Application of Decision Theory in Assessing Marginal Oilfield Risks: Niger Delta Hub Example

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Abstract
Decision theory valuation methodology has been identified as an effective tool in the analysis and management of risks for decision making in marginal oilfield exploitation. Numerous conventional methods in the employ of most international oil companies seem an aberration in marginal oilfield operation due to the uniqueness of the risks and the high cost of implementation. This short coming has resulted in the inability to optimally unlock the economic potentials of marginal oilfields that has remained untapped to replenish fast declining oilfields on account of their low economies of scale. A decision theory approach was successfully deployed in theoretically analyzing decision alternatives with Isiekenesi Oilfield, one of 251 remotely located marginal oilfields in the Nigeria Niger Delta. The study yielded corresponding payoff values for different reserve expectations of low, medium, and high cases in barrels of crude oil. Despite its limitations in not aptly defining the risks in crisp numbers, it successfully predicted the risk ratios of fundamental decision alternatives guided by basic assumptions on state of nature. This approach provides a cost effective first-pass appraisal mechanism needful for decision making process open to investment capitalists engaged in marginal oilfield exploitation.

Keywords: marginal oilfield, reserves, risks, decision theory, Isiekenesi, Niger Delta.

INTRODUCTION
Current risks assessment and management practices by International Oil Companies (IOCs) have not been very effective in marginal oilfields operation due to the small size and remoteness of the oilfields, which in most cases, are very far from existing processing facilities coupled with the complexities of the operation among others. Whereas IOCs operate many oilfields to which they could afford to spread or absorb the risks, local operators or venture capitalists are constrained to just one or few marginal oilfields. In the Nigeria’s Niger Delta for instance, circa 251 identified marginal oilfields are operated by nearly equal number of indigenous companies who could pass as small scale oilfield operators. This caliber of operators lack basic technological know how and managerial skills essential for handling the complexities off marginal oilfields exploitation. Marginal oilfields show great potential to substantially contribute to the national economic fortune of a producing country and could at the same time ruin investors, if the associated risks are not properly identified and managed. Further, marginal oilfields contribute significantly to the national oil reserve and in so facto deserve due attention. Unfortunately, establishing risk management process and database similar to IOCs, require many years of built up experience and deployment of discipline professionals, which can be quite strenuous and expensive. This proposed approach takes into cognizance feasible alternative courses of action in conjunction with the prevailing state of nature and in doing this; appropriate statistical techniques are employed as decision support in arriving at the right course of action.

There has been considerable interest in the development and application of models to risk management. Use of Simulation in risk analysis is common in the risk analysis literature. Some representative works on risk management using Simulation approach include Chapman (1983), Vinnen (1983), Cooper, MaccDonald, and Chapman (1985), Pugh (1986), and Hall (1986). Following these seminal research in the 1980s, further application of Monte Carlo appeared in the 1990s. The works Higgins (1993), Kostetsky (1994), Savvides (1994) as well as Van Groenendaal and Kleijnen (1997) are typical. Interest in Monte Carlo simulation application to risk management has been sustained in recent contemporary period. Coelho, et al. (2005) compared Monte Carlo simulation with Neural Network techniques and observed that the two approaches complement each other. Further Chinbat and Takakuwa (2009) focused on the development of a simulation method for managing risk in Mongolian mining project.

Besides Simulation technique, a variety of approaches had also appeared in the risk management literature. Thus in an effort to further establish the use of risk analysis and, moreover, widen the scope
of applicable model, McCray, et al. (2002) as well as Trumper and Virine (2011) introduced the use of Event Chain. These studies demonstrated that the method is quantitative and also mitigates cognitive and motivational biases inherent in the project risk analysis. Again, heuristic method of making judgment about risk under uncertainty has been studied by Tversky and Kahneman (1974). The authors noted that though the approach is highly economical and effective but it leads to systematic and predictable errors. Also, Kaiser (2010) offers a lively modeling of inventory of assets committed to marginal oilfield production and sketched a perspective of the producing assets.

In particular, the studies Schuyler (2001) and Flyvbjerg (2006) provide interesting treatments of risk analysis of projects using decision theory. In addition, the book Rose (2012) provides detailed treatment on risk assessment and the economic implications for explorationists, managers, and oilfield investors. Yet, a novel approach to risk management known as unknown unknown is presented by Raydugui (2011). The study noted that people risk identification requires thinking outside the box. Also, Bastos and Barton (2004) applied Portfolio Theory that is based on Probabilistic methodology. This was applied to Brazilian electrical system involving development of stand alone hydropower station. Last, Kraft (1982) discussed risk in policy research and noted that risk analysis is a veritable tool for managing risks in projects. Again, works; Ward and Chapman (1991), Harbaugh, et al. (1995), Undram and Takakuwa (2009), and Andersen and Mostue (2011) emphasized the need for the use of risk analysis in managing risks in projects.

In sum, then, the foregoing sample literature review provides palpable supportive evidence to the fact that very little study appears to have been documented in regards to application of Decision Theory to risk management in marginal oilfields. This paper therefore seeks to breach this frontier. Thus, the aim of this paper is to apply Decision Theory in analyzing risks inherent in the marginal oilfields located in the Nigeria Niger Delta.

METHODS
This analytical and case study research design is based on data obtained from three exploratory wells drilled in Isiekenesi, a marginal oilfield located in the Nigeria flank of Niger Delta. More specifically, the data relates to wells drilled in the early 1910s with a 2-D seismic survey acquired sixty years later in the early 70s. The field is a partially appraised, non-concessionary onshore acreage located approximately 63 and 85 Kilometers North East of Izombe and Egbema fields respectively in the Niger Delta. Figure 1 shows the Oil Mining Lease (OML) map of the Niger Delta and Benue Basin with relative location of the Isiekenesi Field.

Figure 1: Location Map of Nigeria Oil Mining Leases
The first well was drilled to a depth of 8,400 feet (2,560 meters) and encountered 271 feet (87 meters) of net oil in four sands. Also, Figure 2 shows the cross-sectional map of the only three exploratory wells. Snowball, non-random sampling technique was followed.

Figure 2: Cross-sectional Map
The estimated expected reserves were taken from preliminary evaluations conducted at the early stage. Further, a 20-year production forecast for three case scenarios; low case, medium case, and high case representing proved, probable, and possible reserves were estimated based on data from the three exploratory wells. Again, another data obtained from the oilfield relate to the initial estimated reserves and are shown in Table 1.
Table 1: Reserve Expectation Scenarios

<table>
<thead>
<tr>
<th>S/N</th>
<th>Sensitivity</th>
<th>Case STOIP (MMSTB)</th>
<th>Reserves (MMSTB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P90</td>
<td>25.3</td>
<td>10.1</td>
</tr>
<tr>
<td>2</td>
<td>P50</td>
<td>36.9</td>
<td>14.2</td>
</tr>
<tr>
<td>3</td>
<td>P10</td>
<td>53.5</td>
<td>22.6</td>
</tr>
</tbody>
</table>

For simplicity, we considered these three alternatives open to prospective venture capitalists for operating a marginal oilfield:

i) Direct Labour (Direct Execution)

ii) Partnership (Equity Sharing)

iii) Outsourcing (with 10% returns)

Expected Value Method (EVM)

This theoretical approach enables the analyst to determine the following:

i) Expected Value $E(x)$ of the reservoir under uncertainty

ii) The associated risk in the management of the reservoir uncertainties.

Let $x$ be a random discrete variable known as the pay-off matrix. Consider a probability or density function $f(x) = p$. Let $\sum_{i=1}^{K} f(x) = 1$, then

$$E(x) = \mu = \sum_i x_i f(x_i), \quad \text{and}$$

$$\text{Variance} \sigma^2 = \text{Risk} \sum_{i=1}^{K} (x_i - \mu)^2 f(x_i)$$

Thus, the higher the variance, the higher the associated risk.

From (1):

$$\sigma^2 = \sum (x_i^2 - 2\mu x_i + \mu^2) f(x)$$

$$= \sum x_i^2 f(x_i) - 2\mu \sum x_i f(x_i) + \mu^2 \sum f(x_i)$$

$$= \sum x_i^2 f(x_i) - 2\mu \mu + \mu^2$$

$$= \sum x_i^2 f(x_i) - \mu^2 $$

(2)

For this oilfield, the state of nature in Table 2 has been estimated as follows:

Table 2: Assumed State of Nature

<table>
<thead>
<tr>
<th>S/N</th>
<th>Alternative</th>
<th>Investment Capital</th>
<th>Income (Reserve)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Direct Labour</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>Partnership</td>
<td>60%</td>
<td>60%</td>
</tr>
<tr>
<td>3</td>
<td>Outsourcing</td>
<td>0%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Case Analysis

The confidence limits are

Confidence Limits $= \bar{y} \pm Z_{\alpha/2} \frac{\sigma}{\sqrt{n}}$, and from statistical Table,

For 90%, $Z_{0.05} = 1.67$

For 50%, $Z_{0.10} = 0.67$

For 10%, $Z_{0.90} = 0.12$

Number of wells, $n = 3$

And, for spatial contiguity of the wells, being that they are in the same region, the standard deviation among the well voluminosity should be $\sigma = 25\%$

A) Proved Case (90% Confidence level), $K=1$, where $n$ is number of exploratory wells.

State of nature = 25/75.

For 90% confidence level

$$UCL = \bar{y} + 1.67 \frac{\sigma}{\sqrt{n}}$$

$$= 10.1 + 1.67 \frac{0.25(10.1)}{\sqrt{3}}$$

$$= 12.535\text{MMSTB}$$

$$LCL = \bar{y} - 1.67 \frac{\sigma}{\sqrt{n}}$$

$$= 10.1 - 1.67 \frac{0.25(10.1)}{\sqrt{3}}$$

$$= 7.666\text{MMSTB}$$

Decision Alternatives | Operating Factor | State of Nature | $S_1 (0.25)$ | $S_2 (0.75)$ |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>12.535</td>
<td>7.666</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
<td>7.521</td>
<td>4.600</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
<td>1.254</td>
<td>0.767</td>
<td></td>
</tr>
</tbody>
</table>

State of Nature = 25/75

$$E(x) = \mu = \sum x_i f(x)$$

$$= (12.535 \times 0.25 + 7.666 \times 0.75)$$

$$= 10.1$$

$$= 5.330$$

$$E(x)_{k=1} = \frac{8.883}{0.888}$$

$$\text{Risk} = \sigma^2 = \sum (x_i^2 f(x_i) - \mu^2)$$

$$= (12.535 \times 7.666)^2$$

$$= 9.883$$

$$= (7.521 \times 4.600)^2$$

$$= 9.883$$

$$= (1.253 \times 0.767)^2$$

$$= 0.888$$

$$= 0.888$$
B) Probable Case (50% Confidence level), K=2, where n is number of exploratory wells. State of nature = 70/30

\[ UCL = \overline{y} + Z_{0.5} \frac{\sigma}{\sqrt{n}} \]  
\[ = 14.2 + 0.12 \frac{0.25(14.2)}{\sqrt{3}} \]  
\[ = 15.573 \text{MMSTB} \]  
\[ LCL = \overline{y} - Z_{0.5} \frac{\sigma}{\sqrt{n}} \]  
\[ = 12.827 \text{MMSTB} \]

<table>
<thead>
<tr>
<th>Decision Alternatives</th>
<th>Operating Factor</th>
<th>Expected Royalty Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>15.573 12.827</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
<td>9.344 7.696</td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
<td>1.557 1.283</td>
</tr>
</tbody>
</table>

\[ E(x)_{k=2} = \sum x \cdot f(x) \]  
\[ = \frac{15.573 \cdot 12.827 + 9.344 \cdot 7.696}{0.7 + 0.3} \]  
\[ = 14.749 \]  
\[ \begin{pmatrix} d_1 \\ d_2 \\ d_3 \end{pmatrix} = \begin{pmatrix} 14.749 \\ 8.850 \\ 1.489 \end{pmatrix} \]

\[ \text{Hence the risk, } \sigma^2 = \sum x^2 \cdot f(x) - \mu^2 \]  
\[ = \frac{15.573 \cdot 12.827 + 9.344 \cdot 7.696}{0.7} - \frac{14.749^2}{1.489} \]  
\[ = 0.089 \]  
\[ = 0.001 \]

\[ \text{Risk, } \sigma^2 \approx 0.021 \]

C) Possible Case (10% Confidence level), K=3, where n is number of exploratory wells. State of nature = 20/80

\[ UCL = \overline{y} + Z_{0.9} \frac{\sigma}{\sqrt{n}} \]  
\[ = 22.6 + 0.12 \frac{0.25(22.6)}{\sqrt{3}} \]  
\[ = 22.992 \text{MMSTB} \]  
\[ LCL = \overline{y} - Z_{0.9} \frac{\sigma}{\sqrt{n}} \]  
\[ = 22.6 - 0.12 \frac{0.25(22.6)}{\sqrt{3}} \]  
\[ = 22.208 \text{MMSTB} \]

\[ E(x)_{k=3} = \sum x \cdot f(x) \]  
\[ = \begin{pmatrix} 22.992 \\ 13.795 \\ 2.299 \end{pmatrix} \]

\[ \text{Hence the risk, } \sigma^2 = \sum x^2 \cdot f(x) - \mu^2 \]  
\[ = \begin{pmatrix} 22.992^2 \cdot 0.2 + 13.795^2 \cdot 0.8 + 2.299^2 \cdot 0.2 \end{pmatrix} \]

Risk, \( \sigma^2 \approx 0.001 \)
4. on account of the spatial contiguity of the three oil wells voluminosity, a fair assumption of 25% variability standard deviation, that is, $\sigma = 25\%$ is assumed

5. State of nature: A fair probability of achieving the projected expected reserve cases are assumed as follows:
   a. 25% for Proved Case
   b. 70% for the Probable Case
   c. 10% for the Possible Case

6. Number of wells, $n = 3$, based on the number of sampled exploratory wells.

**RESULTS**

The results of this study are presented in the following sequence:

3.1 Resistivity log
3.2 Projected cross-sectional map
3.3 20-year estimated production schedule
3.4 Results of statistical computations of risks associated with three decision options

The foregoing outline is taken seriatim.

**Resistivity log Result**

Figure 3 presents the reservoir resistivity log showing the thick accumulation of hydrocarbon distribution with a three layer yield.

**Projected Cross-Sectional Map**

Figure 4.2 provides the cross-sectional map of the three exploratory wells indicating areas of continuity.

**Twenty Year Production Schedule**

Figure 4.3 shows the profiles of the estimated 20-year exploratory production forecast for the three expected cases based on 2-D seismic data.

**Results of Statistical Computations**

**Proved Case Scenario**

This presents the low case expectation with highest level of confidence. The expected pay-off in millions of barrels for the three decision alternatives is as follows:

$$
\begin{align*}
\begin{bmatrix}
\Delta_1 \\
\Delta_2 \\
\Delta_3
\end{bmatrix} &= \begin{bmatrix}
8.883 \\
5.330 \\
0.888
\end{bmatrix}
\end{align*}
$$

While, the associated relative risk is expressed as:

$$
Risk (\sigma^2) = 0.045 \begin{bmatrix}
100 \\
36 \\
1
\end{bmatrix}
$$
Implying that, the ratio of risks associated with the three decision alternatives: direct execution; partnership; outsourcing is 100:36:1. This quantitative risk analysis is an operator’s guide to action.

**Probable Case Scenario**

Again, this presents the medium case expectation with average level of confidence. The expected pay-off in millions of barrels for the three decision alternatives is as follows:

\[
\begin{pmatrix}
4.749 \\
8.850 \\
1.489 \\
\end{pmatrix}
\]

MSTB

And the relative associated risk is given by:

\[
Risk. (\sigma^2) = 0.021 \begin{pmatrix} 75 \\ 27 \\ 1 \end{pmatrix}
\]

Which shows a reduced ratio from the previous Proved case scenario, thus, for probable case, the risk ratio is estimated to be 75:27:1.

**Possible Case Scenario**

This presents the highest case expectation, however, with the lowest level of confidence. In this category, the expected pay-off in millions of barrels for the three decision alternatives is expressed as:

\[
\begin{pmatrix}
22.368 \\
13.419 \\
2.237 \\
\end{pmatrix}
\]

MSTB.

And, the associated risk is given by:

\[
Risk. (\sigma^2) = 0.001 \begin{pmatrix} 89 \\ 35 \\ 1 \end{pmatrix}
\]

In this version, the risk proportion is 89:35:1; showing a significant variation from the previous reserve expectation scenarios.

**DISCUSSION**

Increasingly, interest in marginal oilfields is rapidly emerging owing mainly to the economic benefits. Thus, oil producing countries concerned about the fast depleting reserves without commensurate new discoveries, are now striving to harness the huge potentials from marginal oilfields which hitherto had been neglected. Despite this interest, the exploitation of these marginal oilfields has remained nightmarish due to numerous risks and uncertainties associated with the exploitation as expounded earlier. Apparently, extrapolating the cost of conventional practices by IOCs to managing marginal oilfield risks has not been 100% effective due to several reasons. First, IOCs could absorb or spread some of these risks among their portfolios which other local operators or venture capitalists might not be disposed to handle. Second, the practical approach might be too expensive for the local operators. The approach in question is an accumulation of experience over a long period which is not readily available to the venture capitalists. Hence, a less costly theoretical risk assessment method becomes a veritable tool which this study has proposed.

Evidently, the approach adopted in this study, although a statistical evaluation, but in some way, is a ballpark of simulation methodology in the sense that three different decision alternatives were brought into perspective and analyzed based on certain stated assumptions. The payoffs and the associated risks were weighed up in order to guide the process of taking well informed decisions on investment alternatives.

Objectively, this study has successfully unearthed quantitatively, the relative risks associated with likely decision alternatives when faced with varied expected reserve scenarios under uncertain states of nature.

**CONCLUSION**

Despite limited field data obtained from the marginal oilfield, the study has been successful in using decision tool methodology to provide quantitative insight into the nature and distribution of risks inherent in the marginal oilfield under study. Sure enough, this outcome of the study has demonstrated that a quantitatively guided decision could be reached with sparse data which will not be easy with conventional approach. All the same, by extending the spectrum or bandwidth of the stated state of nature, a sensitivity analysis could be called into play in order to achieve optimization.

**REFERENCES**


