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RISK ANALYSIS OF MODULAR REFINERY IN THE NIGER DELTA REGION OF NIGERIA

Lawrence Echezona Onwuka and Ebigenibo Genuine Saturday

Department of Mechanical Engineering, University of Port Harcourt

ABSTRACT

Risk analysis of a Modular Petroleum Refining Plant in the Niger Delta region of Nigeria was carried out to illustrate the various risk factors common to a typical modular refinery with potential to cause disruption of the refining process when released. The analysis is predicated on the fact that a number of modular refineries are being conceived / constructed in the Niger Delta region and there is inadequate risk assessment to identify, assess, prioritize, evaluate and control risks relating to petroleum refining operations before investment decisions are made and also during refinery operations. The analysis was carried out using a questionnaire to elicit relevant information from industry professionals of considerable years of experience. Data analysis was carried using weigh-scaling method. This assesses and prioritizes the risks associated with the processing units of modular refining configuration. Specifically, the practitioner weighed and assessed the identified potential risks in terms of risk level, relative consequences if it is released, and the most affected objectives. The results obtained show that among other risk elements, technical risk (88%), operational (87%) and organizational risks (78%), with respective consequence levels of 73%, 72% and 68% are high risk elements with higher potential for release. The research outcome can be used by risk management practitioners and investors as a basis for decision making prior to investment.

KEYWORDS: Risk analysis, Weight scaling, Questionnaire, Technical risk, Operational Risk, organizational risk.

INTRODUCTION

Petroleum refineries produce over 80 million barrels of product per day to run the daily global demand for energy [1]. This shows that petroleum refineries are important facilities around the world to accelerate economic growth in various sectors of industrial operation. Petroleum refineries are complex integrated systems which are capital intensive and a constant flow of production infrastructure. Due to complexity of this infrastructure, it is essential to consider precise, engineered operational procedures to assure safety of petroleum refinery operations and to protect people working within these infrastructures and the environment where these facilities are installed. [2]. A modular refinery by definition is a prefabricated processing plant that has been constructed on a skid mounted surfaces, with each structure containing a portion of the entire refining process connected together by piping systems to form a non-complex process. Over the last four decades, Nigeria has consistently struggled to keep its refineries functioning optimally [3]. The outlook of refining has been limited by poor adverse effects of subsidies, poor maintenance and general operational failures. Net consumption of refined petroleum products stood at 777, 000 barrels per/day as at July2018.

Despite having a name plate refining capacity that exceeds demand, Nigeria ranks as the 3rd highest importer of petroleum products in Africa, importing over 80% of the products consumed. Petroleum refining operations have widely increased in the last two decades based on the fact that global demands for energy will on average, increase by 2% per year until 2020 [4]. Over 790 refineries in 116 countries are in full operation, producing petroleum gas, and petrochemical products to meet the increasing energy need around the world in the industrial production sector, power generation sector, transportation sector, commercial sector and marine sectors. The risk analysis processes continually evolve from the conception of the project and engineering phase, through constructions, the commissioning of the units, operating, maintenance and decommissioning of the units. Risk analysis has become an integral part in the decision-making process. It affects productivity, performance, quality and the budget of oil and gas refining process [5]. Like most business decisions, engineering project decisions are taken on the basis of expectation about the future. Decisions taken on the basis of assumptions, expectations, estimations and forecasts of the future event involve taking a risk. Risks are almost impossible to measure with any precision, and difficult to define. Some people draw a distinction between hazard and uncertainty. Risk is when we can make statistical assessment of the probability of a particular event occurring. Risk is the product of the probability of event and the magnitude of loss/gain. Risk assessment is an independent scientific process consisting of hazard identification, hazard characterization, exposure assessment and risk characterization.

Risk management is a process of weighing policy alternatives in consultation with all interested parties, considering the outcome of the risk assessment and other factors relevant for the safety, protection of the environment by selecting appropriate control. Risk communication is an interactive exchange of information throughout the risk analysis process concerning risk, risk related factors, risk perception amongst risk assessors, risk managers, consumers, industry and the academic community and other interested parties, including the explanation of risk assessment findings and the basis of risk management decisions [6]. Restrepo et al. [7] disclosed that the most common cause of accidents and failures are equipment malfunction, corrosion, materials and weld defects, incorrect operation, all of which could result to death, injuries, environmental damage and host of economic damage. Raemdonck et al. [8] carried out risk analysis in the transportation of hazardous materials exploiting historical accident data. Osabutey et al. [9] opined that risk management practices are an interactive process, consisting of steps, which when taken sequentially will enable continual improvement in decision taking. The aim of risk management is to obtain understanding by all parties and agreement on the existing risks, methods of administration in order to improve systems performance, enhance returns on investment and cut down on financial loss. Identified risk affecting functionality of a petroleum refinery include global oil process fluctuations, currency depreciation, health, safety and environment (HSE) management concerns, political interference, pollution and environment concerns, crude oil supply constraints, huge debts as a result subsidizing petroleum products and high operational risks.

El-Arkam [10] combined two tools (HAZOP and FMEA) in risk analysis and assessment in petrochemical plants in order to enhance the speed of hazard identification and risk assessment, predict nature and impact of such accidents. HAZOP is the method recommended for identifying hazards and problems which prevent different operations. It is identified as a preventive tool in risk control. FMEA focuses on determination of all failure modes, causes and consequences of each of the components in the process plant and localization of the damage.

The functionality of a process system can be grouped into two: functional analysis and dysfunctional analysis. Functional analysis performs functional decomposition of an industrial plant in operation to identify, characterizes, classify, prioritize and valorize all the systems functions through structural analysis and design technical (SAFT), multi-level flow diagram (MFM) for representation of plant functions. Dysfunctional analysis focuses on identifying conditions and scenarios with potential for failure, predict their impact on reliability, maintainability, availability, integrity and security of an operational system. A structured method used to identify potential failure of product and determine the failure frequency and impact. When criticality ranking is included in the analysis, it is then referred to as failure modes, effects and functionality analysis (FMECA) and a risk priority number and criticality analysis estimated and performed respectively.

Traditionally risk assessment is performed using static failure probabilities but this approaches failed because the failure probabilities are static but in actual sense the failure probabilities are dynamic. This called for the introduction of dynamic quantitative risk assessment (DQRA) due to the dynamic nature of risk associated with environments such petroleum refineries, offshore production platforms [11]. The DQRA takes advantage of operational data to update the failure possibilities obtained from the initial data design phase. The occurrences and development of fire and explosion hazards caused by leaks on offshore production platform are dynamic in nature [11]. This is because the accidents are emergent properties, which results from mutual influences of risk factors such operational gaps, equipment's malfunction, technology failures and even external or natural influences that escalate continually until the system crashes.

Abdolhamidzadeh et al. [12] concluded that risk involves both the characteristics of a system and the chance of the occurrence of an event that jointly result in loss. The relationship between vulnerability and risk is not commutative since reduced risk vulnerability always means reduced risk outcome but reducing risk outcome does not always reduce vulnerability [12]. Effective planning and response to hazard and other extreme events requires that the vulnerability associated with specific social and decision processes be understood in parallel with understanding of processes and probabilities of risk. This is to ensure that judgment can be made about the appropriate balance between risk and vulnerability-based approaches to risk management. The systematic framework for quantitative risk assessment called optimal risk analysis involves four major steps which include: hazard identification, hazard assessment, consequence analysis and risk evaluation [13]. Hazard identification techniques are equally effective for traditional Greenfield developments and for Brownfield projects or modifications as well as onshore and offshore plants. In this work, a number of risk elements associated with petroleum refining are identified with their respective risk items. The risk level and the consequence level the various risk items could affect are sought based on severity in a scale from 1 to 4. Also, the economic parameters the various risk items could affect mostly are sought. A questionnaire was used to obtain the required information from experienced professionals in the petroleum refining industry The information obtained was statistically analyzed to obtain the average percentage risk level and consequence level his risk element poses to crude oil refining operation.

MATERIALS AND METHODS

The research aims to identify the following:

i. To ascertain the level of application of risk management in a typical modular refinery
ii. To identify and prioritize types and nature of risk factors that affects a typical modular refinery

iii. To find out the relationship between these risk factor variables
iv. To identify the impact of risk assessments in petroleum refining operations.

The basic hypotheses put forward in this research include:

i. Technical risk with associated risk elements (Process equipment's failure, piping system failure, new technology introduction, materials defects and failure, aging and instrumentation failure) have leading role in disruption of petroleum refining process.
ii. Operational risks with associated risk elements (deviations from safe operational procedures, operator's incompetency, inadequate maintenance procedure) individually or jointly can lead to disruption of petroleum refining process.
iii. Organizational risks with associated risk elements (Poor management policy and procedures, poor staffing, Non Staff Trainings and funding risks) individually or jointly can lead to disruption of petroleum refining process.
iv. External risks with corresponding risk elements (Natural risks, militancy/sabotage and Fraud by dishonest persons) individually or jointly can lead to disruption of petroleum refining process.
v. Legal risks with violation of regulations as its risk elements can lead to disruption of petroleum refining process.
vi. Socio-political risks with associated risk elements (Changes in government, and delays in approvals) individually or jointly can lead to disruption of petroleum refining process.

To test these hypotheses, data has to be collected and analyzed using different tools.

Research design

The scope of the information gathering for this project was planned to embrace a wide range of project execution practitioners and owners. In order to achieve the scope envisaged in this study, questionnaires were sent out to experienced operators in the petroleum refining industry. The accident history in the line of the case study and previous projects executed helped to identify the particular mistakes, failures and risk factors that occurred in a petroleum refining operation. Risk identification gave emphasis to the use of checklist as a prompt for the respondents to brainstorm. The respondent's knowledge and creativity were useful in order to identify credible causes and hence applicability of the risk's assessment.

Sampling design and sample size

The projects and construction team of a modular refinery in Rivers state, constituted bulk of the survey areas. Experienced practitioners at the refinery and external individuals with varying years of experience in petroleum refining industry ranging from one to twenty-five years were considered. The sample size used is given by Taro Yamane formula [14]

$$n = \frac{N}{1 + N(e)^2} \quad (1)$$

Where n represents the sample size, N represents the population under study and ***e*** represents the acceptable sampling error, (e = 0.05).

The population size in this study is 55. Hence, the sample size taking the whole number is,

$$n = \frac{N}{1 + N(e)^2} = \frac{55}{1 + 55(0.05)^2} = 49$$

Data collection

Primary data was obtained from questionnaires that were administered. This was appropriately moderated. The questionnaires were designed to obtain sufficient and only relevant information from the respondents who are majorly experienced professionals, operators and consultants from the petroleum refining industry. In preparing the questionnaire, relevant literatures were reviewed and with this, the questions that will elucidate better objective of the survey were designed. The first part of the questionnaire has to do with the respondent's background - the organization, length of time in the industry, number of projects involved in and further information concerning risk management practices in the organization. The second part of the questionnaire presents the different risk items which the respondent need to tick the appropriate box based on the severity or weight of the risk as shown in Table 1.

Table 1: Questionnaire for data generation

Risk Characterization	**Risk levels**				**Consequences**				**Effects**		
	A				B				C		
Risk weightings	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**
1. TECHNICAL RISKS											
i. Process equipment failure											
ii. Piping system failure											
iii. Utilities systems failure											
iv. Materials defects and failure											
v. Instrumentation failures											
2. Operational Risks											
i. Deviations from safe procedures											
ii. Operators incompetency											
iii. Inadequate maintenance procedure											
3. Organizational Risks											
i. Poor management policy and procedures											
ii. Poor staffing											
iii. No staff trainings											
iv. Funding risks											
4. External risk elements											
i. Natural risks											
ii. Militancy/sabotage											
iii. Fraud by dishonest personnel											
5. Legal risks											
i. Clashes with law requirements											

KEY

A. <u>RISK LEVEL</u>

1. Negligible risk
2. Low risk
3. Significant risk
4. High risk

B. <u>CONSEQUENCE LEVEL</u>

1. Negligible consequence
2. Low consequence
3. Significant consequence
4. High consequence

C. <u>EFFECTS ON PROJECTS</u>

1. Cost implications
2. Time delays
3. Quality implications

6. Socio/political risks												
i. Changes in government												
ii. Delays in approvals												

2.4. Data Analysis

The analysis of data obtained established the risk level of the various risk elements in refining operations. Also, the impact of the various risk elements on the project in terms of cost, quality, schedules and safety were evaluated. Data analysis was carried out by weight-scaling method. Specifically, the practitioner weighed and assessed the identified potential risks in terms of risk level, relative consequences if it is released, and the most affected objectives in the following manner. This approach involves comparing estimated levels of risk to assessment criteria, in order to identify the most significant risks, or to exclude minor risks from further analysis. The purpose is also to ensure that use of resources will be focused on the most important risks. In practice, care should be taken not to screen out low risks which occur frequently and can therefore have a significant increasing effect.

The preliminary analysis determines one or more of the following courses of action:

i. Setting aside insignificant risks (so called acceptable risks) which would not justify treatment,
ii. Deciding to treat unacceptable risks,
iii. Setting priorities for risk response.

Risk weighting provides inputs to decisions on whether risks need to be treated, and on the most appropriate risk treatment strategies and methods. Subsequently, the purpose of risk weighting is to assist in making decisions (based on the outcomes of risk analysis) about which risks need treatment and which priority must be assigned for their treatment.

The risk characterization gave rise to risk level with 4 weights, consequences with 4 weights and Effects. Analysis of the collected data follows the following pattern.

Risk level assessment as weighed by the practitioner

Weighting scale:

1 = Negligible risk

2 = Moderate risk

3 = Significant risk

4 = High risk.

In the questionnaire, the individual judgments of the respondent for the various risk items were collated using this scale. The total assessment or weights is obtained by summing the respondents' weights,

Total Weight, $X_T = X_1 + X_2 + ... + X_N$ (2)

Where the subscripts 1, 2. . . N identifies the various respondents and X is the weight assessed by the practitioner under risk level. The mean weight X_m is computed as,

$$X_m = \frac{X_T}{N} \tag{3}$$

The percentage weight X_{100} gives the average risk level of the respondents and equally indicates the level of importance and it is given as,

$$X_{100} = \frac{X_T}{4} \times 100 \tag{4}$$

Consequence level assessment of the risk by practitioner

Weighting Scale:

1 = Negligible consequences

2 = Moderate consequences

3 = Significant Consequences

4 = High Consequence

Here, Y is taken as the weights under consequence level assessment. The total assessment or weights for consequences level of risk items are obtained by summing the respondents' weights:

Total Weight, $Y_T = Y_1 + Y_2 + ... + Y_N$ (5)

Where the subscripts 1, 2. . . N identified the various respondents and Y is the weight assessed by the practitioner. The mean weight Y_m is,

$$Y_m = \frac{Y_T}{N} \tag{6}$$

The percentage weight Y_{100} is,

$$Y_{100} = \frac{Y_T}{4} \times 100 \tag{7}$$

This percentage weight gives the average consequence level of the respondents and equally indicates the level of importance.

Most affected project objective

1 = Cost Implications
2 = Project Delivery Period
3 = Safety

Finally, for descriptive analysis, the respondent indicated the most affected objective if a particular risk occurs by filling either of the numbers 1, 2, 3 in the last column of the questionnaire.

Application of risk module

Upon the fact that refining processes differ from one another, so for a meaningful assessment, a customized risk module is developed for any assessment which serves as a boundary condition between high and low priority risks as in Table 2.

Table 2: Risk assessment module for calculating and prioritizing the assessment of risk levels

S/N	Factors	Weighting	Scale	Maximum score (Weight x Maximum scale)	Assessment	Score
1.	Complexity of technical solution	4	1 = Few Simple Process. 2= Many Simple processes. 3= At least one complex process. 4= Many complex process	16	3	12
2.	Financial consequences of breakdown	4	1= Negligible cost 2= Low cost 3 = Moderate cost 4= High Cost	16	3	12
3.	Environmental consequences of breakdown.	4	1= Negligible risk 2= Moderate risk 3 = Significant risk 4 = High risk	16	2	8
4.	**Total**			**48**		**32**

From Table 2, the assessment column represents the chosen weight from 1 to 4 by the respondent. For a given risk item, the 3 factors in Table 2 can be provided and based on the assessment a total score is obtained. The ratio of the total score to the maximum total score can be obtained (32/48 in Table 2) and compared with a boundary value. A boundary value may be chosen say 0.5. If the ratio is greater than the boundary value, then the risk factor is high but it is low if the ratio is lower than the boundary value. From the feedbacks received in the questionnaires, the ratios were all greater than the boundary value hence all observations were treated.

RESULTS AND DISCUSSION

The results of the data analyzed are shown in Table 3 while Figure 1 shows the average percentage risk level and consequence level of the various risk elements in the petroleum refining operations as assessed by the respondents. The risk elements impact areas in petroleum refining process are shown in Table 4.

Table 3: Respondents' assessment of selected risk factors in petroleum refining operations

Risk elements	Total Weight		Mean Weight		Percentage Weight	
Technical risks	**X**	**Y**	X_T	Y_T	X_{100}	Y_{100}
Process equipment failure	189	169	**3.85**	**3.45**	**96.3**	**86.3**
Piping system Failure	177	152	**3.61**	**3.1**	**90.3**	**78**
Advancement in technology and Innovations	169	149	**3.44**	**3.04**	**86**	**76**
Materials defects and failures	161	131	**3.3**	**2.67**	**82**	**67**
Instrumentation failure	167	115	**2.34**	**2.34**	**85**	**58**
Operational risks						
Deviations from safe operational procedures	179	165	**3.65**	**3.37**	**91**	**84**
Operators Incompetency	164	129	**3.3**	**2.63**	**83**	**66**
Inadequate maintenance procedures	168	134	**3.43**	**2.73**	**86**	**68.3**
Organizational risks						
Poor Management policy and procedures	169	120	**3.45**	**2.45**	**86.3**	**61.3**
Poor staffing	165	146	**3.37**	**2.98**	**83**	**75**
No staff trainings	159	142	**3.24**	**2.89**	**81**	**72.3**
Funding risk	135	122	**2.76**	**2.73**	**63**	**62.3**
External risks						
Natural risk/Disaster	125	90	**2.6**	**1.84**	**65**	**46**
Militancy/Sabotage	120	87	**2.5**	**1.8**	**63**	**45**
Fraud by Dishonest People	117	87	**2.4**	**1.77**	**60**	**44.3**
Legal risks						
Violation of Regulations	105	87	**2.14**	**1.8**	**54**	**45**
Socio/political risks						
Change in government	129	93	**2.63**	**2**	**66**	**50**
Delays in approval	102	73	**2.1**	**1.5**	**53**	**38**

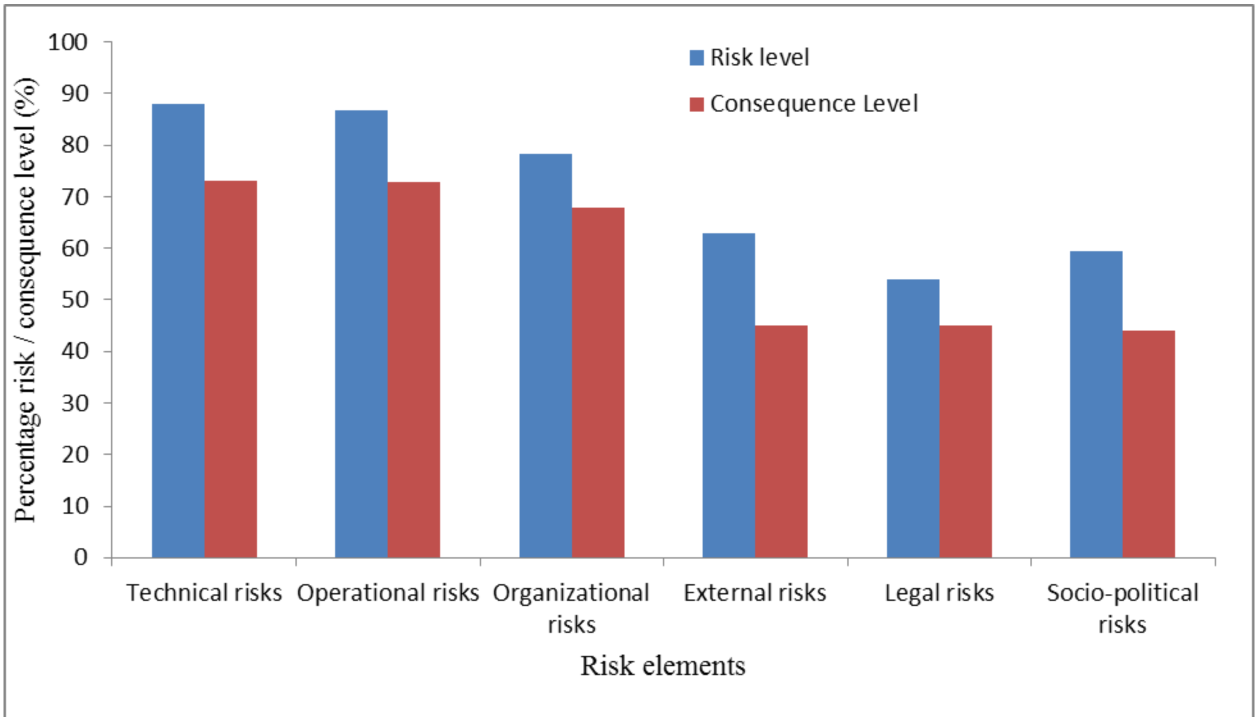

Figure 1: Average percentage risk level and consequence level of the various risk elements

Table 4: Risk elements impact area in petroleum refining process

S/No	Risk elements	Economic objectives mostly affected
1.	Technical risks	Costs and safety
2.	Operational Risk	Costs, quality, safety, delivery schedule
3.	Organizational Risks	Efficiency and cost of production/execution
4.	External Risks	Costs, schedule and environment
5.	Socio-political risk	Schedule
6.	Legal risk	Cost and schedule

Generally, the risk level is greater than the consequence level for each of the risk elements as shown in Table 3. Risk associated with technical aspects is highest while legal risk elements have the lowest risk values as in Figure 1. This is because technical risks are related to equipment failures and as such has greater impact on the refining process. Operational risk elements closely follow the technical risk elements in terms of magnitude. This should be expected as operational risk elements have direct bearing with the refining process. All the risk elements are high enough to have significant impact on petroleum refining process; hence, none should be ignored. Although, technical risk elements are highest in both risk level and consequence level, but, they affect only cost and safety in the economic objectives. Operational risk elements affect more economic objectives as shown in Table 4.

CONCLUSIONS

The risk analysis of a typical refinery carried out in this work identified 6 risk elements (technical risks, operational risks, organizational risk, external risk, legal risk and socio/political risk), their respective individual risk terms, their risk levels, the consequence levels and the economic objectives mostly affected by each of the risk elements. Data was obtained from the industry through questionnaires given to professionals in the petroleum refining industry. It was observed that for each given risk element, the risk level is greater than the consequence level. Of the 6 risk elements, technical risk has the highest risk level of 88%, closely followed by operation risk (87%) and then organizational risk with 78%. Legal risk has the lowest risk level of 54%. The least risk item identified is also capable of disrupting petroleum refining process. Thus, all risk items need to be controlled to have successful refining of crude oil in refineries.

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