Journal of Geoscience and Environment Protection, 2023, 11, 192-204
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Needs and Challenges of Nigeria Petroleum Industry in Assessing Process Safety Cumulative Risk

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How to cite this paper: Maduabuchi, E., Ugbebor, J. N., & Israel, G. O. (2023). Needs and Challenges of Nigeria Petroleum Industry in Assessing Process Safety Cumulative Risk. *Journal of Geoscience and Environment Protection, 11,* 192-204.
https://doi.org/10.4236/gep.2023.117013

Received: May 27, 2023
Accepted: July 21, 2023
Published: July 24, 2023

Abstract

A cross-sectional exploratory assessment of the needs and challenges of petroleum industry in Nigeria, in assessing process safety cumulative risk for major accidents prevention was investigated. A purposive cum random sampling technique was used in this study, among selected petroleum companies operating in Nigeria. Survey questionnaires were received from 216 participants made up of asset integrity engineers/operators, process safety experts, production safety professionals in the petroleum industry in Nigeria. Data analyses were carried out to cover descriptive and inferential statistics. Overall, the study recognized that assessing process safety cumulative risk is not a simple process due largely to the changing nature of safety critical barriers degradation data. The study result showed four main challenges faced by petroleum industries in Nigeria, in assessing process safety cumulative risk: 1) the study showed that 94% of the respondents agreed that there is limited accessibility to safety critical barriers degradation data (little automation). Also 2) 94% of the respondents accounted for poor knowledge of process safety cumulative risk is and agreed it to be of low rating. The result further showed that 3) 90% of the respondents demonstrated that there are no guidance and procedures in assessing process safety cumulative risk and finally 4) 92% of the respondents reported that there is no real-time risk visualization model/tool. Addressing these issues and challenges by the petroleum industries in the study area, will lead to successful assessment of process safety cumulative risk, thereby reducing the risk of major accidents.

Keywords

Process Safety, Cumulative Risk Assessment, Major Accident Prevention, Petroleum Industry

1. Introduction

Globally, major process safety accidents have been occurring in oil and gas facilities (Bubbico et al., 2020a). Despite the fact that they do not happen regularly, they are noted for high consequences, which include absolute loss of assets, ecological damage, reputational damage, significant casualties, and the possible loss of an operating license (Kongsvik et al., 2015; Okoh & Haugen, 2014). These catastrophic events are frequently caused by an intricate interaction of organizational, human, technical, and environmental factors, and their roots are rarely attributed to one factor (Okoh & Haugen, 2014). Major accidents, according to (Bubbico et al., 2020b), are brought on by any one or a combination of the following factors: natural phenomena, human failures, technological failures, environmental problems, and management system failures. Over the years, most industries have prioritized enhancing human and technological factors in their incident prevention measures (Meng et al., 2014). Nonetheless, despite all of these significant efforts to reduce incidents, significant accidents still occur.

The petroleum sector has witnessed a significant number of process safety incidents (Ismail et al., 2014) and these major accidents are usually investigated, and recommendations made. The majority of major accident investigation reports as noted by Refsdal & Urdahl (2014) demonstrate that these major hazard organisation were faced with numerous challenges during the operational stage of the assets, such as signs of weakening safety-critical barriers, however, the signs were either overlooked or simply not handled accordingly. *Hirak Dutta Executive Director Oil Industry Safety Directorate 27* (2013) emphasized that damaged or malfunctioning barriers are "warning signs" and contended that failure to notice these warning signals was a contributing cause in many significant incidents in the sector. In most of these major accidents, process safety risks arising from these warning signals accumulated but plant operators were blind-sided to the cumulative risk impact of these anomalies (Pawłowska, 2015; Refsdal & Urdahl, 2014). According to Refsdal & Urdahl (2014), most of these anomalies in the plant are known by the organization but the cumulative risk of the gaps is not usually understood. Often the information is not transparent to the people who have the responsibility to intervene. A study by Al-Shanini et al., (2014) revealed that some attention is being paid by industry experts to curb the major process safety events to an appreciable extent, from cumulative risk management point of view. However, there are still many problems with managing cumulative risk in the petroleum facilities (Behie et al., 2020). Even though there are many studies in process safety management for major accident prevention (Lee et al., 2016), however there are few studies that consider the concept of process safety cumulative risk assessment in the oil and gas operations (Blacklaw et al., 2011). The aim of this study is to explore the needs and challenges of the petroleum industry in managing process safety cumulative risk for prevention of major accidents in the Niger Delta region.

In process safety risk management, risks are managed by ensuring that all risk controls/barriers work as intended. If a control/barrier in a plant, be it a procedure, equipment or a person is not able to operate as intended, this state represents a deviation in the plant. When there are multiple deviations, the risks presented by the deviations need to be managed proactively, to prevent risks from the deviations accumulating together and pre-disposing the plant to a major accident. Cumulative risk is the combined effect of several risks impacting the safety of the installation/site, focused on the Major Accident Hazards as described in the plant HSE Case (OGUK, 2016).

2. Materials and Methods

2.1. Study Area

The study area is in the Niger Delta region in Nigeria (Rivers and Delta states respectively). The oil and gas facilities operating within the delineated area is the foci of the researcher. The area situates on latitudes 4˚N and 6˚N and longitude 5˚E and 8˚E (Jia et al., 2022). The climatic and other environmental characteristics in addition to the presence of crude oil has resulted in the region playing host to over 18 multinational petroleum companies and many national petroleum companies (Uzoma & Mgbemena, 2015).

2.2. Research Design

A cross-sectional research design was utilized for this study, the key reason being that the findings are representative and can be generalized (Jia et al., 2022). The study data were obtained from both primary sources (focused group of process safety professionals and survey questionnaire) and secondary sources. These data were analysed using qualitative and quantitative techniques such as content analysis, descriptive and inferential statistics (one way analysis of variance). Cronbach's alpha reliability analysis was used to check the reliability of the survey questionnaire.

2.3. Population of the Study

The population sample for this study comprises of asset integrity engineers/operators, process safety experts, production safety professionals in the oil and gas industry in the Niger Delta region of Nigeria. This sample was extracted from both the international and national petroleum companies domiciled in the study area. In all, sample size of the population was 261 participants. The sample size was determined using Cochrain equation (Singh, Ajay, & Masuku, 2014), with a 10% margin included to account for inefficiencies (Bartlett II et al., 2001; Singh, Ajay, & Masuku, 2014). The respondents in this study cut across the upstream, midstream and downstream sectors of the petroleum industry in Nigeria.

2.4. Sample and Sampling Technique

The purposive cum random sampling technique was used in this study. The demographic questionnaire was used as a screening tool for the assessment of the questionnaire. The target population for this study was 261 asset integrity engineers/operators, process safety experts, production safety professionals in petroleum industry in Niger Delta region. The researcher sampled 100% of this population. Of the 261-instrument distributed, 216 were returned and used by the researcher, representing an 83% return rate.

2.5. Data Collection and Quality Control

This study utilized primary and secondary data. The primary data include data collected by the researcher from a focused group of process safety professionals in Nigeria with minimum of 15 years' process safety experience in oil and gas operations and a cross-section of asset integrity engineers/operators, process safety experts, production safety professionals in oil and gas industry in Niger Delta region via survey questionnaire. A focused group was chosen because it enabled gathering of rich qualitative data (Hoseini et al., 2021). The results of the focused group were used as inputs in developing the survey questionnaire. The secondary data was collected from process safety journal articles and used to compare with responses from the questionnaire/checklist.

The study used modified 5-point Likert-scale questionnaires to measure the perceptions of the study's participants. The reliability of the questionnaire was carried out using the test-retest method. The internal reliability of the questionnaire data was conducted using SPSS version 27 to obtain an acceptable Cronbach's alpha value of 0.78. Reliability analysis is vital to ascertain the consistency of the response scores in the questionnaires (Bartlett II et al., 2001; Singh, Ajay, & Masuku, 2014). The random sampling technique was deployed in this study.

2.6. Data Analysis

Descriptive statistics (mean) was used in data analysis and evaluation of challenges of the petroleum industry in assessing process safety cumulative risk. A Likert Mean of ≥3.5 indicated that the statements were accepted among the respondents while a Likert Mean < 3.5 indicated that the statement was rejected by the respondents. To test the hypotheses that "Process safety cumulative risk challenges in the petroleum industry are not significantly different across the study area", the one-way analysis of variance was used to compare the mean scores of the participant's responses across the different locations. SPSS version 27 was used for data analysis.

3. Results and Discussion

The results from this study are presented in the Tables and Figures. **Table 1** and **Figure 1** show the demographic characteristics of the respondents. **Table 2** shows the descriptive statistics on the challenges and needs in the oil and gas industry in assessing process safety cumulative risk while **Table 3** shows the mean scores and analysis of variance on process safety cumulative risk challenges and needs in the oil and gas industry by locations.

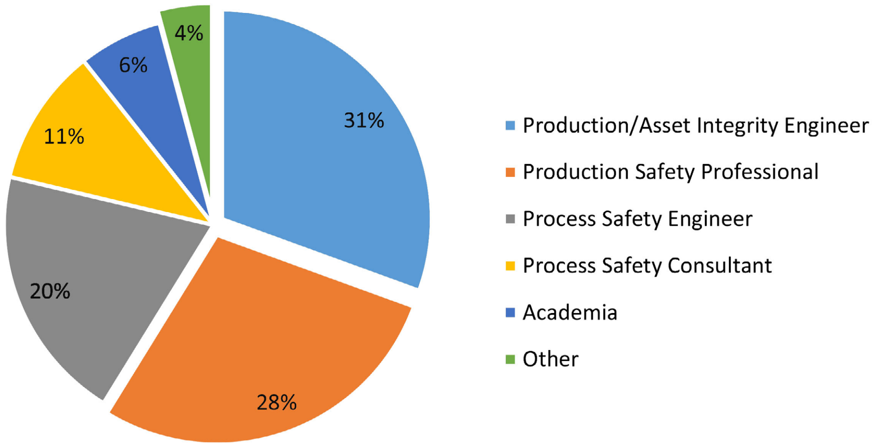

Figure 1. Distribution of respondents by job categories.

Table 1. Demographic characteristics of respondents.

Variables	Categories	Frequency	Percent (%)
Gender	Male	153	70.83
	Female	63	29.17
Age groups	25 - 30	54	25.00
	31 - 40	57	26.39
	41 - 45	48	22.22
	46 - 50	35	16.20
	50 and above	22	10.19
Educational Qualification	HND	38	17.59
	Bachelor's Degree	89	41.20
	Master's degree	61	28.24
	Doctorate degree	27	12.50
	Other	1	0.46
Oil and Gas Experience	1 - 5 years	71	32.87
	6 - 10 year	68	31.48
	11 - 15 years	34	15.74
	Above 15 years	43	19.91
Location	Rivers	65	30.09
	Delta	57	26.39
	Imo	33	15.28
	Bayelsa	25	11.57
	Akwa Ibom	18	8.33
	Lagos	18	8.33

Table 2. Challenges of petroleum industry in assessing process safety cumulative risk.

S/No.	Description of Survey Question (SQ)	SA n (%)	A n (%)	D n (%)	SD n (%)	N n (%)	Weighted mean
SQ1	It is not simple to keep a good overview of the deviations, mitigations and remedial actions on a petroleum facility	89 (41.20)	100 (46.30)	12 (5.56)	2 (0.93)	13 (6.02)	4.2
SQ2	The changing amount of barrier data is difficult to manage which makes it hard to assess existing/new cumulative risks.	88 (40.74)	104 (48.15)	14 (6.48)	0 (0.00)	10 (4.63)	4.2
SQ3	Knowledge is still low in Nigeria on the pathways for process safety risk accumulation due to safety critical impairments in a facility	168 (77.78)	35 (16.20)	4 (1.85)	1 (0.46)	8 (3.70)	4.7
SQ4	There are still no adequate guidance and framework on the management of cumulative risks arising from multiple deviations and impairments in petroleum facilities in Nigeria	162 (75.00)	32 (14.81)	10 (4.63)	2 (0.93)	10 (4.63)	4.6
SQ5	Data collation for process safety cumulative risk is time and labour intensive, resides in dispersed systems, lacking a single point of access	165 (76.39)	38 (17.59)	3 (1.39)	1 (0.46)	9 (4.17)	4.7
SQ6	There is no real time tool in Nigeria that visualizes the accumulation of risks from multiple deviations and impairments in a facility	174 (80.56)	24 (11.11)	8 (3.70)	1 (0.46)	9 (4.17)	4.7
SQ7	Presenting the process safety cumulative risk profile on area plots (plot plan) will give the best view of risk accumulation (cumulative risk)	12 (5.56)	51 (23.61)	11 (5.09)	0 (0.00)	142 (65.74)	3.3
SQ8	Presenting the process safety cumulative risk profile on area plots (plot plan) and bowtie/Swiss-cheese view will give the best view of risk accumulation (cumulative risk)	24 (11.11)	162 (75.00)	5 (2.31)	0 (0.00)	25 (11.57)	3.9
SQ9	Presenting the process safety cumulative risk profile on bowties/Swiss-cheese model will give the best view of risk accumulation	173 (80.09)	39 (18.06)	0 (0.00)	0 (0.00)	4 (1.85)	4.8
SQ10	Using mathematical models (quantitative risk assessment) is better than using "traffic light" scoring system to represent impairment on a barrier	13 (6.02)	20 (9.26)	31 (14.35)	122 (56.48)	30 (13.89)	1.9

SA: Strongly agreed, A: Agreed, N: Neutral, D: Disagreed, SD: Strongly disagreed, *Statement is accepted (criterion mean of responses ≥3.5).

Table 3. Mean scores on process safety cumulative risk issues, challenges and needs in the oil and gas industry by locations.

Location	Mean	SD	ANOVA (*p*-value)
Akwa Ibom	4.45	0.15	
Bayelsa	4.46	0.18	
Delta	4.48	0.25	0.798**
Imo	4.44	0.12	
Lagos	4.52	0.45	
Port-Harcourt	4.53	0.24	

SD: Standard deviation of Mean; ANOVA: Analysis of Variance. **Difference between locations is not statistically significant.

3.1. Demography

Table 1 showed that of the 216 respondents that took part in the survey, 71% of them are men and 29% are female. On age distribution of the respondents 26% are between 31 to 40 years, 25% are between 25 and 30 years, 22% are between 41 and 45 years, 16% are between 46 and 50 years and 10% are above 50 years. On educational qualification, 18% of the respondents have Higher National Diploma, 41% of the respondents have Bachelor's Degree, 28% have Master's Degree and 13% have Doctorate Degree. 33% of the respondents have between 1 to 5 years oil and gas experience, 31% of the respondents have between 6 to 10 years oil and gas experience, 20% of the respondents have above 15 years oil and gas experience and 16% of the respondents have between 11 and 15 years oil and gas experience. 56% of the respondents work in Rivers and Delta States, the two states that have the bulk of petroleum operations in the Niger Delta region. Table 2 also showed the distribution of the job categories of the participants. The highest proportion were production/asset integrity engineer (31%) followed by production safety professional (28%), process safety engineer (20%), process safety consultant (11%), Academia (6%) and other categories (4%).

3.2. Challenges and Needs in the Oil and Gas Industry in Assessing Process Safety Cumulative Risk

Table 2 shows the descriptive statistics on the perceptions of the respondents on challenges in the petroleum industry in assessing process safety cumulative risk. The respondents agreed with most of the constructs in the affirmative with a weighted average that ranged between 3.3 to 4.8. Specifically, 88% of the respondents agreed that it is difficult to keep a good overview of the deviations, mitigations and remedial actions on a petroleum facility; 89% agreed that the changing amount of barrier data is difficult to manage which makes it hard to assess existing and new cumulative risks. 94% of the respondents agreed that knowledge is still low in Nigeria on the pathways for process safety risk accumulation due to safety critical impairments in a facility. 90% agreed that there are still no adequate guidance and framework on the management of cumulative risks in Niger-Delta Nigeria. 94% of the respondents strongly agreed that data collation for process safety cumulative risk is time and labour-intensive, resides in dispersed systems, lacking a single point of access. 92% of the respondents strongly agreed that there is no real time tool in Nigeria that visualizes the accumulation of risks from multiple deviations and impairments in a facility. 80% of the respondents strongly agreed that presenting the process safety cumulative risk profile on bowties/Swiss-cheese model will give the best view of risk accumulation. 86% of the respondents agreed with the construct that presenting the process safety cumulative risk profile on area plots (plot plan) and bowtie/ Swiss-cheese view will give the best view of risk accumulation (cumulative risk).. However, 66% of the respondents were undecided on the construct that presenting the process safety cumulative risk profile on area plots (plot plan) will give the best view of risk accumulation (cumulative risk) and 29% agreed with the construct. 71% disagreed with the construct that using mathematical models (quantitative risk assessment) is better than using "traffic light" scoring system to represent impairment on a barrier.

The one-way analysis of variance was used to compare the mean scores of the participant's responses across the different locations and test the hypothesis: Ho: "Process safety cumulative risk challenges in the petroleum industry are not significantly different across the study area". **Table 3** shows the result. The table shows the mean scores and standard deviation of process safety cumulative risk challenges in the different location. The Analysis of Variance showed no significant difference in the mean scores of process safety cumulative risk challenges in the oil petroleum industry (p = 0.798). Therefore, the null hypothesis "Process safety cumulative risk challenges in the petroleum industry" is not rejected.

4. Discussion

The statistics from **Table 1** suggest that the study's participants that took part in the survey, were seasoned professionals in the oil and gas industry. The survey also indicated the participants' level of education was high and that there was adequate distribution of the research instruments among the Niger Delta States participants' geographical location. These demographic data also suggested that based on the respondents' level of education and years of experience, they have reasonable knowledge about the issues, challenges and needs of the oil and gas industry on process safety cumulative risk assessment for major accident prevention in petroleum operations in Niger Delta. Indeed, the participants' level of industry experience enhances the reliability of this study, as it indicates that most participants have vast experience in the oil and gas industry.

From **Table 2**, assessing process safety cumulative risk is cumbersome and is an ongoing challenge in oil and gas industry in Nigeria (SQ1). Refsdal & Urdahl (2014) collaborated this finding by stating that management and monitoring of overall asset integrity system of a production plant in a very objective and auditable way is challenging. From the survey, it was recognized that barrier data is always in a state of flux and this makes it difficult to manage cumulative risk in an ongoing basis (SQ2). This finding is consistent with the view of Pitblado et al. (2016) that barrier degradation is far from being simple and constant and requires constant vigilance to maintain functionality. Liu (2020) stated that there are about 17 variables that affect barrier performance and these are ever changing. Knowledge of process safety cumulative risk assessment is also low (SQ3) and there is a lack of clear guidance not only on a cumulative risk assessment process and methodology (SQ4), resulting in a relatively low level of competency. This aligns with the view of Behie et al. (2020) that there is no consistent practice or guideline available for monitoring the health of barriers which is the necessary input into cumulative risk assessment. This problem of lack of cumulative risk guidance has been recognized by Oil & Gas UK hence they developed a guidance document on cumulative risk assessment (OGUK, 2016). Barrier degradation data required for assessing process safety cumulative risk is also time and labour-intensive and resides in dispersed systems, lacking a single point of access (SQ5), thereby impeding easy aggregation of the information and making it difficult to create a holistic picture in order to monitor risk. This aligns with the view of (Refsdal & Urdahl, 2014; Pitblado et al., 2016) that barrier integrity information is usually available in different formats and systems and not in a form that will enable the right decisions to be taken to prevent major accidents and the health of safety critical barriers are reported in several management systems (Behie et al., 2020). There is no real-time tool for assessing process safety cumulative risk within the study area (SQ6) and there are also the issue of visualization method (SQ7, SQ8, SQ9 and SQ10), very little consistency in formats for visualizing the cumulative risk. According to Braseth and Sarshar (2012), proper visualization of the risk provides decision-input into work prioritization and execution in an operating facility and visual presentation of risks provide better insights for decision making than textual information (Sarshar & Haugen, 2018). One of the findings of the study is that the use of "traffic light" system is preferred against the use of quantitative risk assessment models (mathematical models) for visualization of the cumulative risk, to enable operational decisions. This agrees with the view of (Kongsvik et al., 2015) on the need to make risk picture more relevant for operational decision making. According to various researchers, quantitative risk models are static (Kanes et al., 2017) and precludes possible updates and integration of the overall risk picture of the facility on a frequent basis (Bubbico et al., 2020a) and does not provide adequate support for operational decisions in oil and gas industry (Kongsvik et al., 2015). Yang & Haugen (2018) also observed that traditional quantitative risk assessment models focus more on design-related issues instead of operational activities that drive the risk level in the facility. The respondents also preferred visualization of the cumulative risk using Swiss-cheese/bowtie model against area plan visualization option. This aligns with the view expressed by Pitblado et al. (2016), recognising bowtie model as a good barrier management and risk communication and recommended some form of dynamic barrier management due to its static form in operational risk management. Bowties provide a suitable level of simplification of the causal factors, summarizing large quantities of data into common scenarios addressing major accident risks and prevention (Mokhtari et al., 2011) and helps operators to focus on high risk areas for major accident prevention instead of the whole plant (Chen et al., 2017). The study also established that there is no real time tool in Nigeria that visualizes the accumulation of risks from multiple deviations and impairments in a facility, which is an area that has not been investigated hitherto in Nigeria. There are also no guideline and methodology for assessing cumulative risk in oil and gas facilities in Niger-Delta Nigeria.

From **Table 3**, the One Way Analysis of Variance (ANOVA) with a p-value of 0.798, it was a clear indication that the challenges in the petroleum industry in assessing process safety cumulative risk are relatively same across the study area, as the ANOVA result showed that there is no significant variation in the challenges across the locations in the study area. This conclusion aligns with the view of (Sarshar et al., 2016) that most issues and challenges with managing major accident risk are common across oil and gas facilities and locations.

Overall, the study recognized that assessing process safety cumulative risk is not a simple process due largely to the changing nature of barrier degradation data in time and space. The study identified four main issues/challenges faced by petroleum industries in Nigeria, in assessing process safety cumulative risk: limited accessibility to barrier degradation data (little automation), poor knowledge of process safety cumulative risk, no guidance/procedures and lack of risk visualization model/tool.

5. Conclusion and Further Work

The aim of the study was to explore the challenges and needs of the petroleum industry in Niger-Delta Nigeria, in assessing process safety cumulative risk. A purposive cum random sampling technique was used in this study among oil and gas companies operating in Niger-Delta, Nigeria. Survey questionnaires were administered to obtain respondents perception on the challenges and needs of the oil and gas industry in assessing cumulative risk. Data analyses were carried out to cover descriptive and inferential statistics. Overall, the study recognized that assessing process safety cumulative risk is not a simple process due largely to the fact that the safety barrier degradation is always in a state of flux. Through this exploratory study, four main needs and challenges are identified as aspects that need to be addressed and focused on, in assessing process safety cumulative risk in Niger-Delta Nigeria, to reduce the risk of major accidents. One challenge is the limited accessibility to barrier degradation data, further exacerbated because of little automation in the integrity data management system. There is also poor knowledge of process safety cumulative risk in the petroleum industry with no guidance and procedures on process safety cumulative risk management. Lack of risk visualization model/tool is also identified as a challenge of the petroleum industry in Nigeria, in managing process safety cumulative risk.

Further work includes proposing improvements within the identified areas to further help the petroleum industries to overcome the obstacles and reduce the risk of major accident through proper assessment of process safety cumulative risk. A limitation for this study is that petroleum industries in the Niger-delta were covered. Therefore expanding the research to cover other countries could be considered.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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