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Analytical determination of acceptable limit of risk levels for the pipeline systems in an existing refinery depot plant

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ABSTRACT

The quest for continuous managing our operating plants systems to achieve a greater-output optimization of process operation and systems maximization, the need for researches on quality mitigation of unforeseen system operation faults. Several research studies have been conducted over the years using several methods to mitigate the system-faults that may occur. However, the methods adopted in this study are: risk assessment framework, determination of risk level and analysis of data.

The Maiduguri depot plant is a vital component of the North-East regional petroleum distribution network. Unfortunately, it faces distinctive challenges concerning of ill-operations that requires the determination of acceptable risk levels for its pipeline and operations. Other challenges encompass geographical vulnerability, security threats, operational significance, regulatory compliance, and data limitations.

In summary, the comprehensive risk assessment of Maiduguri Refinery Depot's pipeline systems has provided valuable insights into the varying risk levels associated with each segment. The findings indicate that Segment 2 poses a high risk due to a combination of elevated probability and severe consequences, necessitating immediate attention and targeted risk mitigation efforts. On the other hand, Segments 1 and 3 align with acceptable risk criteria, reflecting relatively lower likelihoods and less severe consequences. The incident frequency and severity rates further underscore the importance of a nuanced approach to risk management, tailored to the specific characteristics of each segment. These results align with existing studies as seen in the open literatures.

Keywords: Oil and gas, pipelines, reliability, acceptable limits

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INTRODUCTION

In the global scale, oil and gas industry shall continue to plays pivotal roles in the energy and utility production. Nigeria’s energy landscape remains a valuable economic base for the country due to its absolute importance to her GDP. This study is to determine the acceptable limit of risk levels for the pipeline systems in the Maiduguri depot plant, a case study of an existing refinery depot plant. While the specific objectives include: Developing a quantitative risk assessment model tailored to the specific characteristics of the Maiduguri depot plant and evaluating the current risk levels of the pipeline systems within the Maiduguri plant against the established acceptable risk criteria (Ambituuni et Al., 2015).

The significance of this study lies in its potential to enhance safety and operational reliability at the Maiduguri depot plant while also contributing to the broader body of knowledge on tailored risk assessment methodologies for industrial facilities. By developing a specialized quantitative risk assessment model and evaluating current risk levels, this research project offers plant management the tools to proactively identify and mitigate risks, reassuring local communities, and aiding regulatory authorities in enforcing safety standards. Furthermore, it serves as a valuable resource for researchers and academia in advancing the understanding of risk assessment in specific industrial contexts, ultimately promoting safer and more sustainable operations in Maiduguri depot plant and similar facilities across the globe. Ambituuni, A. (2016) and (Ambituuni et al., 2014).

2.0 BACKGROUND LITERATURES

The oil and gas industry plays a pivotal role in the Nigeria's energy landscape and global level at large, providing essential resources for various sectors of society. Within this industry, the transportation of petroleum products from refineries to distribution points relies heavily on pipeline systems (Idris *et al.*, 2022). These intricate networks of pipelines serve as the lifelines of the industry, ensuring the uninterrupted flow of energy resources to meet the world's energy demands. In the review of the literatures, several authors are been depicted as presented in Table 1.

Table 1 Summarised version of reviewed investigations

Author(s)	Research Investigations	Research Benefits	Gaps and Remarks
Fuentes-Bargues et al., 2017	The safe operation of these pipelines is paramount to prevent accidents, protect the environment, and sustain the industry's vital functions.	Networks of pipelines serve as the lifelines of the industry, ensuring the uninterrupted flow of energy resources to meet the world's energy demands.	Addressing the safety and operations of the pipeline systems.
Abdoul Nasser et al., 2021	Addressing the challenges on risk assessment and management and critical components of ensuring the safe and reliable operation of pipeline system.	These risks can result from a multitude of factors, such as corrosion, mechanical wear and tear, third-	When fluid is displaced from the delivery side of the pump, more fluid is sucked from suction

		party damage, and operational errors.	side and thus fluid flow is created
Idris et al., 2022	Study evaluations on rig-plant hazards and effective measures of treating fluid contaminations in an identified chemical plant units	Identified the risks involved, in multitude factors. Proposed solutions to corrosion effects etc.	Created virtual template that address the plant hazards and proffer solutions.

Figure 1 demonstrates a typical overview of pipeline system operation. This is an example of optimised branch execusion in an existing process unit Adewole and Williams (2018) and Akintunde, (2011).

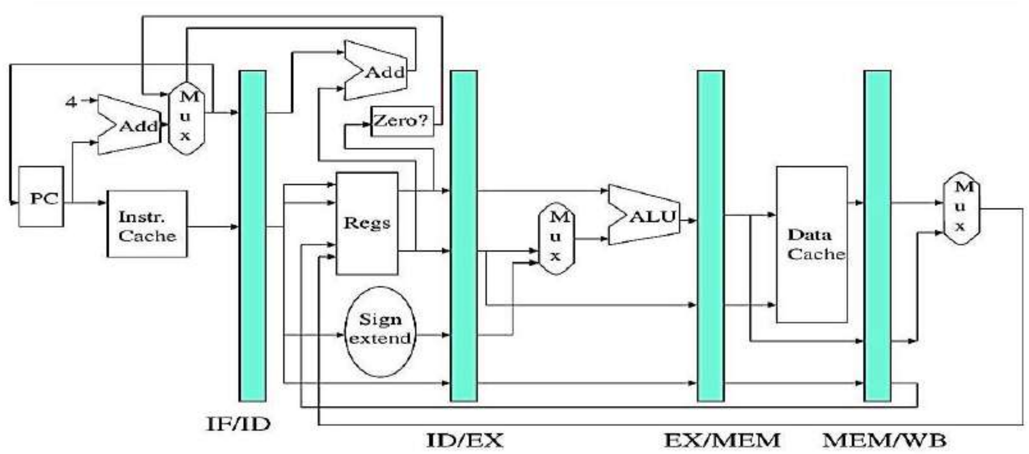

Figure 1: Typical pipeline hazards. **Source:** Akintunde, (2011).

2.1 Brief history of Maiduguri depot plant

Nigeria, as of the year 2011, was not only the largest crude oil producer on the African continent but also ranked among the top 15 petroleum-producing countries globally (Iyiola and Oyewo, 2011). Furthermore, Nigeria boasted the largest natural gas reserves in Africa. The nation consistently yielded millions of barrels of oil equivalent each year. According to the Nigerian National Petroleum Corporation (NNPC) report in 2010, Nigeria recorded a total production of 896 million barrels of crude oil and condensates, with an average daily output of 2.45 million barrels per day (MMbpd). During the same year, eleven oil-producing companies in Nigeria collectively produced 2.4 billion standard cubic feet (Bscf) of natural gas. The modified estimated production trends of crude oil and natural gas in Nigeria from 1998 to 2022 are illustrated in Figure 2.

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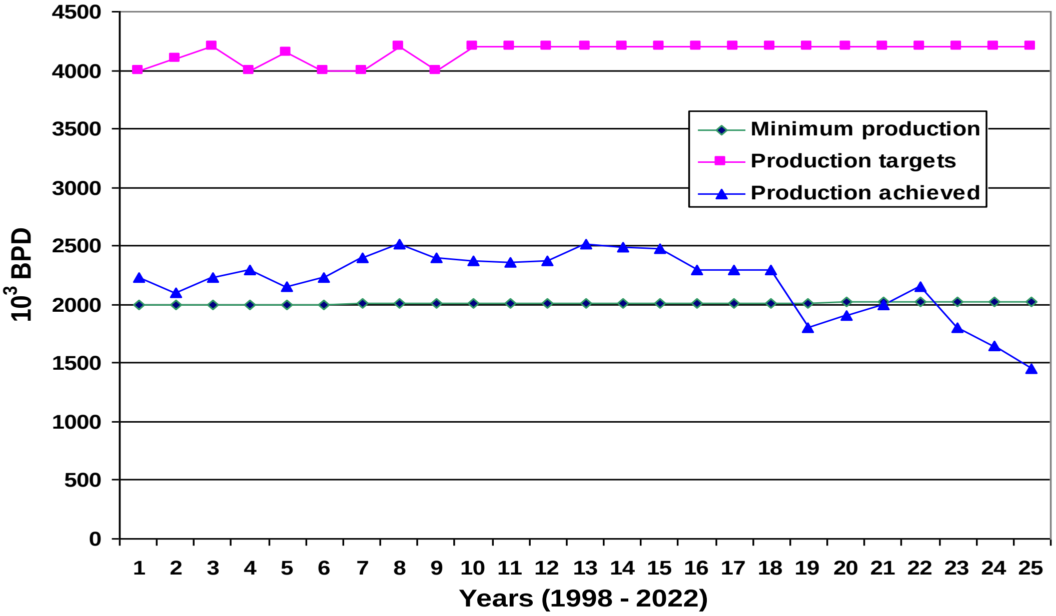

Figure 2 is a modified estimated Nigeria's crude oil and natural gas production in thousand barrels per day (1998-2022). **Source**: (NNPC 2022).

3.0 MATERIALS AND METHODS

3.1 Research Methodology

The study's methodological approach was detailed to encompassing both qualitative and quantitative methods. Qualitative methods are the literature backgrounds and expert consultations, provide foundational insights, while quantitative methods including data analysis and risk modeling, offer a detailed examination of the Maiduguri Depot Plant's pipeline system.

3.2 Risk Assessment Framework

3.2.1 Key Risk Factors

Key risk factors, including the probability (*P*) of an incident and the consequence (*C*) of an incident will be identified and defined for their pivotal role in the assessment framework.

3.2.2 Utilization of a Risk Matrix

A risk matrix is employed to categorize risk levels based on the defined probability and consequence. The matrix utilizes a scale of low, medium, and high to visually represent and prioritize the identified risks.

3.2.3 Proposed Acceptable Risk Criteria

Based on the review, straightforward criteria for determining acceptable risk levels were proposed and are presented in Table 3.

Table 3: Acceptable Risk Criteria

S/No.	Risk (R)	Acceptability
1.	0.00 - 0.50	Low
2.	0.51 - 0.75	Medium
3.	0.76 - 1.00	High

Source: (Idris et al., 2022)

The proposed acceptable risk criteria provide a framework for categorizing risk levels into ‘Low,’ ‘Medium,’ and ‘High’ based on their calculated risk values.

Low Acceptability Range (0.00 - 0.50): Risks falling within this range are deemed acceptable and manageable. Medium Acceptability Range (0.51 - 0.75): Risks within this range may require closer monitoring and potential mitigation measures.

High Acceptability Range (0.76 - 1.00): Risks exceeding this range are considered high and necessitate immediate attention and mitigation.

3.2.4 Determination of risk level

Risk Level Formula

$$\text{Risk Level} = P + C \tag{1}$$

Where P and C represent probability and consequences respectively.

This formula is chosen for its simplicity and effectiveness in quantifying and ranking risks. The addition of probability and consequence provides a holistic view of the risk impact, aiding in prioritization.

3.3 Data Collection

3.3.1 Data Collection

The data collected was through a comprehensive review of historical incident records at the Maiduguri Depot Plant. This includes incident reports, maintenance logs, and relevant documentation was scrutinized to gather information on past incidents, their causes, and the effectiveness of mitigation measures to be instituted.

3.4 Incident Frequency Rate (IFR) and Severity Rate (SR)

3.4.1 Incident Frequency Rate (IFR)

The Incident Frequency Rate (IFR) is a crucial metric that quantifies the frequency of incidents per unit of exposure. It provides insights into how often incidents occur within the Maiduguri Refinery Depot's pipeline systems.

Calculation of IFR:

The IFR is calculated using the formula:

$$\text{IFR}=\frac{\text{Total exposure hours}}{\text{Number of incidents}} \tag{2}$$

The total exposure hours represent the cumulative time during which the pipeline system is operational. This metric helps in understanding the frequency of incidents over a specific time period.

3.4 Severity Rate (SR)

Severity rate (SR) measures the impact of incidents by assessing the severity of their consequences. It provides quantitative evaluation of the severity of incidents per unit of exposure.

$$\text{SR} = \frac{Sum\ of\ severity\ level}{Total\ exposure\ hours} \tag{3}$$

4.0 RESULTS AND DISCUSSIONS

4.1 Risk Assessment Results: Calculated Risk Levels for Each Pipeline Segment

The developed risk assessment framework was applied to the Maiduguri Refinery Depot's pipeline systems. The calculated risk levels for each pipeline segment are presented in Table 4.1.

Table 4.1: Calculated Risk Levels for Each Pipeline Segment

Pipeline segment	Probability (P)	Consequences (C)	Risk level
Segment 1	0.08	0.30	0.38
Segment 2	0.12	0.60	0.72
Segment 3	0.05	0.20	0.25

The calculated risk levels for each pipeline segment were determined by considering both the probability (P) and consequences (C) associated with potential incidents. As seen from Segment 1 with a calculated risk level of 0.38, this falls into the ‘Low’ risk category. This implies that the probability and consequences associated with incidents in this segment are relatively lower. Segment 2 exhibits a higher calculated risk level of 0.72, placing it in the ‘High’ risk category. The increased risk level could be attributed to a combination of higher probability and more severe consequences. Segment 3 with a calculated risk level of 0.25, falls into the ‘Low’ risk category, indicating a relatively lower likelihood and less severe consequences compared to other segments. The findings above are similar to that of (Smith et Al., 2015) who found that severe consequences lead to high risk level Khan and Al Nabhani, (2020), (Lepikhin et al., 2020).

4.2 Incidents, consequences and severity

Incidents were identified and consequences were assessed using the risk matrix. The data on incidents and their consequences is provided in Table 4.2.

Table 4.2: Data on incidents, consequences and severity

Incidents	Probability (*P*)	Consequences (*C*)	Risk level	Severity
1	0.08	0.3	0.38	Major
2	0.12	0.6	0.72	Critical
3	0.05	0.2	0.25	Minor

The table above provides an overview of specific incidents, their probabilities, consequences, risk levels, and severity. Incident 1 classified as ‘Major’ severity with a risk level of 0.38, indicating a moderate level of risk associated with this incident. Incident 2 is identified as ‘Critical’ with a risk level of 0.72, signifying a high level of risk. This incident demands immediate attention due to its potential severe consequences. Incident 3 labeled as ‘Minor’ with a risk level of 0.25, suggesting a lower risk level compared to the other incidents.

4.3 Determination of Acceptable Risk

4.3.1 Comparison of Calculated Risks with Acceptable Criteria

The calculated risk levels were compared with the proposed acceptable risk criteria. The results are presented in Table 4.4.

Table 4.3: Comparison of Calculated Risks with Acceptable Criteria

Pipeline segment	Calculated Risk level	Acceptability
Segment 1	0.38	Low
Segment 2	0.72	High
Segment 3	0.25	Low

The comparison table allows us to assess whether the calculated risks for each pipeline segment align with the proposed acceptable risk criteria.

Segment 1: With a calculated risk level at 0.38 falling within the ‘Low’ acceptability range, this segment is in alignment with acceptable risk criteria.

Segment 2: The calculated risk level at 0.72 falls within the ‘High’ acceptability range, indicating an elevated risk level that requires immediate attention.

Segment 3: With a calculated risk level of 0.25, falling within the ‘Low’ acceptability range, this segment aligns with acceptable risk criteria.

4.4 Incidents frequency rate (IFR) and severity rate (SR)

Table 4.4: Incidents frequency rate (IFR)

Pipeline segment	Number of incidents	Total exposure hour	Incident frequency rate (IFR)
Segment 1	1	3000	$\frac{1}{3000}$
Segment 2	1	2000	$\frac{1}{2000}$
Segment 3	1	5000	$\frac{1}{5000}$

The incident frequency rate (IFR) provides valuable insight into the frequency of incidents within each pipeline segment. Segment 2 has the highest IFR, indicating a relatively higher occurrence of incidents per unit of exposure hours. This suggests that segment 2 is more susceptible to incidents, and targeted risk management strategy may be necessary to address this higher frequency.

Segment 1 and 3 on the other hand; exhibit lower IFR, signifying a comparatively lower frequency of incidents. While the segments 1 and 3 may still benefit from continuous monitoring and preventive measure to maintain their low incident frequency.

Table 4.5: Severity rate (SR)

Pipeline segment	Sum of severity levels	Total exposure hour	severity rate (SR)
Segment 1	0.38	3000	$\frac{0.38}{3000}$
Segment 2	0.72	2000	$\frac{0.72}{2000}$
Segment 3	0.25	5000	$\frac{0.25}{5000}$

The severity rate (SR) assesses the impact of incidents based on severity level. Segment 2 exhibit the highest SR, indicating a higher impact of incidents in terms of severity. This emphasizes the need for enhanced risk mitigation strategies to address the severity of incident in segment 2.

The segments 1 and 3, was found with the lower SR and experiencing less severe consequences per unit of exposure hours. While these segments demonstrate a relatively lower impact, continuous efforts to reduce severity and enhance emergency response preparedness can contribute to maintaining a favorable risk profile. The above results cohere with the findings of (Ambituuni et Al., 2015) and Roberts, (2017). Who studies risk management framework for safe transportation of petroleum products in Nigeria.

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The comprehensive risk assessment of Maiduguri Refinery Depot's pipeline systems has provided valuable insights into the varying risk levels associated with each segment. The findings indicate that Segment 2 poses a high risk due to a combination of elevated probability and severe consequences, necessitating immediate attention and targeted risk mitigation efforts. On the other hand, Segments 1 and 3 align with acceptable risk criteria, reflecting relatively lower likelihoods and less severe consequences. The incident frequency and severity rates further underscore the importance of a nuanced approach to risk management, tailored to the specific characteristics of each segment. These results align with existing studies, such as those by (Ambituuni et al., 2015) and Roberts, (2017), emphasizing the need for a dynamic risk management framework in the petroleum industry.

5.2 Recommendation

In other to consolidate on these findings, the following recommendations are put forth:

1. Implement a focused risk mitigation strategy for Segment 2, incorporating infrastructure upgrades, technological advancements, and enhanced emergency response preparedness to address the critical incident identified.
2. Maintain a proactive stance by implementing regular monitoring, preventive measures, and rigorous safety protocols for Segments 1 and 3. This includes ongoing inspections, maintenance activities, and adherence to industry best practices.
3. Develop and enact a comprehensive emergency response plan that covers incidents of varying severity. This plan should encompass clear communication channels, well-defined coordination protocols, and periodic drills to ensure preparedness and effectiveness in emergency scenarios.

REFERENCE

Abdoul Nasser, A. H., Ndalila, P. D., Mawugbe, E. A., Emmanuel Kouame, M., Arthur Paterne, M., Li, Y. (2021). Mitigation of risks associated with gas pipeline failure by using quantitative risk management approach: A descriptive study on gas industry. *Journal of Marine Science and Engineering*, 9(10), 1098.

Adewole, F. A., & Williams, W. C. (2018). Acute exposure guideline levels (AEGLs). *Evaluation of the Effects and Consequences of Major Accidents in Industrial Plants,* 2(1), 533-540.

Akintunde, M., Olajide, A. (2011). Environmental impact assessment of Nigerian National Petroleum Corporation (NNPC) Awka mega station. *American Journal of Scientific and Industrial Research*, 2(4), 511-520.

Ambituuni, A. (2016). A risk management framework for downstream petroleum product transportation and distribution in Nigeria. *Research gate*.

Ambituuni, A., Amezaga, J., & Emeseh, E. (2014). Analysis of safety and environmental regulations for downstream petroleum industry operations in Nigeria: Problems and prospects. *Environmental Development*, 9, 43-60.

Ambituuni, A., Amezaga, J. M., & Werner, D. (2015). Risk management framework for safe transportation of petroleum products in Nigeria: Learning from past accidents and good practices. *Risk Management*, 17(4), 329-351.

Fuentes-Bargues, J., González-Cruz, M., González-Gaya, C., Baixauli-Pérez, M. (2017). Risk analysis of a fuel storage terminal using HAZOP and FTA. *International Journal of Environmental Research and Public Health*, 14(7), 705.

Idris, M. N., Dalla, A. M., & Okaforocha, I. I. (2022). Study Evaluations on Rig-Plant Hazards and Effective Measures of Treating Fluid Contaminations from Chemical Process Units. *African Journal of Engineering and Environmental Research* (AJEER), 5(1), 2992-2828.

Khan, F., Al Nabhani, K. (2020). Risk assessment and management of TENORM waste disposal options in the oil and gas industry. *Nuclear Radioactive Materials in the Oil and Gas Industry*, 91-123.

Lepikhin, A., Leschenko, V., & Makhutov, N. (2020). Defects assessment in Subsea pipelines by risk criteria. Issues on Risk Analysis for Critical Infrastructure Protection [Working Title].

NNPC (2022), The Nigerian National Petroleum Corporation publications.

Samuel Iyiola Oni and Mark Oyewo (2011) Gas flaring, transportation and sustainable energy development in the Niger-Delta, Nigeria. DOI: 10.1080/09709274.2011.11906345

Roberts, D. T. (2017). Applying risk assessment at the worker level. 2017 Petroleum and Chemical Industry Technical Conference (PCIC).

Smith, S. A., Mclaury, B. S., Shadley, J. R., Roberts, K. P., Rybicki, E. F., Rincon, H. E., Hassani, S., Al-Mutahar, F. M., Al-Aithan, G. H. (2015). Erosion–corrosion in oil and gas pipelines. Oil and Gas Pipelines, 399-422.