Original Research Article

Causes of Safety Barrier Failures at Oil and Gas Facilities in Nigeria: A Technical Approach

Abstract

This study investigates the company-controlled causes of barrier failure in Niger Delta region of Nigeria. Also, it focuses on oil and gas facilities and their operations involving hydrocarbon handling. Safety Barriers in the oil and gas industry are crucial safety systems designed to prevent hazards and mitigate the consequences of incidents. These barriers, encompassing technical, operational, and organizational elements, play a significant role in handling hazardous substances and preventing their unintended release. Despite their importance, barrier failures have been identified as major causes of process safety incidents globally, including Niger Delta region ofNigeria. A cross-sectional research design, using a questionnaire to collect primary data from 132 personnel across 12 facilities, was employed. Statistical data analyses were carried out using XLSTAT Version 2016. Findings indicate that process upsets and technical/physical failures are significant risk influencing factors, while human and operational errors, though present, are less impactful. Key technical failures include degradation of valve sealing and flange gaskets, while process upsets often result from overpressure and malfunctioning transmitters. The study highlights the need for improved risk reduction strategies and periodic training to enhance safety practices in the Niger Delta's oil and gas industry. Recommendations include increasing technical components of risk strategies and ensuring regular maintenance and compliance with safety regulations.

Keywords:

Safety barrier failures, Hydrocarbon handling, Hazards, Operational elements, Events, Niger Delta, XLSTAT

1. Introduction

A barrier is a safety system, or component of a safety system that is in place to prevent a hazard progressing to an event, or to minimize the consequences of the event, should it occur (ISC, 2014). They are essential components of safety systems, playing a critical role in preventing hazards from escalating into events or minimizing their impact (Ames et al., 2017). Norwegian Petroleum Safety Authority (PSA) (2013) defined barriers as any technical, operational and organizational elements that are intended to individually or collectively reduce the possibility of a specific error, hazard or accident occurring or limits its harm. In summary, barriers are physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents. Barriers can be hardware (e.g. relief valves) or human (e.g. permit procedures) or a combination of both (Pitblado et. al., 2016; Wang et. al., 2017). The three main elements of barriers are: 1) technical which deals with equipment design (valves, bracings, redundancy or life-saving appliances), material properties, process complexity, human-machine interface, maintainability, and system feedback; 2) operational which deals with personnel competency, work environment, personnel workload; and 3) organizational which deals with policies, procedures hierarchy, rules and regulations etc.(Qiao et al., 2022).Safety barrier management systems are crucial in safety management practices, highlighting the importance of a comprehensive approach to designing and implementing these systems (Singletary et al., 2023).

The concept of safety barriers extends across various industries, including the oil and gas sector, where methodologies like the ARAMIS Project are utilized to quantify safety barrier performance and enhance resilience (Molnar et al., 2022). The oil and gas industry deal with large volume of hazardous substances in its daily operations, from drilling to production, storage, transportation, separation etc., even the produce of the industry (hydrocarbon) is highly volatile hence the need for a highly effective process safety management in the industry(Naji et al., 2021).These hazardous substances along with the hydrocarbon produced must be safely stored, separated and transported through various method to avoid their unwanted release. The most effective safety system used to prevent the unwanted release of these substances is safety barriers. Safety barriers are crucial in preventing unintended substance releases, addressing concerns like leaks, fires, and enabling safe evacuations (Dahl & Kongsvik, 2018). However, these barriers are susceptible to failure due to various reasons. Several factors have been identified worldwide to be the major causes of process safety incidents in the oil and gas industry, with the major factor being barrier failure. Barrier failures, also known as loss of containment incidents, in oil and gas facilities are typically attributed to five main categories: human and operational errors, technical failures, process upsets, external events or loads, and design failures (Sklet, 2006). Human and operational errors are due to failures that occur during normal production (open valves or drains), during maintenance (inadequate installation of equipment, isolation failure, draining, purging prior to maintenance, depressurization etc.). Process upsets failures are due to under pressure, overpressure, process overflow, etc. Technical failures are due to equipment, mechanical and physical degradation caused by aging, corrosion, fatigue, or wear-out. External events or loads failures are due to collisions, falling objects, bumping etc. Design failures are design error of equipment (Sklet, 2006).

The Nigeria oil and gas industry has had its own share of process safety issues due to barrier failure.Although it is difficult to itemize major process incidents in the country due to secrecy employed by oil and gas companies in the country, the devastating effects of these incidents are bound in the Niger Delta region. From Ogoni in Rivers State to Nembe in Bayelsa state all the way to Delta state; the devastating effects of pipeline leakage and explosion, valves and manifold failure, etc. can be seen in the various communities in the Niger Delta. Most of these incidents have been attributed to sabotage, a convenient excuse for the oil and gas companies, without considering other causes of the barrier's failures, especially those controlled by oil and gas companies. This knowledge gap is what necessitated the researcher to embark on a study to identify major company-controlled causes of barriers failure (loss of primary containment) in the region. This research focused mainly on oil and gas facilities in the Niger Delta region of Nigeria while the process entails only hydrocarbon (oil and gas) releases. Furthermore, only risk influencing factors that are under the control of the companies (technical, organizational and operational) were considered in the study.The aim of the study was the identification of major company-controlled causes of barriers failure (loss of primary containment) in the Niger Delta of Nigeria.

2. Methodology

Research design

This research employed cross sectional research design aided with survey method. The design allowed the researcher to gather quantitative data through the use of questionnaire to obtain information on the causes of barrier failures at the facilities while observing and measuring the concern phenomena together with some factors that might be necessary for the study.

Hypotheses

Four Null hypothesis were employed and designated as H_{01}, H_{02}, H_{03} and H_{04}, respectively.

Where:

H_{01}: Human and operational errors do not contribute significantly to loss of primary containment at oil and gas facilities in the Niger Delta, Nigeria;

H_{02}: Process upsets do not contribute significantly to loss of primary containment at oil and gas facilities in the Niger Delta, Nigeria;

H_{03}: Technical failures do not contribute significantly to loss of primary containment at oil and gas facilities in the Niger Delta, Nigeria; and

H_{04}: Design failures do not contribute significantly to loss of primary containment at oil and gas facilities in the Niger Delta, Nigeria.

Study Area

The Niger Delta region in southern Nigeria is situated in the Gulf of Guinea between longitude (5.05°E-7.17°E) and latitude (4.15° N-7.17°N). It is home to a diverse population of approximately 31 million individuals, belonging to over 40 distinct ethnic groups. These groups encompass but are not limited to the Ukwuani, Abua, Bini, Ohaji/Egbema, Itsekiri, Efik, Esan, Ibibio, Annang, Oron, Ijaw, Igbo, Isoko, Urhobo, Kalabari, Yoruba, Okrika, Ogoni, Ogba–Egbema–Ndoni, Epie-Atissa, and Obolo peoples. collectively, they speak the use of around 250 distinctive dialects. The linguistic groupings spoken within the Niger Delta place embody the Ijaw languages, Itsekiri language, critical Delta languages, Edoid languages, Yoruboid Languages, and Igboid languages. The Niger Delta has a high level of biodiversity, as evidenced by the presence of mangroves that possess the potential to sequester carbon and sustain a rich array of flora and fauna. Additionally, the agricultural and fishing activities in the region serve as crucial sources of income for a significant portion of the local population. The Niger Delta is an area abundant in petroleum resources, housing the majority of the country's reserves. The Niger-Delta region accommodates a significant majority of the oil fields, namely more than 90%, and a substantial number of operational wells, over 1400, inside the borders of Nigeria.

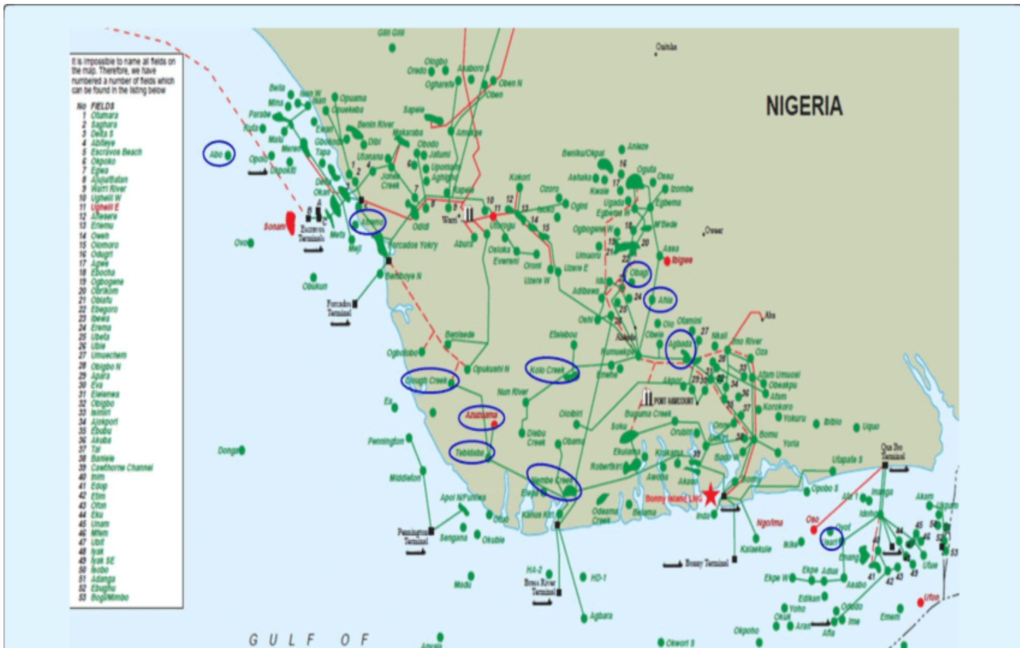

Figure 1: Map of oil and gas facilities in Niger-Delta (Abrakasa&Nwankwoala, 2019)

Sources of data

Only primary data obtained through a questionnaire was used for the research.

Sampling Method

Purposive sampling method was adopted for the research; twelve oil and gas facilities that satisfied an already developed inclusive and exclusive criteria were sampled for the study. This was done to acquire specific data for all the operations in the oil and gas supply chain since not all the facilities perform all the operations. Furthermore, eleven (11) personnel were drawn from each facility, this makes up 132 personnel for all the sampled facilities. Therefore, 132 personnel make up the sample size, consisted of facility managers, safety engineers, maintenance engineers, facility integrity manager, corrosion engineers, and safety coordinators of the sampled facilities.

Inclusion Criteria

i. Facility must have been in operation for more than ten (10) years
ii. Operations must include handling, processing, separation, transportation, and storage of either crude oil or natural gas.
iii. The facility must have experienced barrier failure within the last 5 years.

Exclusion Criteria

i. Facilities that withheld consent for inclusion in the study
ii. Facilities outside the Niger Delta region
iii. Facilities that have experience prolong shutdown, continuous shutdown,which lasted for more than one month in the last 10 years.

Research Instrument

The study made use of a self-structured questionnaire as the research instrument. Items in the questionnaire were developed by the researcher from process safety literatures (Sklet, 2006; PSA, 2013; Pitblado et. al., 2016) and safety and research experts(Safety heads at Total Energies, SPDC, and Exxon-Mobil). The questionnaire contained statementsaimed at identifying the causes of barrier failure at the facilities. Content validity of the questionnaire was performed by oil and gas safety experts and other knowledgeable persons in survey research. The reliability was determined using the test-retest method with a Cronbach alpha reliability coefficient of 0.88.Due to the difficulty in accessing the respondents, the developed questionnaire was encoded into a Google form and the link sent to the respondents via email. This method allowed the researcher to receive responses from the respondents without being physically present. To avoid duplication of responses, the researcher encoded the Goggle form to receive only one response from a mail address. This was done after the email addresses of all the respondents have been collected and recorded. For the analysis, the researcher only used responses from the email addresses that tallies with those initially acquired. For the analysis of the acquired data, the study used both descriptive & inferential statistics.

Results

Risk Influencing Factors (RIFs) that causes barrier failure

The result of evaluating the six risk influence factors that causes the safety barriers in oil and gas industry in the Niger Delta to fail is presented herein. Table 1 presents 24 operational errors and the corresponding mean and standard deviation values arising from statistical data analyses as per respondent responses on the questionnaires.

The result from Table 1 shows that mean values of respondents responses on items 1-24 ranges from 1.9-2.7 with corresponding Standard Deviations (SDs) of 0.41019-0.76997 from oil and gas facilities in Niger Delta. The mean responses for items 7, 21, and 24 are above the criterion mean value of 2.50 while mean responses of all the other items are below the criterion mean. Furthermore, the grand means for human error and operational error are lower than the criterion mean of 2.5; hence they were rejected. The result implies that human and operational errors is not among the Risk Influencing Factors (RIFs) that causes barrier failure (loss of primary containment) at oil and gas facilities in the Niger Delta.

However, a critical examination at the items in the operational statements revealed that item 7 which relates to failure due to degraded safety barrier performance (overdue maintenance) poses a mean value greater than the criterion mean. This implies that the respondents identify failure due to degraded safety barrier performance (overdue maintenance) as an operational error that contributes to loss of primary containment at their facility. Furthermore, the respondents also affirmed that failure due to situational error dictated by situation specific factors (time pressure, workload etc.), and failure due to inaccurate risk perception or worker becomes complacent which are both human errors is a Risk Influencing Factor (RIF) that causes barrier failure (loss of primary containment) at oil and gas facilities in the Niger Delta.

Table 1: Analysis of the components of human and operational errors that causes barrier failure

OPERATIONAL ERRORS	**Mean**	**Std. Deviation**
Failure due to mal-operation of valve(s).	2.1	.63932
Failure due to poor communication among operating staffs and control room operators	2.3	.76997
Failure due to roles duplication	1.7	.70147
Failure due to mal-operation of temporary hoses/instrument air/hydraulic lines etc	2.4	.63932
Failure due to lack of water in water locks in the drain system	1.9	.59295
Failure due to poor shift hand over	2.0	.63246
Failure due to degraded safety barrier performance (overdue maintenance)	2.6	.65222
Failure due to the use of wrong tools & equipment	2.3	.76997
Failure to follow operational procedure and routines	2.4	.72320
Failure due to poor/inadequate risk assessment	2.5	.73625
Failure due to impact from dropped object	1.9	.63932
Grand Mean	**2.2**	**.681**
HUMAN ERRORS		
Failure due to incorrect fitting of flanges or bolts during maintenance	2.3	.60356
Failure due to valve(s) in incorrect position after maintenance	2.3	.51331

Failure due to erroneous choice or installation of sealing device	1.9	.41019
Failure prior to or during disassembling of hydrocarbon system	2.3	.56625
Failure due to break-down of the isolation system during maintenance	2.2	.48469
Failure during perceptual input via the senses. -Sensory error	2.0	.47809
Failure of recall from memory-Memory Error	2.0	.58554
Failure in work judgement, decision making or planning-Decision Error	2.2	.74907
Failure when taking action including speech-Action Error	2.0	.41404
Failure due to situational error dictated by situation specific factors(time pressure, workload etc)	2.5	.69693
Failure due to deliberate deviation from rules, procedures regulations etc	2.1	.58282
Failure due to errors of Judgement-Rule based mistake	2.3	.60356
Failure due to inaccurate risk perception or worker becomes complacent	2.7	.70991
Grand mean	**2.2**	**.569**

The result from Table 2 shows that mean values of respondents' responses on items 25-33 ranges from 1.9-2.7 with corresponding SDs of 0.50631 - 0.73679 from twelve oil and gas facilities in Niger Delta. The mean responses for items 29-32 are above the criterion mean value of 2.50 while mean responses of all the other items are below the criterion mean. Furthermore, the grand mean which represents the process upset is greater than the criterion mean of 2.6; hence is accepted. The result implies that process upset is a Risk Influencing Factor (RIF) that causes barrier failure (loss of primary containment) at oil and gas facilities in the Niger Delta

A further breakdown of the items revealed the failures that significantly causes failures due to process upset; they are: failure due to overpressure, failure due to overflow/overfilling, failure due to level transmitter and pressure transmitter malfunction, failure due to mal-operation of pressure valves, and failure of pressure operational valves.

Table 2: Analysis of the components of process upsets that contributes to barrier failure

PROCESS UPSETS	Mean	Std. Deviation
Failure due to overpressure	2.6	.73679
Failure due to overflow/overfilling	2.9	.69179
Failure due gas blowby	2.0	.58554
Failure due to liquid carry over	2.4	.64488
Failure due to level transmitter malfunction	3.7	.56625
Failure due to pressure transmitter malfunction	2.8	.60684
Failure due to mal-operation of process valves	3.2	.50631
Failure of pressure operational valves	2.9	.56061
Excessive temperature of the process	1.2	.58282
Grand mean	**2.6**	**.609**

The result from Table 3 shows that mean values of respondents' responses on items 34-43 ranges from 1.6-3.4 with corresponding SDs range of 0.50631 -0.69693 from twelve oil and gas facilities in Niger Delta. The mean responses for items 41-43 are below the criterion mean value of 2.50 while mean responses of all the other items are greater than the criterion mean. Furthermore, the grand mean which represents the technical/physical failures is greater than the criterion mean of 2.5; hence is accepted. The result implies that technical/physical failures is among the Risk Influencing Factors (RIFs) that causes barrier failure (loss of primary containment) at oil and gas facilities in the Niger Delta.

A further breakdown of the items revealed the failures that significantly causes failures due to technical/physical failures, they are: failure due to degradation of valve sealing, failure due to degradation of flange gasket, failure due to loss of bolt tensioning, failure due to degradation of welded pipes, failure due to erosion that causes external corrosion, failure due to internal corrosion of piping, and failure due to excessive vibrations.

Table 3: Analysis of the components of technical failures contribution to barrier failure

S/N	TECHNICAL/PHYSICAL FAILURES	Mean	Std. Deviation
34	Failure due to degradation of valve sealing	2.7	.47809
35	Failure due to degradation of flange gasket	2.7	.62425
36	Failure due to loss of bolt tensioning	2.6	.50395
37	Failure due to degradation of welded pipes	3.4	.51331
38	Failure due to internal corrosion of piping	3.2	.46718
39	Failure due to erosion that causes external corrosion	2.7	.51331
40	Failure due to excessive vibrations	2.6	.50631
41	Failure due to insufficient fire and gas coverage area	2.0	.63746
42	Failure due to insufficient firefighting /protection system	1.6	.55420
43	Failure due to incompetency of maintenance personnel's	2.2	.69693
	Grand mean	**2.6**	**.550**

The result from Table 4 shows that mean values of respondents' responses on items 44-51 ranges from 2.0-2.4 with corresponding SDs range of 0.50631 -0.70991 from twelve oil and gas facilities in Niger Delta. The mean responses for all the items 44-51 are less than the criterion mean value of 2.50. Furthermore, the grand mean which represents the design related failures is less than the criterion mean of 2.5; hence is rejected. The result implies that design related failures is not a Risk Influencing Factors (RIFs) that causes barrier failure (loss of primary containment) at oil and gas facilities in the Niger Delta.

Table 4: Analysis of the components of design failures contribution to barrier failure

S/N	DESIGN RELATED FAILURES	Mean	Std. Deviation
44	Failure due to faulty equipment design	2.3	.70991
45	Failure due to equipment incompatibility	2.0	.60880
46	Failure due to not following design specification	2.0	.50631
47	Failure due to wrong assumptions in design	2.3	.70147
48	Failure due to wrong inputs to design simulation	2.1	.62234
49	Failure to consider inherent safer designs	2.0	.55420
50	Failure to execute a detailed HAZOP at early phase of project	2.4	.68776
51	Failure due to deficiency in project team skill set	2.0	.50631
	Grand Mean	**2.1**	

The result as presented in Table 5 shows ranking RIFs based on the likelihood to cause barriers failure. Amongst the four items, technical errors ranked first with a mean score of 2.37. Process upsets followed closely with a mean score of 2.20. Operational errors came third with a mean score of 2.19, human errors came fourth with a mean score of 2.12 while design failure came fifth with a mean score of 1.74. This means that among the various errors with the likelihood to cause failures, technical errors were the most pivotal.

Table 5: Ranking RIFs based on their likelihood to cause barriers failure

Items	SA	A	D	SD	Mean	Remark
Operational Errors	4	36	60	24	2.19	Third
Human Errors	3	30	70	21	2.12	Fourth
Technical Errors	4	52	54	14	2.37	First

Process Upsets	2	32	79	11	2.20	Second
Design Failure	0	11	70	43	1.74	Fifth

Table 6: Relationship between human and operational errors and loss of primary containment at oil and gas facilities

Human and operational errors	**Loss primary containment**	
	coefficient of correlation	**p-value**
Human errors	.460	.539
Operational errors	.294	.601

Table 7: Relationship between process upsets and loss of primary containment at oil and gas facilities

	Loss primary containment	
	coefficient of correlation	**p-value**
Process upsets	.489	0.000*

***Correlation is significant at p<0.05**

Table 8: Relationship between technical failure and loss of primary containment at oil and gas facilities

	Loss primary containment	
	coefficient of correlation	**p-value**
Technical failures	.801	0.000*

***Correlation is significant at p<0.05**

Table 9: Relationship between design failure and loss of primary containment at oil and gas facilities in Niger Delta

	Loss primary containment	
	coefficient of correlation	**p-value**
Design failures	.527	0.071

Tables 6-9 are the results of the hypotheses testing at 0.05 significance level, The p-values for both human and operational errors are greater than 0.05, indicating that these factors do not significantly contribute to the loss of primary containment. While human and operational errors do affect process safety barriers, their consequences are deemed insignificant in causing containment loss. However, the study cautions that if these errors are not properly addressed, they could accumulate and potentially contribute to containment loss in the future.

Furthermore, the p-value for process upset is less than 0.05, indicating a significant contribution of process upsets to the loss of primary containment. Common process upsets, such as overpressure and overfilling of storage vessels, are identified as major causes. The study points out that these issues can be controlled through adequate technical risk reduction strategies. Maintenance practices are highlighted, with only 32% of respondents affirming monthly checks on transmitters, suggesting that more frequent maintenance could reduce these failures. Additionally, the p-value for technical failures is less than 0.05, indicating a significant contribution of technical failures to the loss of primary containment. Various technical failures, such as degradation of valve sealing, flange gasket, welded pipes, and corrosion, are identified as common causes. The study reveals that some facilities perform maintenance on a need basis, leading to frequent containment losses. Preventive maintenance is recommended to mitigate these issues, aligning with Sklet's (2005) assertion that process safety aims to prevent accidents that could lead to severe consequences. Finally, the p-value for design failures is greater than 0.05, indicating that design failures do not significantly contribute to the loss of primary containment. Although design failures are not a significant factor, the study implies that addressing other significant factors, such as technical failures and process upsets, could enhance overall safety.

Discussion

The identified Risk Influencing Factors (RIFs) that causes barriers failure (loss of primary containment) at oil and gas facilities in the Niger Delta are process upsets (2.6 ± 0.609), and technical/physical failures (2.6 ± 0.550).Overpressure and overfilling of the storage vessels/tanks due to pressure/level transmitter malfunction, failure due to mal-operation of process valves, failure of pressure operational valves are the major components of process upsets that causes barrier failures at oil and gas facilities in the Niger Delta. This result is buttressed by the hypothesis result which shows a significant contribution of process upsets to the loss of primary containment in the facilities. Common process upsets, such as overpressure and overfilling of storage vessels, are identified as major causes. A closer look at these process upsets issues will reveal that they are caused by technical failures that leads to process upsets rather than an unpredictable behavior of the process. Maintenance practices are highlighted, with only 32% of respondents affirming monthly checks on transmitters, suggesting that more frequent maintenance could reduce these failures.Therefore, proper implementation of all the components of the technical risk strategy will eliminates or reduce the frequency of barrier failures (loss of primary containment) caused by process upsets. To address these challenges effectively, it is imperative to focus on enhancing technical risk management practices, implementing proactive maintenance strategies, and investing in advanced monitoring and control systems (Dahl & Kongsvik, 2018). By prioritizing the identification and rectification of technical failures that contribute to process upsets, oil and gas facilities can significantly reduce the occurrence of barrier failures and enhance overall operational safety (Dahl & Kongsvik, 2018). Additionally, leveraging predictive maintenance technologies and real-time monitoring tools can further improve the reliability and integrity of safety barriers in the oil and gas industry (Asad et al., 2019a).

Furthermore, this study revealed that the technical and physical failures contributing to barrier failures in oil and gas facilities in the Niger Delta encompass a range of components, including degradation of valve sealing, flange gasket degradation, loss of bolt tensioning, degradation of welded pipes, erosion leading to external corrosion, internal corrosion of piping, and excessive vibrations. These failures pose significant risks to the integrity of safety barriers, potentially resulting in loss of primary containment and subsequent safety incidents in the region. This result aligns with result of the hypothesis testing which shows a significant contribution of technical failures to the loss of primary containment. The identified components of technical failures, such as valve sealing degradation and flange gasket failures, highlight the critical role of equipment integrity in maintaining safety barriers (Ingraffea et al., 2014). Additionally, issues like loss of bolt tensioning and degradation of welded pipes underscore the importance of structural robustness and maintenance practices in preventing barrier failures (Ingraffea et al., 2014). Erosion-induced external corrosion and internal corrosion of piping further emphasize the need for proactive corrosion management strategies to safeguard against barrier failures (Ingraffea et al., 2014). Excessive vibrations, as another component of technical failures, point to the significance of monitoring and addressing dynamic stresses that can compromise barrier effectiveness (Ingraffea et al., 2014). To address these technical and physical failure components effectively, oil and gas facilities in the Niger Delta must prioritize comprehensive asset integrity management, regular equipment inspections, corrosion control measures, and vibration monitoring programs (Khan et al., 2015). By implementing proactive maintenance practices, utilizing advanced materials, and integrating predictive technologies, facilities can enhance the reliability and longevity of safety barriers, reducing the likelihood of barrier failures and enhancing overall operational safety (Zacchaeus, 2023).

Although the grand means of operational error (2.2±0.681), and human errors (2.2±0.569) are below our criterion mean and made us reject that they do cause barrier failures at oil and gas facilities in the Niger Delta, there are some components that were identified by the respondents to significantly cause failures at their facilities. For operational error; failure due to poor/inadequate risk assessment, failure due to degraded safety barrier performance (overdue maintenance) were identified to significantly cause loss of primary containment.For human errors; failure due to situational error dictated by situation specific factors (time pressure, workload etc.), failure due to inaccurate risk perception or worker becoming complacent cause's barrier failure at the facilities.This result aligns with result of the hypothesis testing which shows that human and operational errors do affect process safety barriers. However, the study cautions that if these errors are not properly addressed, they could accumulate and potentially contribute to containment loss in the future. This caution is justifiable as the identified failures, due to human and operational errors, are problems of operational and organizational risk reduction strategies; situational error dictated by situation specific factors (time pressure, workload etc.), and failure due to inaccurate risk perception or worker becoming complacent are issues that can be addressed by proper/adaptable work environment and manageable workload (both of which have been identified as components of operational risk reduction strategy). When personnel are overworked, they tend to lose their situational awareness and become complacent in their duty thereby becoming a risk. Moreover, investing in training programs for personnel on equipment maintenance and integrity can further strengthen the barrier protection systems in place (Asad et al., 2019b).

Conclusion

The Nigeria oil and gas industry has had its share of process safety issues; the devastating effects of these incidents abound in the Niger Delta region. From Ogoni in Rivers State to Nembe in Bayelsa state all the way to Delta state; the devastating effects of pipeline leakage and explosion leading to oil spills can be seen in the various communities in the Niger Delta. The study highlights the critical importance of safety barriers in preventing the loss of primary containment (LOPC) in oil and gas facilities in the Niger Delta, Nigeria. The research identified key Risk Influencing Factors (RIFs) contributing to barrier failures, particularly focusing on process upsets and technical/physical failures. The findings underscore that process upsets, such as overpressure and overfilling, and technical failures, including degradation of valve sealing and corrosion, are significant contributors to barrier failure.Notably, the study's hypothesis testing revealed that human and operational errors, along with design failures, do not significantly contribute to LOPC in the region. However, it emphasizes that while these factors may not be primary causes, they could still indirectly impact safety if not properly managed. Therefore, a comprehensive safety management system must address all potential risk factors.One of the key recommendations from this study is the implementation of proactive maintenance strategies to mitigate the identified risks. The findings show that only 32% of respondents reported conducting monthly maintenance checks, suggesting a need for more frequent and thorough maintenance practices. By enhancing technical risk management practices, facilities can significantly reduce the likelihood of process upsets and technical failures.

Recommendations

One of the key recommendations from this study is the implementation of proactive maintenance strategies to mitigate the identified risks. The findings show that only 32% of respondents reported conducting monthly maintenance checks, suggesting a need for more frequent and thorough maintenance practices. By enhancing technical risk management practices, facilities can significantly reduce the likelihood of process upsets and technical failures.Additionally, investing in advanced monitoring and control systems, such as predictive maintenance technologies and real-time monitoring tools, can further improve the reliability and integrity of safety barriers. These technologies enable early detection of potential issues, allowing for timely intervention and reducing the risk of barrier failures.Overall, the study emphasizes the necessity for a holistic approach to safety barrier management in the oil and gas industry. By prioritizing technical risk reduction strategies, improving maintenance practices, and leveraging advanced technologies, oil and gas facilities in the Niger Delta can enhance their safety performance and minimize the risk of hazardous substance releases. This approach not only protects the environment and local communities but also ensures the sustainable operation of oil and gas facilities in the region.

Reference

Ames, A., Xu, X., Grizzle, J., &Tabuada, P. (2017). Control barrier function based quadratic programs for safety critical systems. *Ieee Transactions on Automatic Control*, *62*(8), 3861-3876.

Asad, M., Hassan, R., Sherwani, F., Aamir, M., Soomro, Q., & Sohu, S. (2019a). Design and development of a novel knowledge-based decision support system for industrial safety management at drilling process. *Journal of Engineering Design and Technology*, *17*(4), 705-718.

Asad, M., Hassan, R., Sherwani, F., Abbas, Z., Shahbaz, M., & Soomro, Q. (2019b). Identification of effective safety risk mitigating factors for well control drilling operation. *Journal of Engineering Design and Technology*, *17*(1), 218-229.

Dahl, Ø. and Kongsvik, T. (2018). Safety climate and mindful safety practices in the oil and gas industry. *Journal of Safety Research*, *64*, 29-36.

Ingraffea, A., Wells, M., Santoro, R., & Shonkoff, S. (2014). Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012. *Proceedings of the National Academy of Sciences*, *111*(30), 10955-10960.

ISC (2014). *Process Safety and the ISC*. ISC

Khan, F., Rathnayaka, S., & Ahmed, S. (2015). Methods and models in process safety and risk management: Past, present and future. *Process Safety and Environmental Protection*, *98*, 116-147.

Molnar, T., Ames, A., & Orosz, G. (2023). Control barrier functionals: safety-critical control for time delay systems. *International Journal of Robust and Nonlinear Control*, *33*(12), 7282-7309.

Naji, G., Isha, A., Mohyaldinn, M., Leka, S., Saleem, M., Rahman, S., &Alzoraiki, M. (2021). Impact of safety culture on safety performance; mediating role of psychosocial hazard: an integrated modelling approach. *International Journal of Environmental Research and Public Health*, *18*(16), 8568.

Pitblado, R., Fisher, M., Nelson, B., Fløtaker, H., Molazemi, K., & Stokke, A. (2016). Concepts for dynamic barrier management. *Journal of Loss Prevention in the Process Industries*, *43*, 741-746,

PSA (2013). *Principles for barrier management in the petroleum industry*. Norwegian Petroleum Safety Authority (PSA)

Qiao, W., Huang, E., Guo, H., Liu, Y., & Ma, X. (2022). Barriers involved in the safety management systems: a systematic review of literature. *International Journal of Environmental Research and Public Health*, *19*(15), 9512.

Singletary, A., Ahmadi, M., & Ames, A. (2023). Safe control for nonlinear systems with stochastic uncertainty via risk control barrier functions. *Ieee Control Systems Letters*, *7*, 349-354.

Sklet, S. (2006). Safety barriers, definitions, classifications, and performance. *Journal of Loss Prevention in the Process Industries*, *19*, 494-506.

Wang, L., Ames, A., &Egerstedt, M. (2017). Safety barrier certificates for collisions-free multirobot systems. *Ieee Transactions on Robotics*, *33*(3), 661-674.

Zacchaeus, M. (2023). Optimizing safety performance through risk-based modeling in Nigeria's oil and gas sector. *The Journal of Engineering and Exact Sciences*, *9*(10), 17799.