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# RELIABILITY ANALYSIS OF CRUDE OIL EXPLORATION IN NIGER DELTA, NIGERIA

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**Abstract:** This work examines the reliability of oil exploration by some oil companies operating in the Niger Delta using parametric and nonparametric reliability methods. Here, reliability models are used to determine the probability that an oil company will operate without spill over some time period $t$. Finding reveals that oil exploration by Nigeria Agip Oil Company (NAOC), Shell Petroleum Development Company (SPDC), Mobil Producing Nigeria-Exxon Mobil in Nigeria (MPN) and Chevron Nigeria Ltd, SEPLAT Petroleum Development Company, TOTAL Nigeria, Pipelines and Product Marketing Company (PPMC), ESSO Exploration and Production Nigeria Ltd, ADDAX Petroleum Development Nigeria Limited, Niger Delta Petroleum Resources Ltd (NDPR), Shell Nigeria Exploration and Production Company (SNEPCO), and Pan Ocean Oil Corporation (Nigeria) Ltd (POOCN) in the Niger Delta area of Nigeria is characterized by frequent spills that occur in approximately 1, 3, 3, 6, 37, 45, 51, 63, 97, 183, 207, and 342 days respectively. The Mean time to oil spill in the entire Niger region stands at approximately 5 days.
**Keywords:** Crude Oil, Exploration, Oil Spill, Reliability.

## 1 Introduction

Crude oil spillage is one of the major environmental problems facing the Niger delta region of Nigeria since the first commercial production by Royal Dutch Shell in 1950s (Egbe and Thompson, 2010). Oil spills have been reoccurring and exerting deleterious impact on the ecosystem. These have led to contamination of drinkable water, serious pollution and obliteration of vegetation, wildlife and resort centres, as well as destruction of lives and properties along the Nigerian coastal area. Oil spills have negatively impacted on the natural resources upon which many Niger Delta communities have their source of livelihood (Oyebamiji and Mba, 2014). According to Raji and Abejide (2013), the Niger Delta region is rated as the most spills impacted and oil polluted area in the world. It is estimated that Nigeria depends on the oil sector for 95% of her export earnings and 85% of government revenue and most of the exploration is done in the Niger Delta (Kadafa, 2012). However, most people of the region are living in abject poverty and have been exposed to a number of health perils. This is

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because most people in this region depend on agriculture for their livelihood. This has resulted to youths' agitation and restiveness, which births kidnapping, thuggery, thefts, and other social vices. On the whole, oil spills have adversely affected the health conditions of both human and nonhuman inhabitants of the affected areas (Salako, et. al., 2012).

The subject of crude oil spillage has become of much interest to academics, professionals, governmental and nongovernmental organisations owing to the frequency of occurrence and also its impact on the ecosystem. For instance, an assessment of environmental problems associated with oil spill and gas flaring has been conducted by Kadafa (2012). This work traced that among the various factors responsible for environmental pollution, oil pollution was also a major factor with attendant effects on water and land degradation. According to the report by Amnesty International (2013), factors identified to be responsible for oil spillage in the zone include corrosion of oil pipes and tanks, sabotage, port operation and inadequate care in oil production operations and engineering drills. A historical review on the number of oil spills and quantity lost in the Niger Delta between 1976-2000 has been documented. It was discovered that while the quantity of oil spilled was on the decrease, oil spill incidences were on the increase (Salako, et. al. (2012). A link between negligence and poverty as causes of pipeline vandalization has been examined by Oteh and Eze (2012). Ibaba and Olumati (2009) examined the link between sabotage induced spillage and human rights violations. They argued that the policy which forbids the payment of compensations to sabotage induced spillage is a violation of economic rights.

It has been observed that many research works on crude oil spills in Nigeria's Niger Delta focuses more on the number (incidence) of spills, causes of spills, economic and environmental impacts, and security implications, Oshwofasa and Anuta (2012). However, there is a basic and pertinent question which this work seeks to answer. The question is; how often does crude oil spill occur in the Niger Delta Region of Nigeria? In other words, what is the rate of occurrence of crude oil spills in the Niger Delta? Our interest in this research is to attempt to answer this basic question using scientific approach. In particular, we will study the rate at which crude oil spills occur in 12 major oil exploration companies in the Niger Delta region using reliability models. Here we define reliability as the probability that an oil company will operate without a spill over a period of time $t$. The remainder of this article is arranged as follows: In section 2 we will briefly describe the study area-the Niger Delta; section 3 presents reliability model and other statistical methods that will be used in the analysis. Results of the analysis with discussion are presented in section 4. Finally, a conclusion is drawn in section 5.

## 2 The Niger Delta Region

The present day Niger Delta region consists of 9 states of Nigeria, namely; Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and River States. The Niger Delta Region Occupies about 7.5% of Nigeria's land mass and it is located in the Atlantic coast of the Southern part of Nigeria. It is rated as the world second largest Delta with a coastline of about 450km. The Niger Delta has a population of over 31 million people. The main occupation of the people living in the Niger Delta region is generally Agriculture and in particular fishing (Onwubiko et. al. (2013).

## 3 Methods

### 3.1 Reliability Model

Reliability is defined as the probability that a system will function over some time period t. For the purpose of this work, we are concern with the system of oil exploration by some oil companies in the Niger Delta region of Nigeria. We assume that the system fails once there is a spill. From our data, time to failure, T for all companies follows a weibull distribution, except that of NAOC which did not fit any parametric distribution. Suppose T is weibull, the probability density function is given as

$$f(t)=\frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} e^{-(\frac{t}{\theta})^{\beta}}, \beta>0, t\geq 0, \theta>0$$

where $\beta$ and $\theta$ are the shape and scale parameters respectively. $\theta$ is also known as the characteristics life, reliability function is given as

$$R(t)=\exp\left\{-\int_0^t \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} dt\right\}$$

$$=e^{-\left(\frac{t}{\theta}\right)^{\beta}}$$

Failure rate function is given as

$$h(t)=\frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1}$$

Mean time to failure is

$$\text{MTTF}=\theta\,\Gamma\left(1+\frac{1}{\beta}\right)$$

And variance

$$\sigma^2 = \theta^2 \left\{ \Gamma(1+\frac{2}{\beta}) - \left[ \Gamma(1+\frac{1}{\beta}) \right]^2 \right\}$$

where $\Gamma(x)$ is the gamma function defined as $\Gamma(x) = \int_0^\infty y^{x-1} e^{-y} dy$

To analyse the data from NAOC we consider the nonparametric approach using Kaplan-Meier estimation method. We choose the nonparametric method because NAOC data did not follow any known parametric distribution. Interested readers who want to know more about reliability models can consult Ebeling (1997).

### 3.1.1 Kaplan-Meier (K-M) estimator

The Kaplan-Meier estimator, otherwise known as the product limit estimator is a nonparametric method that is suited for the analysis of reliability data. In the oil spill context, we will give the actuarial-simple definition of K-M estimator. This method is based on calculating the number of failures (spills) in a time interval, $r_i$ versus the number of operating units in the time period, $n_i$. The formula for the Kaplan-Meier estimator is given by

$$\hat{R}(t_j) = \prod_{i=1}^{j} \left(1 - \frac{r_i}{n_i}\right) \; ; \; j = 1, \cdots, m$$

where,

$m =$ the total number of intervals

$n =$ the total number of cases

The variable $n_j$ may be defined by

$$n_j = n - \sum_{i=0}^{j-1} s_i - \sum_{i=0}^{j-1} r_i \; ; \; j = 1, \cdots, m$$

$r_i =$ the number of failures in intervals $i$.

$s_i =$ the number of censored cases in intervals $i$.

## 3.2 Estimation of the Rate of Crude Oil Spills in the Entire Niger Delta

Note that the parametric and non-parametric reliability models that we have defined in section 3.1 and subsection 3.1.1 will help us to estimate the rate of spills (i.e. mean time to spills) for each of the 12 oil exploration companies that is considered in this work. Now, to estimate the mean time to spills in the entire Niger Delta we adapt the weighted mean approach. The basic assumption is that each of the 12 oil exploration companies operates independently.

### 3.2.1 The Weighted Mean

Given a non-empty set of data $\{x_1, x_2, \cdots, x_n\}$, the weighted mean is defined by

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i-1}^{n} w_i}$$

where

$w_i =$ the weight of $i^{th}$ data set

If the weights are normalized $\sum_{i-1}^{n} w_i = 1$.

Note that the set $\{x_1, x_2, \cdots, x_{12}\}$ represents the mean time to spills for the 12 oil exploration companies considered in this work. The weight, $w_i$ is defined as the probability of occurrence of of spills in the $i^{th}$ oil exploration company. By the classical definition of probability we have $w_i$ as

$$w_i = \frac{n(i)}{N}$$

where

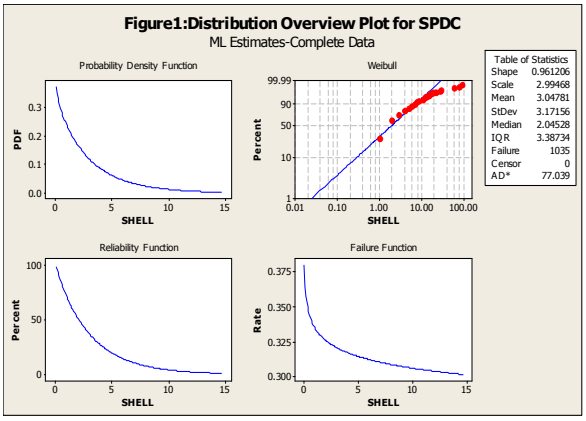
$n(i) =$ Number of spills in the $i^{th}$ company

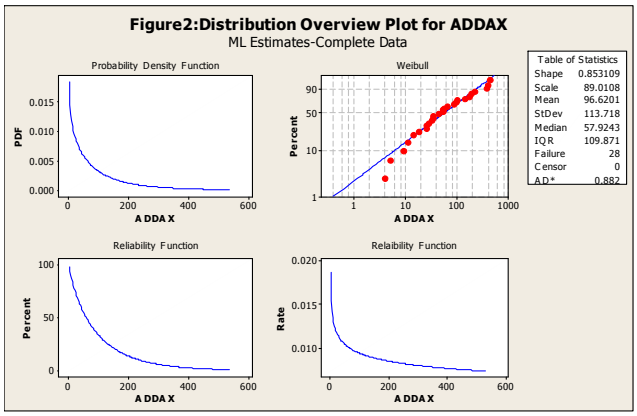
$N =$ Total Number of spills

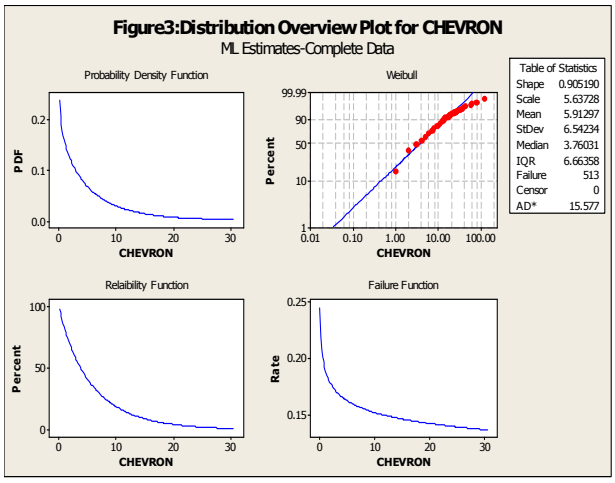
## 3.3 Data and Analysis

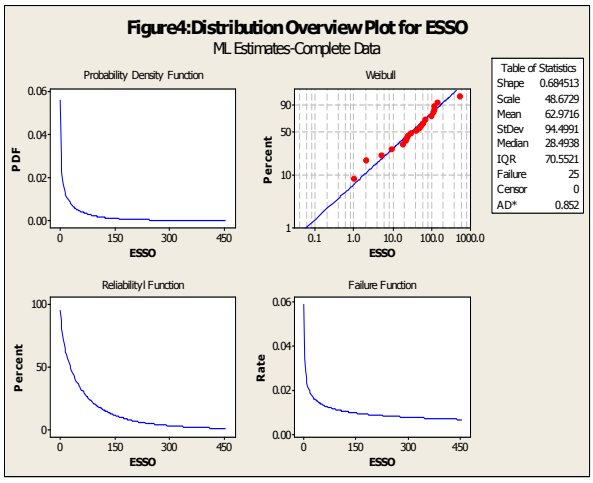
The data used for this research has its source from National Oil Spill Detection and Response Agency (NOSDRA). The agency which is under the Ministry of Environment, charged with the responsibility of detection of oil spill and monitoring responses from all oil producing companies. The data has, among other information, the record of oil spills (irrespective of quantity) incidence with dates from January, 2006 to May, 2014 from 16 oil companies operating in the Niger Delta. With this information, inter event (of spill) times were generated. A total of 6288 oil spill incidences with volume 211377.165 bbl were recorded from the 16 oil companies. However, 4 out of the 16 oil companies recorded only one incidence of spill. We then considered 12 companies in our reliability analysis. See Figure13 and 14 for the plots on the incidence and volume of oil spill by companies within the period.

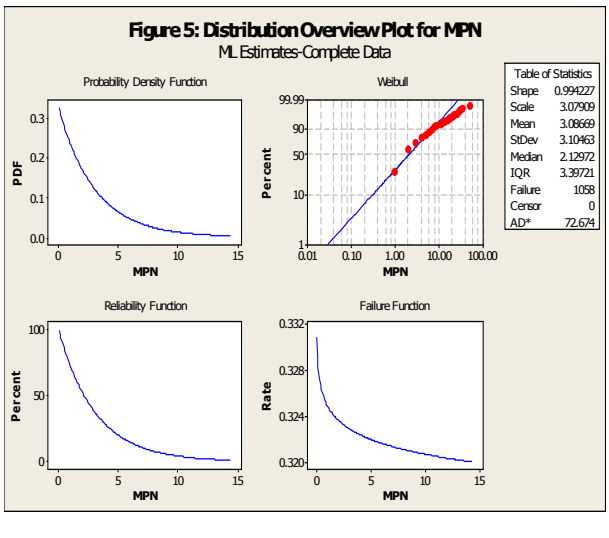
## 4.0 Results and Discussion

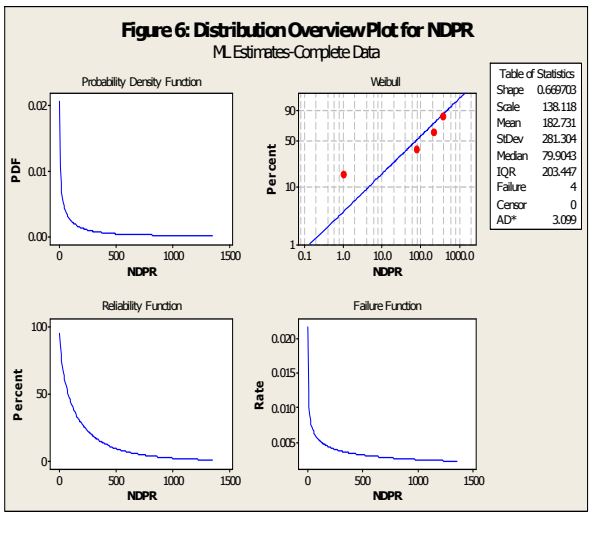


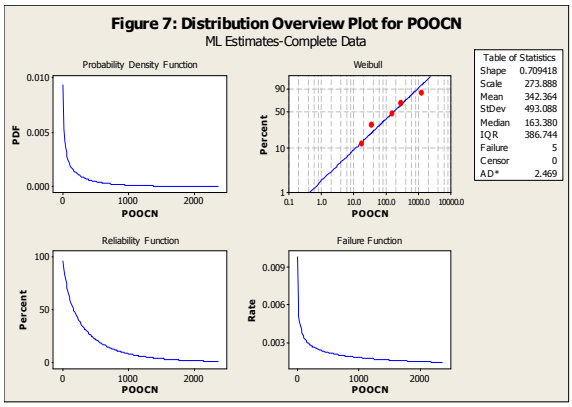


Figure 7: Distribution Overview Plot for POOCN
ML Estimates-Complete Data
Probability Density Function
Weibull
Reliability Function
Failure Function
PDF
Percent
Rate
POOCN
Table of Statistics
Shape 0.709418
Scale 273.888
Mean 342.364
StDev 493.088
Median 163.380
IQR 386.744
Failure 5
Censor 0
AD* 2.469

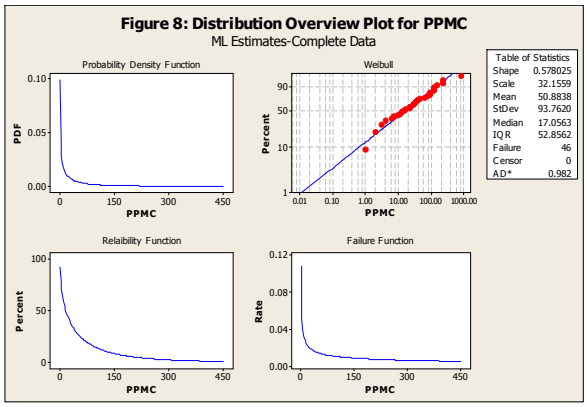


Figure 8: Distribution Overview Plot for PPMC
ML Estimates-Complete Data
Probability Density Function
Weibull
Reliability Function
Failure Function
PDF
Percent
Rate
PPMC
Table of Statistics
Shape 0.578025
Scale 32.1559
Mean 50.8838
StDev 93.7620
Median 17.0563
IQR 52.8562
Failure 46
Censor 0
AD* 0.982

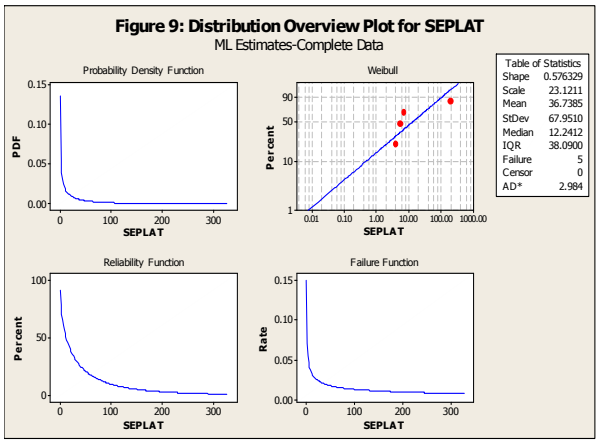


Figure 9: Distribution Overview Plot for SEPLAT
ML Estimates-Complete Data
Probability Density Function
Weibull
Reliability Function
Failure Function
PDF
Percent
Rate
SEPLAT
Table of Statistics
Shape 0.576329
Scale 23.1211
Mean 36.7385
StDev 67.9510
Median 12.2412
IQR 38.0900
Failure 5
Censor 0
AD* 2.984

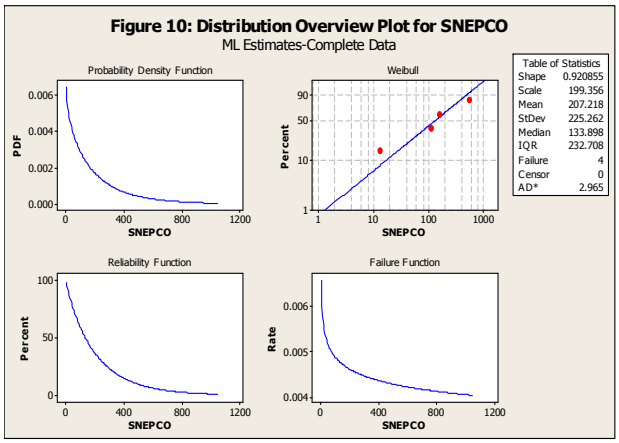


Figure 10: Distribution Overview Plot for SNEPCO
ML Estimates-Complete Data
Probability Density Function
Weibull
Reliability Function
Failure Function
PDF
Percent
Rate
SNEPCO
Table of Statistics
Shape 0.920855
Scale 199.356
Mean 207.218
StDev 225.262
Median 133.898
IQR 232.708
Failure 4
Censor 0
AD* 2.965

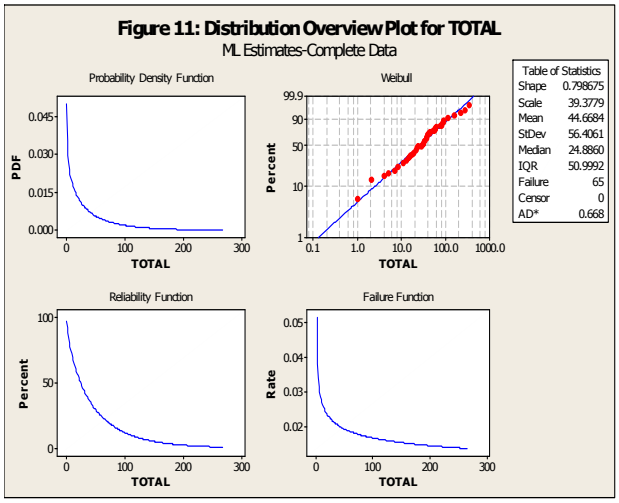


Figure 11: Distribution Overview Plot for TOTAL
ML Estimates-Complete Data
Probability Density Function
Weibull
Reliability Function
Failure Function
PDF
Percent
Rate
TOTAL
Table of Statistics
Shape 0.798675
Scale 39.3779
Mean 44.6684
StDev 56.4061
Median 24.8860
IQR 50.9992
Failure 65
Censor 0
AD* 0.668

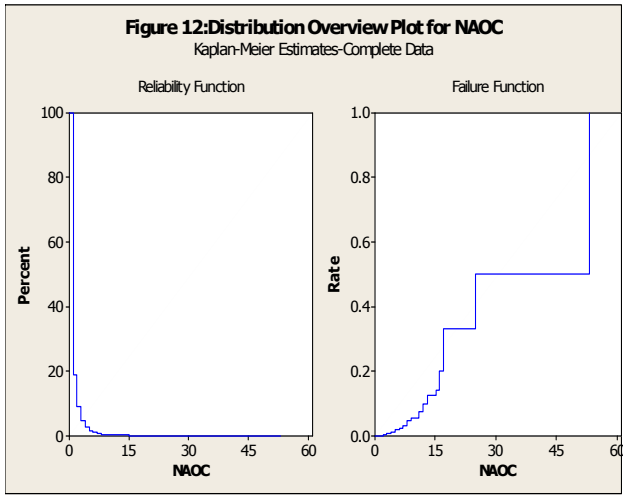


Figure 12:Distribution Overview Plot for NAOC
Kaplan-Meier Estimates-Complete Data
Reliability Function
Failure Function
Percent
Rate
NAOC

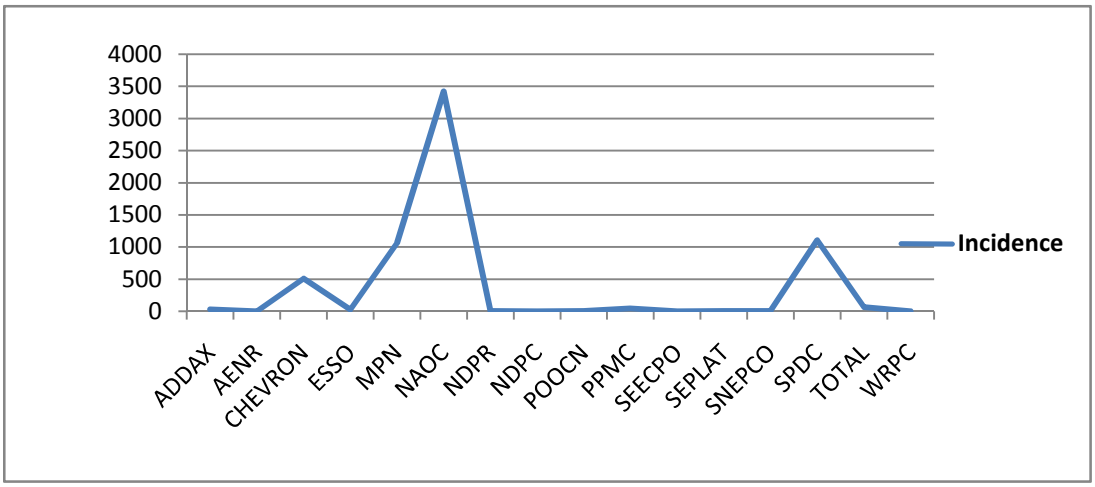



**Figure13:** A plot of Incidence of Oil Spill in Niger Delta (2006-May,2014)

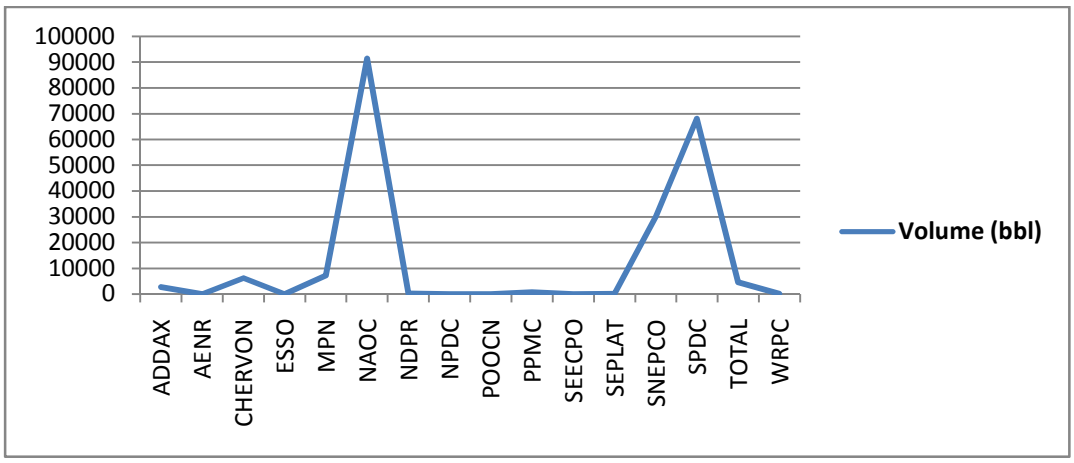



**Figure 14:** A plot of the Volume of Oil Spilled in Niger Delta (2006-May,2014)

Figure 1-11 presents the parametric distribution overview plots for SPDC, ADDAX, CHEVRON, MPN, NDPR, POOCN, PPMC, SEPLAT, SNEPCO, and TOTAL respectively. Each overview showcases failure time graphs, namely from the top left, probability density function, probability plot, reliability function, and failure function. It can be seen that all the points are approximately on the straight line on the weibull probability plot, so the weibull distribution is a good choice for the parametric analysis. All the reliability function graphs are decreasing which indicates that system reliability decreases with time. In particularly, the probability that SPDC will carry out its operations without spill within 5 days is about 0.19, while the probability that TOTAL will operate without spill for 28 days is about 0.48. Failure functions for all the companies are decreasing, an indication for early failure. Figure 12 present the nonparametric distribution overview for NAOC, with decreasing reliability

function graph. In this case the probability that the NAOC will operate without spill for at most a day is 0.19.

In table 1, we present the summary of the estimates of relevant parameters for the reliability analysis for each of the oil company. Column 2 shows that all the shape parameters are less than one ($\beta < 1$), a confirmation of systems with early failure. Column2 has scale parameters, which is the value (in days) by which 63.2% of all failures would have occurred. In column 8, MTTF's are presented with the least value from NAOC=1.4310 and the highest from POOCN=342.4048.

**Table 1: Summary of reliability analysis by company**

| Company | Shape | Scale | StD | IQR | AD* | MTTF |
|---|---|---|---|---|---|---|
| ADDAX | 0.8531 | 89.0108 | 113.718 | 109.871 | 0.882 | 96.6212 |
| CHEVRON | 0.9052 | 5.9129 | 6.5423 | 6.6636 | 15.577 | 6.2021 |
| ESSO | 0.6845 | 48.6729 | 94.4991 | 70.5521 | 0.852 | 62.9827 |
| MPN | 0.9942 | 3.0791 | 2.1297 | 3.3972 | 72.672 | 3.0871 |
| NAOC | - | - | - | 0 | - | 1.431 |
| NDPR | 0.6697 | 138.118 | 281.304 | 203.447 | 3.009 | 182.7715 |
| POOCN | 0.7094 | 273.888 | 493.088 | 386.744 | 2.469 | 342.4048 |
| PPMC | 0.578 | 32.1559 | 93.762 | 52.8562 | 0.982 | 50.9124 |
| SEPLAT | 0.5763 | 23.1211 | 67.951 | 38.09 | 2.984 | 36.7602 |
| SNEPCO | 0.9209 | 199.356 | 225.262 | 232.708 | 2.965 | 207.2106 |
| SPDC | 0.9612 | 2.9947 | 3.1716 | 3.3873 | 77.039 | 3.0477 |
| TOTAL | 0.7986 | 39.3779 | 56.4061 | 50.9992 | 0.668 | 44.6703 |

To obtain the rate of crude oil spill in the Niger Delta we note the following:

(i) that the total number of spills ($N$) recorded for the 12 oil companies is 6217

(ii) the distribution of these spills by company is ADDAX=29, CHEVRON=514, ESSO = 24, MPN=1059, NAOC=3420, NDPR=5, POOCN=6, PPMC=47, SEPLAT=6, SNEPCO=3, SPDC=1036, TOTAL=68.

Consequently, if $\bar{x}_T$ represent the mean time to spill in the Niger Delta Region then

$$\bar{x}_T = \frac{29}{6217}(96.6212) + \frac{514}{6217}(6.2021) + \frac{24}{6217}(62.9827) + \frac{1059}{6217}(3.0871) + \frac{3420}{6217}(1.431) + \frac{5}{6217}(182.7715) + \frac{6}{6217}(342.4048) + \frac{47}{6217}(50.9124) + \frac{6}{6217}(36.7602) + \frac{3}{6217}(207.2106) + \frac{1036}{6217}(3.0477) + \frac{68}{6217}(44.6703) = 5.0025$$

Hence, the mean time to oil spills in the Niger Delta is approximately 5 days

## 5 Conclusions

In this paper, a reliability analysis on crude oil exploration in the Niger Delta region of Nigeria was carried out. This research answer a basic question: how often do oil spills occur in the region based on individual companies? From this analysis it can be said that crude oil exploration in the Niger Delta region of Nigeria is characterized by incessant spills. Finding reveals that oil exploration by Nigeria Agip Oil Company (NAOC), Shell Petroleum Development Company (SPDC), Mobil Producing Nigeria-Exxon Mobil in Nigeria (MPN) and Chevron Nigeria Ltd, SEPLAT Petroleum Development Company, TOTAL Nigeria, Pipelines and Product Marketing Company (PPMC), ESSO Exploration and Production Nigeria Ltd, ADDAX Petroleum Development Nigeria Limited, Niger Delta Petroleum Resources Ltd (NDPR), Shell Nigeria Exploration and Production Company (SNEPCO), and Pan Ocean Oil Corporation (Nigeria) Ltd (POOCN) in the Niger Delta area of Nigeria occur in approximately 1, 3, 3, 6, 37, 45, 51, 63, 97, 183, 207, and 342 days respectively. The Mean time to oil spill in the entire Niger region stands at approximately 5 days.

Oil companies and security operatives can leverage on the information provided here to effectively management oil exploration and security detailing to curb crude oil spill that may be due to assignable causes like poor operation and vandalism. Further studies should be carried out to identify the risk factors associated with the spills.

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