} = \sum_{i=\substack{3^{rd}\ party\ damage \\ Design \\ Operation\ Construction \\ Corrosion}} [Weight_i \text{ x } Score_i] \quad (2)$$

In addition, the Pipeline LoF can be obtained with the following weight and score shown in table 2.

TABLE 2: PIPELINE LIKELIHOOD OF FAILURE (LOF) SCORE AND WEIGHT

Pipeline LoF (LoF^{SP})	Weight (Default)	Score
Corrosion Factor		
Mechanical Corrosion	2.50	0 - 10
Internal Corrosion	6.25	0 - 10
External Corrosion	16.25	0 - 10
Safety Operation & Construction Factor		
Hazard Mitigation Factor	8.75	0 - 10
Inspection and Construction Execution	5.00	0 - 10
Operation Procedure	6.25	0 - 10
Maintenance Procedure	5.00	0 - 10
Design Factor		
Safety	8.75	0 - 10
Fatigue	3.75	0 - 10
Integrity Verification	6.25	0 - 10
On Bottom Stability	6.25	0 - 10
Third Party Damage Factor		
Backfill/Trenching Protection	6.25	0 - 10
Activity Level Threat	8.75	0 - 10
Surface/Above Ground Facilities Factor	3.75	0 - 10
Damage Prevention	6.25	0 - 10

4. CONSEQUENCE OF FAILURE (CoF)

Both for pipeline and platform consequences of failures (CoF) are evaluated by using El Reedy [7] approach. The El Reedy approach is a financial based CoF, which is highly versatile. In this study, a three component and simplified financial based CoF calculation is presented. However, these factors and calculation steps can be easily adjusted if the company has their own method in calculating how asset failure may impact their company financially.

El Reedy proposed that the CoF can be calculated by the total sum of three main financial loses components: environmental losses (C_E), business losses (C_B), and safety losses (C_s)

$$CoF = C_E + C_B + C_S \quad (3)$$

The environmental loses [7] are calculated based on the fixed environmental cost (F_C), significant distance offshore function $f(d)$, marginal variable cost V_C, daily production (D_P), and minimum released oil (R). These factors are included to account for the clean-up effort, lawsuit and fines, natural resource damage, and 3rd party retributions. To account for the high difficulty of shoreline clean-up process, the distance to shoreline is represented by the $f(d)$ function which gradually decreases as it go further offshore.

$$C_E = f(d) \times \{F_C + V_C \times min(D_P, R)\} \quad (4)$$

Based on El Reedy, the highest consequence cost is the fixed environmental cost (F_C) in open sea, on this study the reference for environmental cases is referred to Cost of Bouchard Oil Spill 2023 [12].

Business losses [7] are sum of deferred production loss (C_{DP}) and replacement cost (C_R). For offshore assets, the replacement costs are typically a more significant contributor rather than deferred production cost due to the difficulty in accessing underwater and offshore infrastructures.

$$C_B = C_{DP} + C_R \quad (5)$$

Safety losses C_S [7] calculation is equal to the number of people exposed (C_{ex}), multiplied by the location and the marginal safety loss per person (N) as a result of failure. G is the penalty factor for assets involving gas hydrocarbon which increases the overall C_S by 20% to account for the volatility and higher explosivity of the substance.

$$C_S = C_{ex} \times N \times G \quad (6)$$

5. Risk Categorization

Both LoF and CoF categorization of both platforms and pipeline assets are assessed in terms of their Cumulative Distribution Function (CDF). Two CDF calculation are conducted in the study to see their effects on the overall risk category: the first is by direct data ranking, the second is by equivalent normal distribution function. The categorization range criteria used in the Petro-AIMS are based on El Reedy [7], as shown in table 3.

TABLE 3. CDF FOR LIKELIHOOD SCORE BASED ON EL REEDY [7]

Category	Range	CDF
1	≤S1	≤5%
2	S1-S2	5% - 50%
3	S2-S3	50% - 70%
4	S3-S4	70% - 95%
5	>S4	>95%

Consequence

Likelihood	A	B	C	D	E
1	Y	Y	Y	R	R
2	G	G	Y	Y	R
3	W	W	G	Y	R
4	W	W	G	G	Y
5	W	W	G	G	Y

FIGURE 2: RISK MATRIX PROPOSED BY API FOR THE CATEGORIZATION OF QUALITATIVE RISK [10]

By implementing these LoF and CoF score categorization, the risk can then be directly evaluated by using the typical five-by-five matrix that recommended by API (figure 2). Alternatively, since both the LoF and the CoF are evaluated quantitatively, Risk can also be evaluated by CDF categorization similar to LoF and CoF, by using the following equation (figure 3):

$$Risk = LoF \times CoF \tag{3}$$

The present study will focus on the alternative method of direct LoF and CoF multiplication, taking advantage of the quantitative LoF and CoF evaluation.

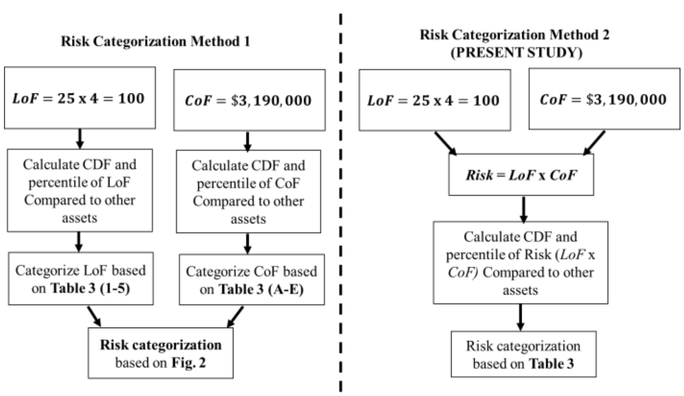

FIGURE 3: RISK CATEGORIZATION VARIATION USED IN THE PRESENT STUDY

6. PLATFORM AND PIPELINE GENERAL DATA

Platform and Pipeline data was investigated for four platforms that are connected to ~70 km offshore pipeline. All assets are located offshore of the north coast island which has high marine traffic activities but relatively low sea states. The assets location and interconnectivity illustration can be seen in figure 4. The platform assets general description is shown in table 4, while the pipeline assets general description are shown in table 5.

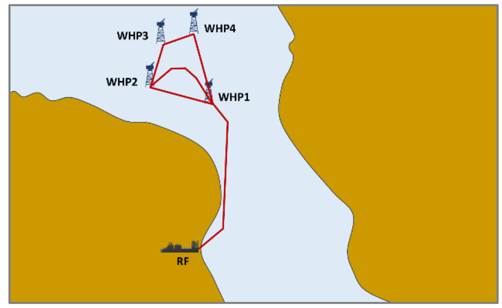

FIGURE 4: PLATFORM AND PIPELINE ILLUSTRATION LOCATION

TABLE 4: PLATFORM ASSETS

Assets Name	Depth	Number of Legs	Type
WHP1	12.0 m	4 legs	Well Head Platform
WHP2	7.0 m	8 legs	Well Head Platform
WHP3	31.5 m	3 legs	Well Head Platform
WHP4	12.5 m	3 legs	Well Head Platform

TABLE 5: PIPELINE ASSETS

Pipeline Name	Pipeline Size	Length (km)	Location From	Location To
18" WHP1-RF	18”	40.00	WHP1	RF
16" WHP2-WHP1	16"	8.00	WHP2	WHP1
12" WHP1-WHP2	12"	5.50	WHP1	WHP2
6" WHP2-WHP1	6"	8.00	WHP2	WHP1
12" WHP3-WHP4	12"	2.40	WHP3	WHP4
6" WHP4-WHP3	6"	2.41	WHP4	WHP3
12" WHP4-WHP2	12"	1.80	WHP4	WHP2
6" WHP2-WHP4	6"	1.80	WHP2	WHP4

In addition to the actual pipeline and platform asset data, several hypothetical cases are added for sensitivity analysis, providing more comprehensive understanding of the semi-quantitative risk evaluation method behavior. In the sensitivity analysis, the default data set is expanded by changing one asset data at a time from a baseline case, while other data are kept constant. For this sensitivity analysis, the platform WHP1 and 16” WHP2-WHP1 pipeline is chosen as the default or baseline data. The illustration of the sensitivity study case is shown in figure 5. A total of 20 cases for platform LoF, 30 cases for pipeline LoF, and 12 cases for CoF analysis are expanded from the baseline data. The whole data set that are considered in this study is shown in table 6 and table 7.

TABLE 6: PIPELINE LOF AND COF ADDITIONAL DATA SET FOR SENSITIVITY ANALYSIS, EXPANDED FROM 16" WHP2-WHP1 PIPELINE DEFAULT DATA

Additional Data Set for Pipeline LoF Sensitivity Study
C1 Op stress < 60% specified minimum yield
C10 Non-owned, no involvement
C11 Inspection -> non
C12 Construction -> non
C13 Written op procedure -> non
C14 Downtime -> 30 days
C15 Written main procedure -> non
C16 Written main schedule -> non
C17 Actual/design WT >1.8
C18 Hydrostatic pressure/MOP <1
C19 Hydrostatic pressure date test > 10 years
C2 Operating Temp < 100F
C20 Design fatigue 15 yrs Rem fat 5 yrs
C21 Integrity Ver -> No inspection
C22 Stability Mitigation -> Non
C23 Foreign crossing -> High
C24 Fishing/crabbing -> High
C25 Anchoring -> High
C26 Water depth >100m
C27 Shore approach -> yes
C28 Distance to ground facility > 1km
C29 Route Maps -> non
C3 Age < 10 years
C30 Right of Way -> poor
C4 Strongly Corrosive
C5 Never Corrosive
C6 No internal protection
C7 Sacrificial Anode <100% consumed
C8 CP Potential >5mV/m
C9 MOP Potential: High
Default/Baseline
WHP1-RF KP 00-15
WHP1-RF KP 15-30
WHP1-RF KP 30-40
WHP2-WHP1 KP00-08
WHP2-WHP1 KP00-08
WHP2-WHP1 KP00-08
WHP2-WHP4 KP00-08
WHP3-WHP4 KP00-08
WHP3-WHP4 KP00-08
WHP4-WHP2 KP00-08

Additional Data Set for Platform CoF Sensitivity Study
WHP1-RF KP 00-15
WHP1-RF KP 15-30
WHP1-RF KP 30-40
WHP1-WHP2 KP00-08
WHP2-WHP1 KP00-08
WHP2-WHP1 KP00-08 - CB Annual rate of return on investment 15%
WHP2-WHP1 KP00-08 - CB Daily Gas Production 133.18
WHP2-WHP1 KP00-08 - CB Gas Price 86.98 USD/MMBTU
WHP2-WHP1 KP00-08 - CB Number of down time 90
WHP2-WHP1 KP00-08 - CB Oil Price 182.01 USD/bbl
WHP2-WHP1 KP00-08 - CB Replacement Cost 35400000
WHP2-WHP1 KP00-08 (Default)
WHP2-WHP4 KP00-08
WHP3-WHP4 KP00-08
WHP4-WHP2 KP00-08
WHP4-WHP3 KP00-08
WHP2-WHP1 KP00-08 - CE Distance offshore > dist offshore to open sea
WHP2-WHP1 KP00-08 - CE Min released oil 5000 bpd
WHP2-WHP1 KP00-08 - CS Not produce gas
WHP2-WHP1 KP00-08 - CS Number of Crew 10
WHP2-WHP1 KP00-08 - CS Number of Crew 2
WHP2-WHP1 KP00-08 - CS Number of Crew 50

TABLE 7: PLATFORM LOF AND COF ADDITIONAL DATA SET FOR SENSITIVITY ANALYSIS, EXPANDED FROM WHP1 PLATFORM DEFAULT DATA

Additional Data Set for Platform LoF Sensitivity Study
Bracing System - K and Diamond
Bracing System - Unknown
Bracing System - X
Earthquake Load - 0.3g
Earthquake Load - 0.4g
Earthquake Load - 0.5g
Grouted Piles - Non
Number of Boat Landing - 2
Number of Boat Landing - 3
Number of Boat Landing - 5 - >10
Number of Conductors - 8-10
Number of Legs - 3
Number of Legs - 6
Number of Legs - 8
Pile - not exist
WHP 1
WHP 1 Default
WHP 2
WHP 3
WHP 4
Year of Installation - 1966
Year of Installation - 1976
Year of Installation - 1986
Year of Installation - 1996

Additional Data Set for Platform CoF Sensitivity Study
WHP 4
WHP 3
WHP 2
WHP 1 Default
CS - Number of Crew 50
CS - Number of Crew 10
CS - Number of Crew 0
CS - Not produce gas
CE - Distance offshore > dist offshore to open sea
CE - Daily Oil Prod > default (750)
CB - Replacement Cost 35785000
CB - Oil Price 162.01 USD/bbl
CB - Number of down time 90
CB - Gas Price 36.98 USD/MMBTU
CB - Daily Gas Production 32.64
CB - Annual rate of return on investment 15%

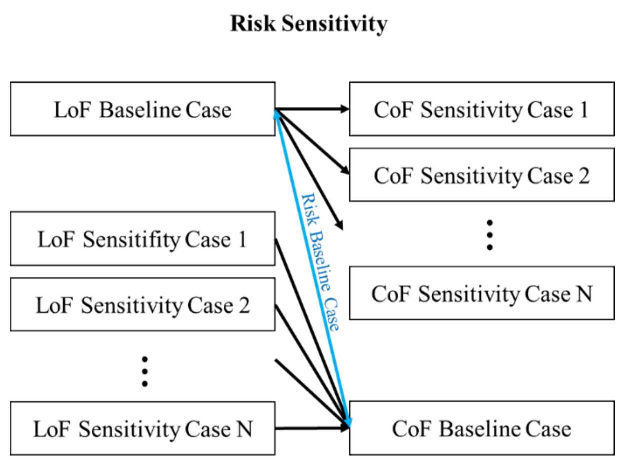

FIGURE 5: RISK SENSITIVITY CASE

7. PETRO-AIMS PLATFORM AND PIPELINE RISK ANALYSIS

The platform risk analysis results are presented in figure 6 – figure 8, while the pipeline risk analysis results are presented in figure 9 – figure 11. From the results, the use of direct data ranking for LoF, CoF, and Risk categorization resulted in at least one asset always be classified in the highest category (category 5). Therefore, one need to always keep in mind that the risk analysis presented here is done in relative manner. Once a mitigative / reparative action is taken, other asset will take over as the asset with the highest risk category. To mitigate this problem when asset data is scarce, the normal distribution approach is also presented as an alternative. From the analysis, platform with the highest risk category is WHP1 platform without piling data. On the other hand, pipeline with the highest risk category is the 6" WHP2-WHP4 pipeline without inspection data. Worst case in platform assets come from the hypothetical case sensitivity analysis data set. On the other hand, the worst case in pipeline assets come from actual field data.

The summary of category level comparison between LoF, CoF, and Risk is shown in table 8. For example, out of a total of 24 cases in the platform asset LoF, there are 9 data in normal dist. method which category increases when compared to the same data point in the direct data ranking method (hence the 9/24 value in the first cell in table 8). It can be seen that both the platform LoF, pipeline CoF and pipeline risk overall category with normal distribution CDF tends to be higher than that of direct data ranking CDF. The opposite trend occurs on the platform CoF and pipeline LoF. Meanwhile, the platform risk comparison shows almost identical number of category change to higher and lower categories when using normal distribution CDF, effectively nullifying the discrepancies. Based on table 8 analysis, we suggest the user to use the normal distribution CDF with caution, especially when dealing with platform LoF and pipeline risk categorization.

TABLE 8: CHANGE IN THE LOF, COF, AND RISK CATEGORIZATION FOR NORMAL DISTRIBUTION CATEGORY VS DATA RANKING CATEGORY

Normal dist. category when compared to direct data ranking category		LoF	CoF	Risk
Category difference in Platform asset	Higher	9/24	0/16	7/36
	Lower	1/24	3/16	8/36
Category difference in Pipeline asset	Higher	1/41	5/22	25/54
	Lower	8/41	2/22	5/54

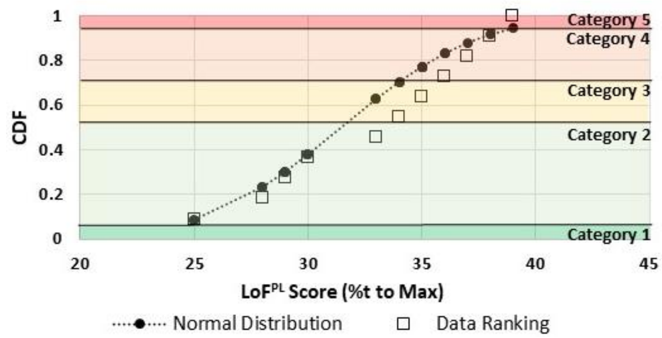

FIGURE 6: PLATFORM LOF

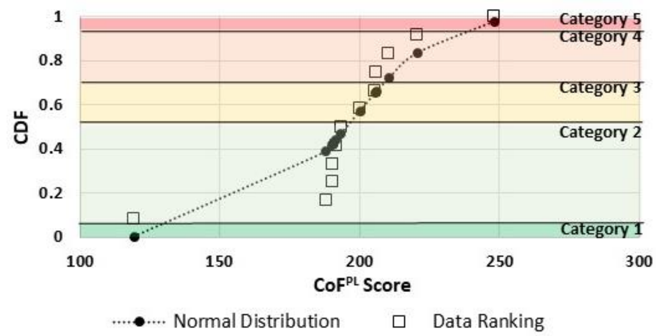

FIGURE 7: PLATFORM COF (IN MIL. USD)

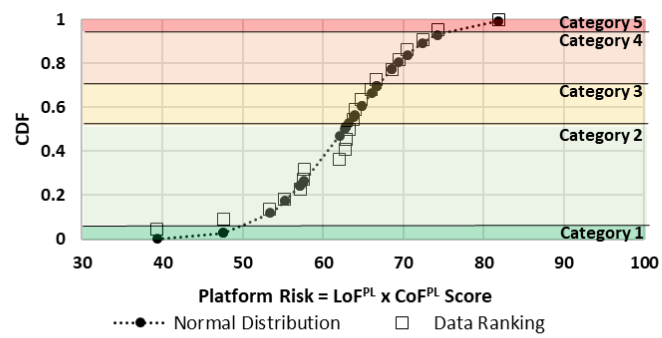

FIGURE 8: PLATFORM RISK = LOF^{PL} X COF^{PL}

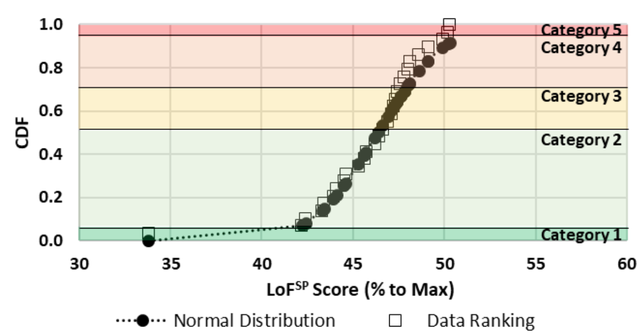

FIGURE 9: PIPELINE LOF^{SP}

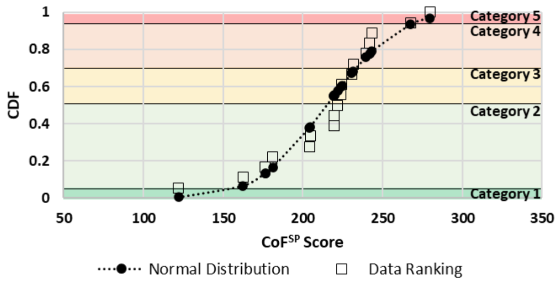

FIGURE 10: PIPELINE COF (IN MIL. USD)

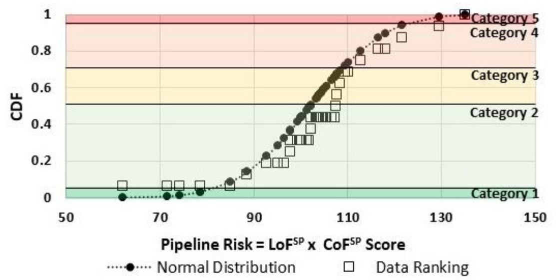

FIGURE 11: PIPELINE RISK = LOF^{SP} X COF^{SP}

8. LoF SENSITIVITY ANALYSIS

Several hypothetical cases as defined in table 6 and table 7 are run in Petro-AIMS to provide the sensitivity analysis results, which are shown in table 9 and table 10.

Based on the sensitivity analysis, the third-party factor is the most significant factor in determining the pipeline LoF. When compared to the baseline pipeline data where the pipeline is located on water depth smaller than 100m, the same pipeline that is located on deeper water depth has LoF score that is decreased by 12% (from the max score value). This occurs because in the shallower water depth the anchoring, fallen object impact, fish trawler, burial requirement, and waves risk factor increases dramatically. The second most significant factor in determining the pipeline LoF is the design factor, specifically the integrity verification factor. The baseline pipeline data consider a thorough integrity verification was conducted in 2022. When no integrity verification was conducted in the last 5 years from the data input date, the LoF of the pipeline increases by 4% (from the max score value).

For the platform sensitivity analysis, the change in load factors due to additional members (i.e. number of conductors, number of boat landings) is found to be insignificant to the change in the total LoF score. The most significant contributor to the total LoF score are the earthquake, year of installations, and the existance of piling data.

In Petro-AIMS system, user can adjust the importance of each LoF factors by adjusting the weighing factors. The actual weighing factor that is used should be based on the local failure data, as might be found on ref. DNV RP-F116 Integrity Management of Submarine Pipeline Systems for pipeline assets. The ability to adjust these factors according to local conditions shows the versatility of the Petro-AIMS.

TABLE 9: PIPELINE LOF^{SP} SENSITIVITY ANALYSIS RESULTS

Pipeline Asset	LoF^{SP}				
	Third Party	Design	Op. & Cons.	Corrosion	Total
C26 Water depth >100m	9.8%	9.2%	0.6%	14.2%	33.8%
C28 Distance to ground facility > 1km	18.2%	9.2%	0.6%	14.2%	42.2%
WHP2-WHP1 KP00-08	13.0%	11.9%	10.3%	7.2%	42.4%
C5 Never Corrosive	22.2%	9.2%	0.6%	11.3%	43.3%
WHP3-WHP4 KP00-08	6.5%	16.5%	8.4%	12.0%	43.4%
C1 Op stress < 60% specified minimum yield	22.2%	7.5%	0.6%	13.6%	43.9%
WHP1-RF KP 30-40	14.9%	13.8%	10.4%	5.0%	44.1%
WHP1-RF KP 00-15	15.3%	13.3%	10.4%	5.5%	44.5%
WHP1-RF KP 15-30	15.3%	13.8%	10.4%	5.0%	44.5%
WHP2-WHP1 KP00-08	12.6%	16.4%	10.1%	5.5%	44.6%
C20 Design fatigue 15 yrs Rem fat 5 yrs	22.2%	8.3%	0.6%	14.2%	45.3%
C2 Operating Temp < 100F	22.2%	9.2%	0.6%	13.6%	45.6%
C3 Age < 10 years	22.2%	9.2%	0.6%	13.6%	45.6%
C17 Actua/design WT >1.8	22.2%	7.5%	1.8%	14.2%	45.7%
Default/Baseline	22.2%	9.2%	0.6%	14.2%	46.2%
C14 Downtime -> 30 days	22.2%	9.2%	0.8%	14.2%	46.4%
C19 Hydrostatic pressure date test > 10 years	22.2%	9.6%	0.6%	14.2%	46.6%
WHP3-WHP4 KP00-08	11.5%	16.5%	8.1%	10.8%	46.9%
C9 MOP Potential: High	22.2%	10.1%	0.6%	14.2%	47.1%
C16 Written maint schedule -> non	22.2%	9.2%	1.6%	14.2%	47.2%
C29 Route Maps -> non	23.2%	9.2%	0.6%	14.2%	47.2%
C30 Right of Way -> poor	23.2%	9.2%	0.6%	14.2%	47.2%
C13 Wirtten op procedure -> non	22.2%	9.2%	1.7%	14.2%	47.3%
C11 Inspection -> non	22.2%	9.2%	1.8%	14.2%	47.4%
C12 Construction -> non	22.2%	9.2%	1.8%	14.2%	47.4%
C22 Stability Mitigation -> Non	22.2%	10.4%	0.6%	14.2%	47.4%
C15 Written maint procedure -> non	22.2%	9.2%	2.0%	14.2%	47.6%
C18 Hydrostatic pressure/MOP <1	22.2%	9.5%	1.7%	14.2%	47.6%
C27 Shore approach -> yes	23.6%	9.2%	0.6%	14.2%	47.6%
C4 Strongly Corrosive	22.2%	9.2%	0.6%	15.8%	47.8%
C23 Foreign crossing -> High	23.8%	9.2%	0.6%	14.2%	47.8%
C24 Fishing/crabbing -> High	23.8%	9.2%	0.6%	14.2%	47.8%
WHP2-WHP1 KP00-08	12.8%	19.0%	10.4%	5.8%	48.0%
C6 No internal protection	22.2%	9.2%	0.6%	16.1%	48.1%
C10 Non-owned, no involvement	22.2%	9.2%	2.5%	14.2%	48.1%
C25 Anchoring -> High	24.6%	9.2%	0.6%	14.2%	48.6%
C7 Sacrificial Anode <100% consumed	22.2%	9.0%	0.6%	17.3%	49.1%
C8 CP Potential >5mV/m	22.2%	9.0%	0.6%	17.3%	49.1%
WHP4-WHP2 KP00-08	15.0%	16.5%	6.4%	12.0%	49.9%
C21 Integrity Ver -> No inspection	22.2%	13.2%	0.6%	14.2%	50.2%
WHP2-WHP4 KP00-08	14.3%	16.0%	10.0%	10.0%	50.3%

TABLE 10: PLATFORM LOF^{PL} SENSITIVITY ANALYSIS RESULTS

Platform Asset	LoF^{PL}			
	Load	Strength	Asset Data	Total
Year of Installation - 1986	6.0%	14.0%	5.0%	25.0%
Year of Installation - 1996	6.0%	14.0%	5.0%	25.0%
WHP 3	14.0%	8.0%	6.0%	28.0%
WHP 4	14.0%	8.0%	6.0%	28.0%
Number of Legs - 8	9.0%	10.0%	9.0%	28.0%
WHP 2	12.0%	6.0%	11.0%	29.0%
Number of Legs - 6	9.0%	11.0%	9.0%	29.0%
Year of Installation - 1976	8.0%	14.0%	7.0%	29.0%
WHP 1	23.0%	2.0%	5.0%	30.0%
Bracing System - X	9.0%	11.0%	10.0%	30.0%
WHP 1 Default	9.0%	14.0%	10.0%	33.0%
Year of Installation - 1966	9.0%	14.0%	10.0%	33.0%
Number of Conductors - 8-10	9.0%	14.0%	11.0%	34.0%
Number of Boat Landing - 2	9.0%	14.0%	11.0%	34.0%
Bracing System - Unknown	9.0%	16.0%	10.0%	35.0%
Number of Boat Landing - 3	9.0%	14.0%	12.0%	35.0%
Number of Boat Landing - 5 - >10	9.0%	14.0%	12.0%	35.0%
Grouted Piles - Non	9.0%	14.0%	12.0%	35.0%
Earthquake Load - 0.3g	11.0%	14.0%	10.0%	35.0%
Bracing System - K and Diamond	9.0%	17.0%	10.0%	36.0%
Number of Legs - 3	9.0%	16.0%	11.0%	36.0%
Earthquake Load - 0.4g	13.0%	14.0%	10.0%	37.0%
Earthquake Load - 0.5g	14.0%	14.0%	10.0%	38.0%
Pile - not exist	9.0%	14.0%	16.0%	39.0%

9. FRAMEWORK IMPLEMENTATION IN PETRO AIMS

Petro-AIMS is an integrated oil and gas industry assets integrity management system that was developed by PT Mineering Energi Internasional, with the assistance of its clients and partners. In the real-world case where the offshore platform and pipeline assets risk are often strongly connected, the use of uniform risk assessment approach such as the one in Petro-AIMS is beneficial in various way, namely:

1. Opening the possibilities of using risk ranking and assessment methods other than the restrictive classical 5 x 5 risk matrix
2. Simplifying the training needed for AIMS engineer to operate Petro-AIMS;
3. Opening possibility for future development where system or plant risk (joint likelihood of failure) comprising of both platform and pipeline can be assessed;
4. Minimizing the database input effort where the offshore platform and subsea pipeline share the same data;
5. Combined with integrated issue tracking, maintenance tracking, document database, and revenue tracking for pipeline and offshore platform assets, Petro-AIMS can be used to improve the management level decision making process

In Petro-AIMS system, Platform and pipeline input data are obtained from FEED or Detail Design Documents, data sheets, detail drawing, and survey or inspection data. These data are entered into the Petro AIMS software as data input. The software will automatically calculate the LoF and CoF using both Muhlbauer [8] and El Reedy [7] semi quantitative techniques. Semi-quantitative approach is defined as qualitative score categorization of likelihood of failure (LoF), and quantitative evaluation of the LoF score assessment and CoF value.

During the lifetime of platform operation, structural issues such as jacket damages (dents, holes, cracks, and bends), marine growth, anode depletion and other issues may occur. These issues can be recorded in the issue tracking features. The open issues mark the issues that hasn't been resolved while the close issues mark the resolved issues as shown in figure 12. Various open issues are considered as the LoF calculation input as well.

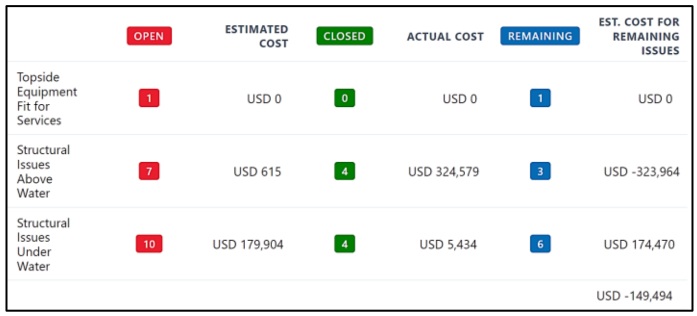

FIGURE 12: TRACKING FEATURES OF THE STRUCTURAL ISSUES

In structural assessment, the condition of the structure data is obtained from the inspection results. Over time the inspection data will become less valuable, and to maintain the structural condition inspection needs to be done in a timely manner. The inspection reminder features will remind the user for the inspection time, day or moths before according to the user input as shown in figure 13.

FIGURE 13: INSPECTION REMINDER

Data input such as anode depletion, wall thickness, and pipeline free span can vary overtime. In some cases, it is necessary to keep track the data variation to predict the future behavior of the asset's issue. To accommodate this need, additional data input tracking are installed in the software. As example, pipeline free span length tracking is shown in figure 14 below.

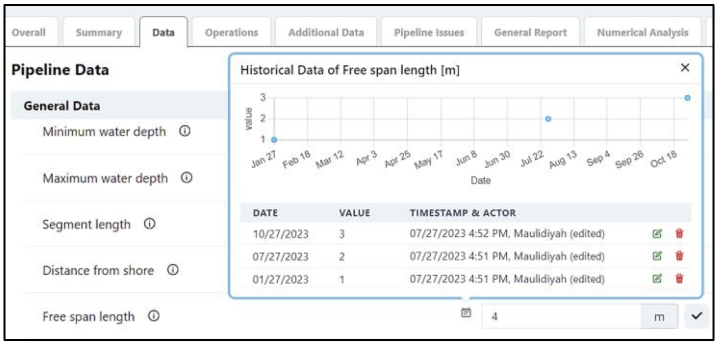

FIGURE 14: DATA INPUT TRACKING

To keep track of the Assets throughout its lifecycle, all associated documents such as FEED document, DED document, as built drawing documents, up to survey or investigation documents need to be well documented. These documents are often scattered between disciplines departments. Petro-AIMS provide data management system as shown in figure 15, so all stake holders, can easily access the document data.

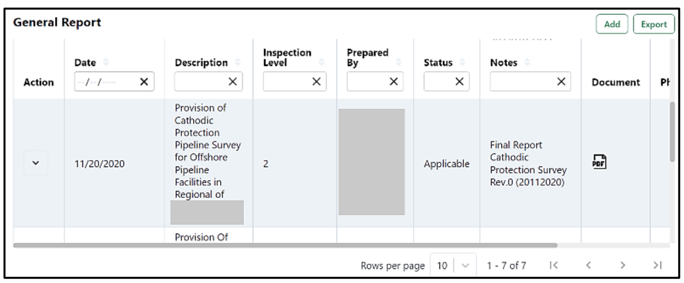

FIGURE 15: DATA MANAGEMENT SYSTEM

10. ADDITIONAL DEMONSTRATION OF THE PRESENT METHOD'S PRACTICALITY

Another benefit of LoF percentage calculation is cost risk performance analysis. When deciding whether to repair or not, using the Petro-AIMS we can compare the LoF shift score when there is repairing and when not with the cost of repairment vs asset fails.

TABLE 11: EXAMPLE OF COST RISK PERFORMANCE ANALYSIS

Initial Pipeline Condition	
Initial LoF	45.8%
Initial Anode Condition	82.2 kg
Anode Depleted Condition	
Depleted Anode LoF	47.5%
Depleted Anode	40 kg
Cost Basis	
Repair Cost per Anode [11]	$126.98
Pipeline Asset Cost [12]	$4,000,000

Based on information on table 11, assume there are 10 anodes that are needed to be replace, the cost of repairing:

$$Cost\ of\ Repairing = 10 \times \$126.98 = \$1{,}269.8 \quad (7)$$

The cost of assets failure consequence:

$$Cost\ of\ Failure\ Consequence = LoF \times CoF = (47.5\% - 45.8\%) \times \$4{,}000{,}000 = \$52{,}000 \quad (8)$$

Comparing the repairment cost and the cost of assets failure consequence, Petro-AIMS user can conclude that reparation is more financially beneficial than to let the system fails. This shows that Petro-AIMS is a practical tool to help with user's decision-making process.

Further demonstration of Petro-AIMS practicality is shown by its capability to evaluate both platform and pipeline assets in the same framework. This approach is made possible by employing the Muhlbauer and El Reedy method is discussed in this section.

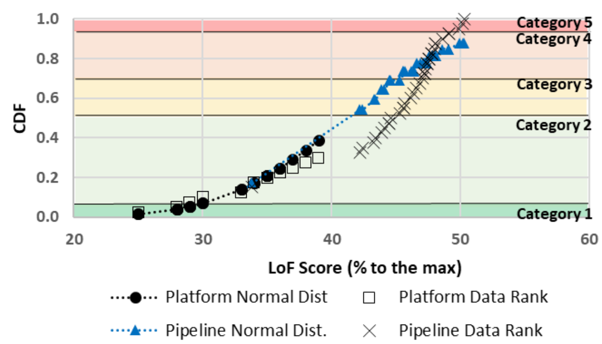

FIGURE 16: INTEGRATED PLATFORM AND PIPELINE LOF

Figure 16 shows the combined LoF results of both platform and pipeline assets. Based on the figure, one can deduced that platform assets has lower LoF in overall. Both platform and pipeline LoF weighing factor may be adjusted based on this combined LoF analysis, to better reflect the field condition and all assets relative likelihood of failure.

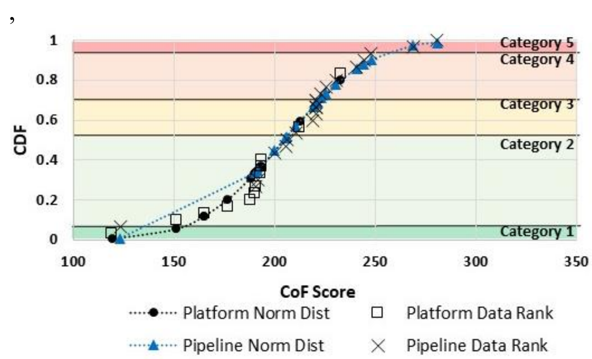

FIGURE 17: PLATFORM AND PIPELINE COF

The platform and pipeline CoF score combination is more straightforward to implement than that of LoF due to the absolute nature of the financial based CoF. The combined CoF value from platform and pipeline assets are shown in (figure 17). Pipeline CoF data mostly higher than platform CoF, since the environmental losses in near shore pipeline contributed higher cost than the environmental cost for offshore platform. The combined platform and pipeline risk categorization is shown in figure 18. Based on the results, it is shown that due to the higher overall likelihood of failure of pipeline assets, pipeline assets dominate the high risk categories. The highest combined risk occur on pipeline with cases the number of down time in 90 days.

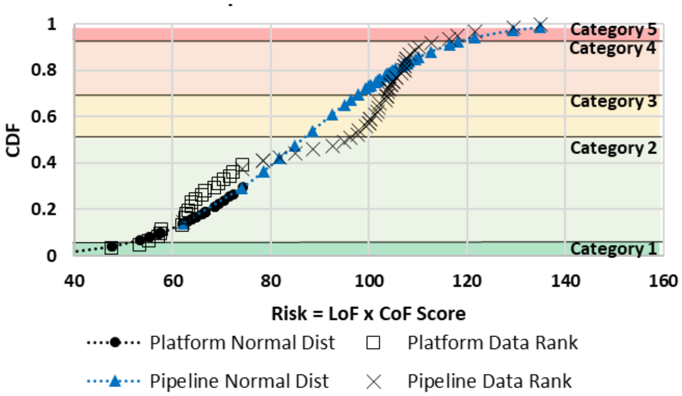

FIGURE 18: PLATFORM AND PIPELINE RISK = LOF × COF

11. CONCLUSION

In conclusion, this study investigates the implementation of two distinct risk assessment methods, the Muhlbauer [8] technique for pipeline assets and the El Reedy [7] method for offshore jacket platform assets, within one integrated AIMS environment (Petro-AIMS). The real-world application of this combined risk assessment approach in a case involving four interconnected offshore platforms and approximately 70 km of subsea pipeline demonstrates the practical benefits of Petro-AIMS.

Furthermore, the study conducted sensitivity analyses on various risk factors through hypothetical case studies, validating the robustness of the proposed method. The implementation of consistent LoF and CoF analysis for both platform and pipeline assets demonstrates Petro-AIMS as a practical and effective tool for asset integrity management functions. Overall, this research contributes to advancing the field of risk assessment in the oil and gas industry, offering a comprehensive and integrated approach that improves decision-making processes and ensures the integrity of interconnected assets.

REFERENCES

[1] Tawekal, R.L., Mahendra, M., Defrinaldo, S., Kurniawan, D.B., Ilman, E.C., Perdana, F. and Purnawarman, F.D., 2017. Risk based underwater inspection (RBUI) for existing fixed platforms in Indonesia. International Journal of Research in Engineering and Science (IJRES), 5(7).

[2] R.L. Tawekal, M. Mahendra, B. Banarwoto, F. Gumilang, I.G.N. Wiratmaja Puja, E. Islami, D.B. Kurniawan, E.C. Ilman, A.I. Masudi, F.D. Purnawarman, "Development of offshore platform structural risk-based underwater inspection in Indonesia Authors" International Journal of Applied Engineering Research, 2015, Vol 10, 37161-37169

[3] Tawekal, J.R. and Tawekal, R.L., 2018. Risk reliability-based underwater inspection method for jacket platforms in Indonesia. International Journal of Structural Integrity, 9(5), pp.603-615.

[4] Tanujaya, V.A., Tawekal, R.L. and Ilman, E.C., 2022. Vessel traffic geometric probability approaches with AIS data in active shipping lane for subsea pipeline quantitative risk assessment against third-party impact. Ocean Systems Engineering, 12(3), p.267.

[5] Dzikowski RE, Marcjan KR. Analysis of Ship Traffic Over Subsea Pipeline in the Gdańska Bay Area. "Analysis of Ship Traffic Over Subsea Pipeline in the Gdańska Bay Area." Annual of Navigation (2017).

[6] De Stefani, Vania, and Peter Carr, "A model to estimate the failure rates of offshore pipelines." International Pipeline Conference. Vol. 44236. 2010.

[7] El-Reedy Mohammed A. (2012). Offshore Structures: Design, Construction and Maintenance. Gulf Professional Publishing, ISBN 0123854768.

[8] Muhbauer, W.Kent. (2004). Pipeline Risk Management Manual: Ideas, Techniques, and Resources, Third Edition. Gulf Professional Publishing, ISBN 0-7506-7579-9.

[9] Akbarinia, Golam Reza, et al, "Application of Kent Muhlbauer method to risk assessment of urban gas pipelines." Journal of Pipeline Systems Engineering and Practice 13.1 (2022): 05021011.

[10] American Petroleum Institute, Structural Integrity Management of Fixed Offshore Structures (API RP 2SIM, 2014)

[11] Mehrafrooz, B., Edalat, P., & Dyanati, M. (2019). Cost consequence-based reliability analysis of bursting and buckling failure modes in subsea pipelines. Journal of Ocean Engineering and Science.

[12] Oil Spill Cost for Environmental in 2023. Cost of the Bouchard No. 120 Oil Spill Cost. Retrieved January 8, 2023, from https://buzzardsbay.org/buzzards-bay-pollution/oil-pollution/oil-spill-4-28-03/oil-spill-costs/