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Research Article

A Fuzzy-Logic Theoretic Approach to Modelling Marginal Oilfield Risks

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Abstract: Risk has remained a debilitating enigma against the full realization of marginal oilfield potentials and lack of its contribution to the economy. This stems from the inability on the part of the operators to identify, quantify and apply the risk profile to correctly adjust the return on investments in marginal fields. This study provides a veritable tool that systematically transforms the qualitative risk variables from its linguistic expressions to quantitative functions using fuzzy logic in combination with conventional risk analysis techniques. Accordingly a total of six risk attributes were isolated using Delphi technique. And, in all, 53 risk variables were identified and used to craft a questionnaire scaled with RensisLikerts 5-point attitudinal scale which were subsequently administered to 42 respondents. A computed Kendall Coefficient of Concordance of W = 0.75 and chi-squared value (x^2) of 546 which is greater than 27.69 recorded in the statistical table showed an incontrovertible level of agreement among the judges in ranking the variables, hence, a null hypothesis of disconcordance among the judges was rejected at a p-value of 0.01. Again, the study was able to establish that an investment risk level of 0.71 on a scale of 0 to 1 is associated with this Isiekenesi field in the Nigeria Niger Delta, whereupon signifying a snag in the overall return on investment. Further, our results indicate that security of property and personnel pose the greatest challenge to investment in the marginal field of Niger Delta.

Keywords: Delphi technique, fuzzy logic, Isiekenesi, marginal oilfield, reserves, risks

INTRODUCTION

There is genuine concern that Nigeria's crude oil reserve of circa 40 billion barrels may dry up in less than 50 years going by the average daily depletion of 2.2 million barrels (Donnelly, 2008), if the contributory marginal oilfields is not fully exploited to replenish the reserve base. This is exacerbated by the National Bureau of Statistics (2011) report indicating that the economic strength of the country is heavily dependent on crude oil, accounting for nearly 95% of her export earnings. Efforts to enlist local investors in exploiting the nation's nearly 251 fields with approximately 2.3 billion barrels of reserves as a strategy to contain the insecurity in its energy future (Egbogah, 2011), is hampered by a plethora of risks and uncertainties. These fields were abandoned and classified as marginal oilfields by International Oil Companies (IOCs). The operation of these marginal oilfields represents an economic activity knotted with complex decision challenges (Chinbat and Takakuwa, 2008) which is compounded by technical and logistics constraints to wit:

- Very small sizes of reserves/pool to the extent of not being economically viable
- Lack of infrastructure in the vicinity and profitable consumers
- Prohibitive development costs, fiscal levies and technological constraints

Unfortunately, all government efforts and previous works were centered on addressing only the legal tangle on equity participation and operatorship of marginal fields in Nigeria leaving the much tortuous risks and uncertainties unaddressed. Some of these works are contained in many government releases (DPR, 1996; Usman, 1996; Atsegbua, 2005; Onyeukwu, 2006). However, IOCs continuously engage in wide-ranging conventional risk management techniques where the risks are either absorbed, albeit, with a premium, or the consequential costs spread among their portfolios. This, to some extent require, in some cases, drilling multi-million dollar appraisal wells to further understand the uncertainties in a field, which local investors can ill afford. So far, there has been an extensive literature on the various approaches to handling risks in projects but unfortunately, none appear to have addressed risks in marginal fields operation. These include both sophisticated and less sophisticated capital budgeting techniques such as Heuristic method, Expected Value method, Net Present Value (NPV), Internal Rate of

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Return (IRR), Pay-Back Period (PBP), discounted profit to investment ratio (DPIR), or the benefit/cost relationship. These are contained in such works as Solomon (1966), Smith (1967), Tversky and Kahneman (1974), McCray *et al*. (2002), Bastos and Bortoni (2004), Couillard (1995), Berzinsh *et al*. (2006), Knemeyer *et al*. (2009), Petreska and Kolemisevska-Gugulovska (2010), Kaiser (2010) and Nederlof (2011). The use of simulation methods including integrated approaches with Monte Carlo method has become a trend as reported in the various works like: Jin *et al*. (2010) and Risso *et al*. (2011). Unfortunately, most of the conventional risk management tools have some debilitating limitations in their applications. A lot of it is guided by referral experience whereby decisions are taken subjectively and benchmarked qualitatively, lacking validity logic with no quantification. These limitations directly and indirectly add to the overall cost of an investment necessitating huge investment in managing both the known and unknown risks. This study advocates an approach that is capable of handling multi-criteria risk management issues like normalization, robustness, hedging, weighting and probability distribution (Svenda *et al*., 2006). Fuzzy logic technique is now emerging as the new paradigm in risk analysis and is being broached here as the panacea for managing risks and uncertainties in marginal oilfields exploitation. The objective of the study straddles on simple extrapolation that managing the inherent risks and uncertainties leads to an optimized exploitation of the marginal oilfields, thus increasing the economic revenue potentials (Alaneme and Igboanugo, 2012). Fuzzy logic technique is an intuitive problem solving technique with widespread applicability, especially in the areas of control and decision making (Viot, 1996). Fuzzy logic technique too, has been largely employed in project risk management especially in China; see for example, Jian-Wei and Zhonghua (2008) and Kumar *et al*. (2008). Others include: Cao *et al*. (2009), Xue *et al*. (2009) and Guo and Zhang (2009). Later, Li *et al*. (2007) and Wang and Qiao (1993) extended the realms of application of Fuzzy algorithm to involve triangular and trapezoidal fuzzy numbers respectively.

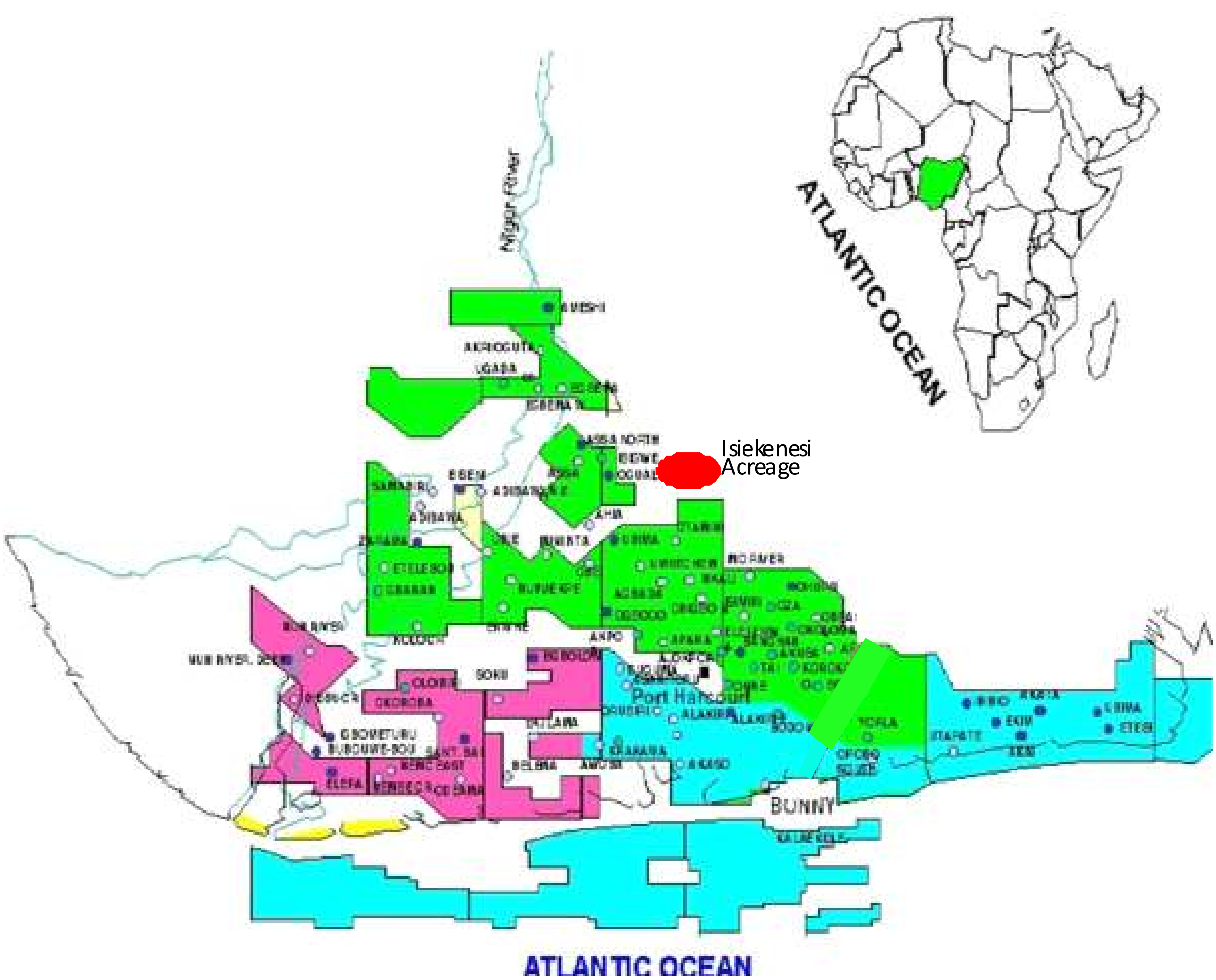

Fig. 1: Location map of Nigeria oil mining leases

METHODOLOGY

This pioneering study conducted between 2010 and 2012 which addresses marginal oilfield risk used Isiekenesi field, a partially appraised marginal oilfield in the Nigeria Niger Delta. The case study research design is based on data obtained from three exploratory wells, more specifically, the data relate to wells drilled in the early 1910s with a 2-D seismic survey acquired 60 years later in the early 70s. The field is a non-concessionary onshore acreage located approximately 63 and 85 Km 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.

The field was however abandoned on account of its low volume deposit of hydrocarbon after the three

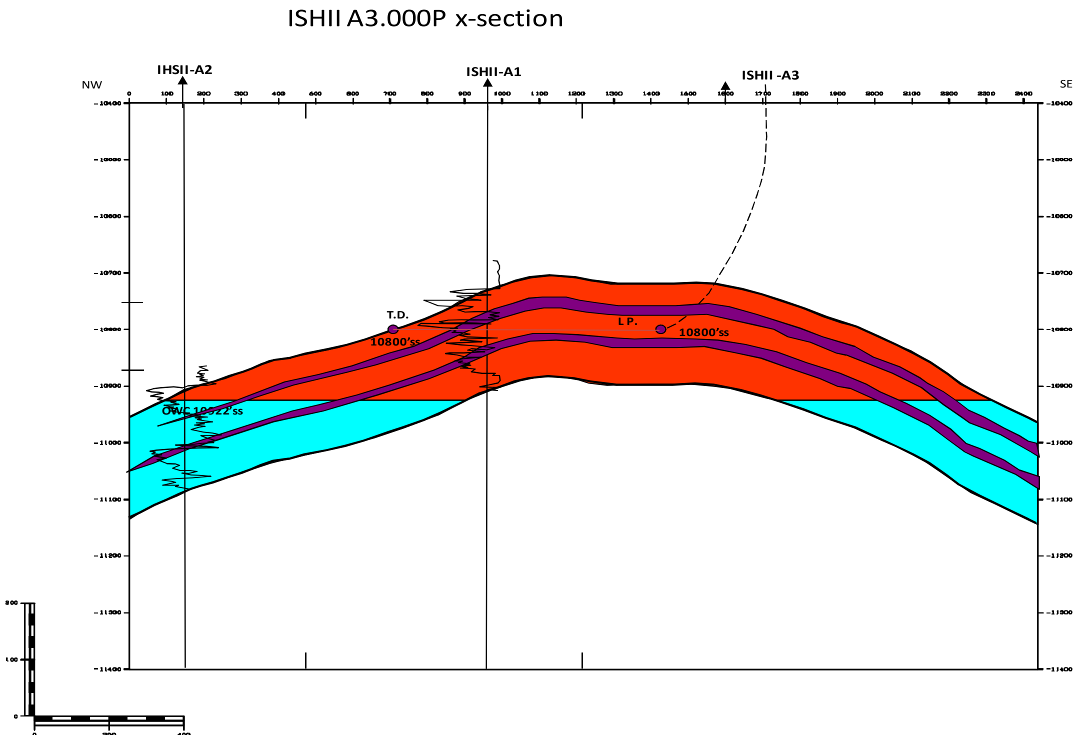

Fig. 2: Cross-sectional map

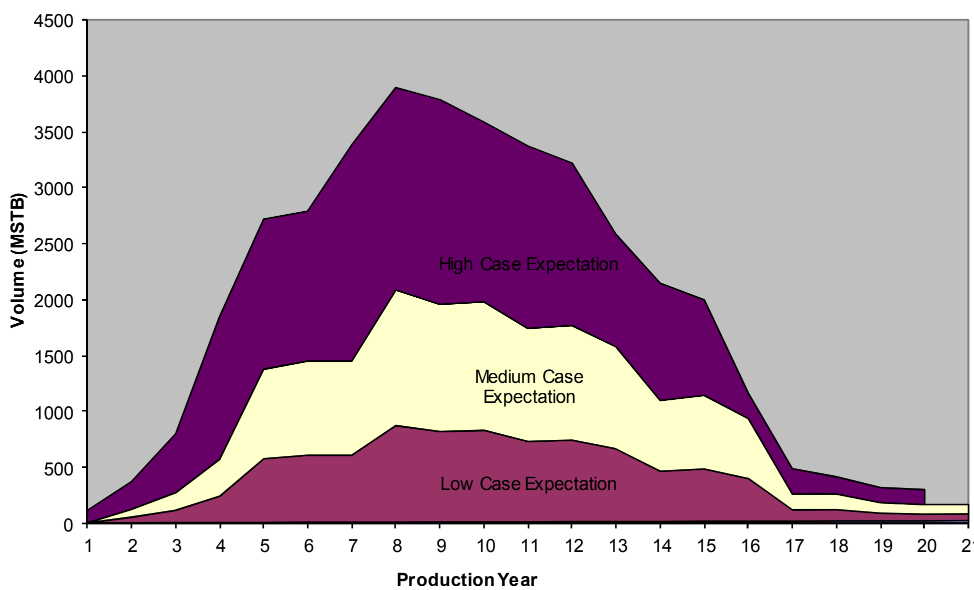

Fig. 3: Twenty years oil production forecast

Table 1: Reserve expectation scenarios

S/N	Sensitivity	Case STOIIP (MMSTB)	Reserves (MMSTB)
1	P90	25.3	10.1
2	P50	36.9	14.2
3	P10	53.5	22.6

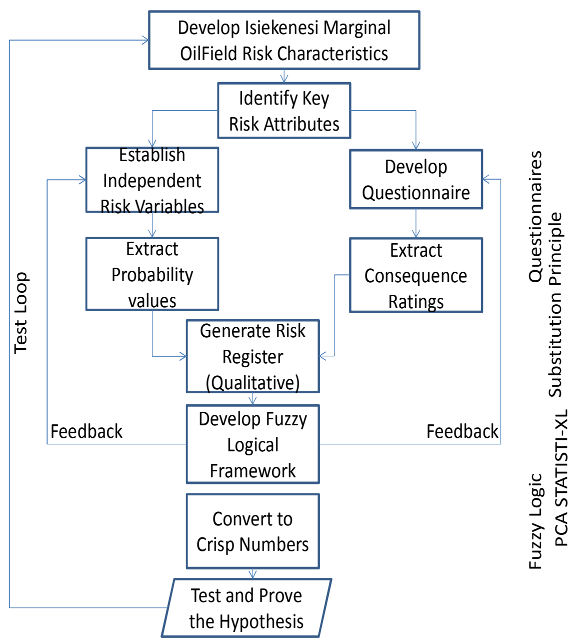

Fig. 4: Risk extraction management process

exploratory wells. The seismic survey showed some unconnected faults that will require more appraisal wells to establish possible contacts with other faults. 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. This study analysis is based on the minimal data obtained from the wells and Fig. 2 shows the cross-sectional map of these three exploratory wells.

The expected estimated reserves and a 20-year production forecast as presented in Fig. 3 for three case scenarios: low case, medium case and high case representing proved (P10), probable (P50) and possible (P90) reserves, were taken from the preliminary evaluations report. The data obtained from the field relating to the initial estimated reserves are presented in Table 1.

The overall data gathering methodology and processing schematic is presented in Fig. 4.

Nine judges were engaged in an iterative Delphi technique to isolate and define aggregated pools of potential risk attributes whose merit order were statistically determined through Pair wise Ranking method according to Turnstone'slaw of comparative judgment. The associated key risk variables (scale items) with potential to evolve into risks in marginal oilfields' exploitation were identified and defined

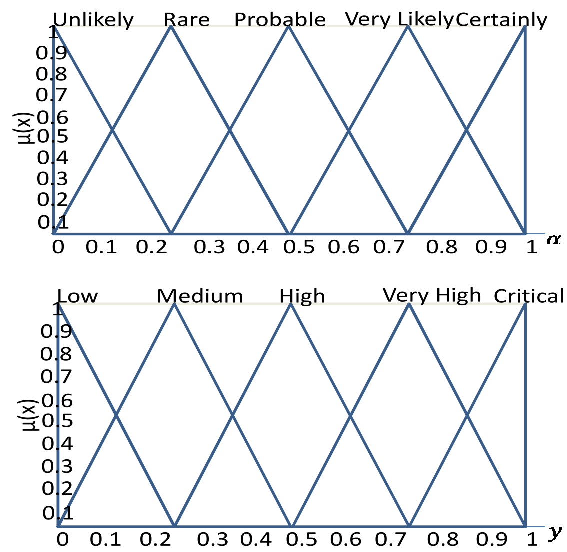

Fig. 5: Triangular fuzzy numbering framework for probability and consequence

through a wide range of methods namely: literature/journal reviews, interviews, telephone calls, brain storming, technical group discussions and so forth. Thereafter, a set of questionnaire was crafted using RensisLikert's 5-point attitudinal scale to qualitatively extract linguistic expressions of the level of risk probabilities and consequences inherent in the case study marginal oilfield operation. Responses from 42 respondents were collated to generate the qualitative risk register which forms the input to a Fuzzy logic Analysis. For simplicity, the resultant qualitative risk register was systematically converted to quantitative risk model using triangular Fuzzy logic numbering system developed by Chen and Hwang (1992) as presented in Fig. 5.

The overall weighted risk value was subsequently computed with the general form of fuzzy weighted average in risk operation and decision analysis by Junag *et al*. (1991):

$$R = \frac{\sum_{i=1}^{n} W_i * R_i}{\sum_{i=1}^{n} W_i} \tag{1}$$

where,

R = The weighted average
R_i = The rating
W_i = The corresponding weight

However, to reduce the complexity of comparisons and arithmetic exercise in deriving the weighted average of the rating, we utilized a more Fuzzy Weighted Average algorithm (EFWA) suggested by Lee and Park (1997). For the average fuzzy rating of each variable, where N is the number of respondents or judges and X the individual fuzzy ratings, the computation was generated as follows:

$$\sum F(X)/N \quad (2)$$

The fuzzy risk values were computed and further converted to crisp values for generating risk factored expected payoffs of investment. The defuzzified risk ranking and levels of significance was computed using the following relationships

$$\text{Level weight average} = \int_0^1 y * \left(a_1(y) + a_2(y)\right) / d_y \quad (3)$$

$$= \frac{\int_0^1 y * (a_1(y) + a_2(y))/2 d_y}{\int_0^1 y dy} \quad (4)$$

$$= \int_0^1 y \left[\left(a_1 + y\,(a_m - a_1) + y\,(a_2 - a_m y)\right)\right] / d_y \quad (5)$$

For a triangular fuzzy number (a_1, a_m, a_2), the resulting equation becomes:

$$= \quad 2/3\ a_m + 1/6(a_1 + a_2) \quad (6)$$

where,
a_1 = The minimum risk range-pessimistic value
a_m = The most likely risk range-mean value
a_2 = The maximum risk range optimistic value

Subsequently, ameasure of the extent of agreement to which the judges ranked the variables among themselves was computed using the Kendall coefficient of concordance, (W), where:

$$W = \frac{S}{\frac{1}{12} k^2 \left(n^3 - n\right)} \quad (7)$$

While chi squared, provided the significance level at which the coefficient of concordance (W) was adjudged as acceptable or otherwise using the general relation:

$$\chi^2 = K\,(N\text{-}1)\,W \quad (8)$$

where, K is the number of judges, N is the number of questions; N-1 is the degree of freedom and W is the Kendall coefficient of concordance.

RESULTS AND DISCUSSION

Results of this study are sequentially presented in the following order.

Weighted risk attributes: A convergence of opinion of 7 out of 9 was achieved after the third round of reviews. Table 2 shows a ranked order of the Risk Attributes developed primarily through Delphi technique. The weighting was obtained using pair wise comparison ranking methodology where each risk attribute is compared to other risk variables. This would lead to a systematic extraction of the risk variables.

Table 2: Weighted risk attributes

No	Risk Attributes	Weighted leveling
A	Reservoir uncertainties	10
B	Financial (Economics/Commercial) risks	8.3
C	Political risks	6.6
D	Social & Environmental risks	4.8
E	Technical and Operational Risks	3.5
F	Wells Performance	1.7

Fuzzy framework of the risk variables: A hierarchical link of the risk variables with the high order function of perceived marginal oil and gas risks is presented in Fig. 6. The framework systematically aids in the computation and conversion of fuzzy inferences from the linguistic reasoning.

Fuzzified risk register: Using the fuzzy assignment logic in Fig. 4 and retaining the coded references in Fig. 6 for simplicity, the average fuzzy representation of all the linguistic expressions from the 42 judges is presented in Table 3. For each variable, the average triangular fuzzy numbers characterizing the membership function of the linguistic terms was calculated using Eq. (8). The computed averages show the most pessimistic, the probable and the most optimistic risk values.

Fuzzy assessment accretion: Computing the Fuzzy weighted average of the cumulative risks of the marginal field as tabulated in Table 3 using Fig. 4:

$$\mu_1 P(X_1) = \begin{cases} 1, x = 0, x < 0 \\ (0.3 - x/(0.3), 0 \le x \le 0.3 \end{cases} \quad (9)$$

$$\mu_2 P(X_2) = \begin{cases} (x - 0)/(0.25),\ 0 \le x \le 0.3 \\ (0.5 - x)/(0.25)\,, 0.25 \le x \le 0.5 \end{cases} \quad (10)$$

$$\mu_3 P(X_3) = \begin{cases} (x - 0.3)/(0.2),\ 0.3 \le x \le 0.5 \\ (0.7 - x)/(0.2)\,, 0.5 \le x \le 0.7 \end{cases} \quad (11)$$

$$\mu_4 P(X_4) = \begin{cases} (x - 0.5)/(0.25),\ 0.5 \le x \le 0.75 \\ (1.0 - x)/(0.25)\,, 0.75 \le x \le 1.0 \end{cases} \quad (12)$$

$$\mu_5 P(X_5) = \begin{cases} (x - 0.7)/(0.3),\ 0.7 \le x \le 1.0 \\ 1, x = 1 \end{cases} \quad (13)$$

$$\mu_1 C(Y_1) = \begin{cases} 1, y = 0, y < 0 \\ (0.3 - y/(0.3), 0 \le y \le 0.3 \end{cases} \quad (14)$$

$$\mu_2 C(Y_2) = \begin{cases} (y - 0)/(0.25),\ 0 \le y \le 0.3 \\ (0.5 - y)/(0.25)\,, 0.25 \le y \le 0.5 \end{cases} \quad (15)$$

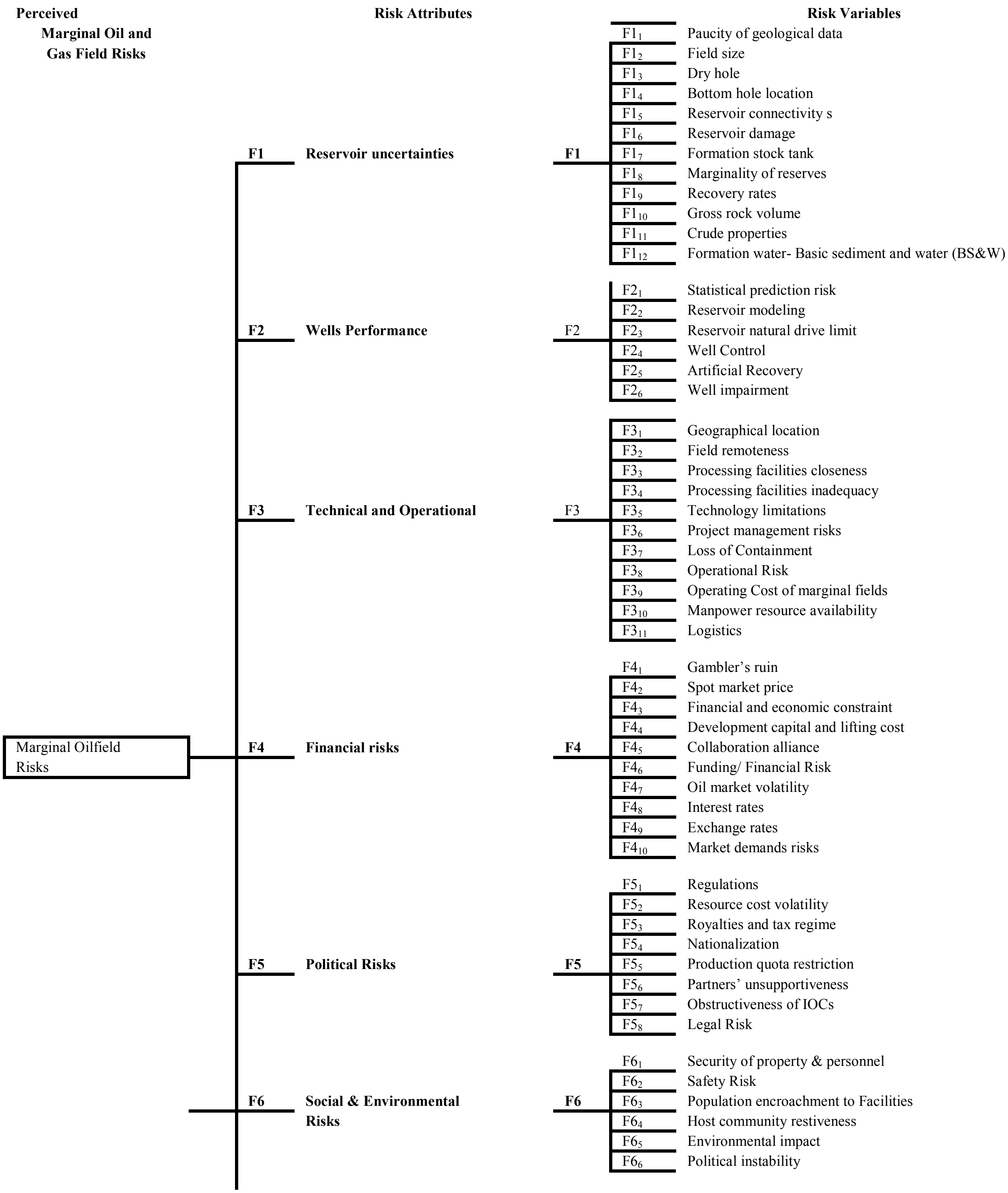

Fig. 6: Fuzzy framework of marginal oilfield inherent risks

$$\mu_3 C(Y_3) = \begin{cases} (y-0.3)/(0.2), & 0.3 \le y \le 0.5 \\ (0.7-y)/(0.2), & 0.5 \le y \le 0.7 \end{cases} \quad (16)$$

$$\mu_4 C(Y_4) = \begin{cases} (y-0.5)/(0.25), & 0.5 \le y \le 0.75 \\ (1.0-y)/(0.25), & 0.75 \le y \le 1.0 \end{cases} \quad (17)$$

$$\mu_5 C(Y_5) = \begin{cases} (y-0.7)/(0.3), & 0.7 \le y \le 1.0 \\ 1, y = 1 \end{cases} \quad (18)$$

Considering two values for α, such as 0 and 1, in the intervals of x_i and y_i yields the following:

Table 3: Fuzzified risk register

Risk attributes	Risk variables	Average Fuzzy probability (P)	Average Fuzzy consequence (C)	Fuzzy risk = (P x C)	Defuzzified crisp risk rating	μ	δ	SKW	KURT
F1	$F1_1$	0.32, 0.57, 0.8	0.28, 0.52, 0.76	0.09, 0.30, 0.61	0.31	0.33	0.24	0.42	-1.13
F1	$F1_2$	0.55, 0.8, 0.94	0.08, 0.29, 0.54	0.04, 0.23, 0.50	0.25	0.27	0.26	0.85	0.14
F1	$F1_3$	0.33, 0.58, 0.8	0.27, 0.5, 0.73	0.09, 0.29, 0.59	0.31	0.32	0.24	0.45	-1.06
F1	$F1_4$	0.29, 0.54, 0.78	0.19, 0.4, 0.65	0.05, 0.22, 0.51	0.24	0.26	0.23	0.67	-0.70
F1	$F1_5$	0.29, 0.54, 0.78	0.07, 0.3, 0.55	0.02, 0.16, 0.43	0.18	0.20	0.19	0.79	-0.12
F1	$F1_6$	0.27, 0.52, 0.76	0.24, 0.47, 0.72	0.07, 0.24, 0.55	0.26	0.29	0.24	0.62	-0.81
F1	$F1_7$	0.28, 0.5, 0.73	0.49, 0.72, 0.83	0.14, 0.36, 0.61	0.36	0.38	0.32	0.51	-0.90
F1	$F1_8$	0.33, 0.57, .79	0.12, 0.34, 0.57	0.04, 0.19, 0.45	0.21	0.23	0.22	0.95	0.39
F1	$F1_9$	0.54, 0.79, 0.91	0.3, 0.54, 0.77	0.16, 0.43, 0.7	0.43	0.44	0.31	0.33	-1.00
F1	$F1_{10}$	0.26, 0.50, 0.74	0.06, 0.29, 0.54	0.02, 0.15, 0.40	0.17	0.19	0.19	0.89	0.05
F1	$F1_{11}$	0.32, 0.56, 0.77	0.03, 0.11, 0.36	0.01, 0.06, 0.28	0.09	0.11	0.15	1.53	2.33
F1	$F1_{12}$	0.3, 0.54, 0.76	0.08, 0.17, 0.42	0.02, 0.09, 0.32	0.12	0.14	0.18	1.51	1.94
F2	$F2_{13}$	0.26, 0.49, 0.73	0.07, 0.3, 0.54	0.02, 0.15, 0.39	0.17	0.19	0.20	1.00	0.35
F2	$F2_{14}$	0.29, 0.54, 0.77	0.10, 0.33, 0.57	0.03, 0.18, 0.44	0.19	0.21	0.21	0.84	-0.14
F2	$F2_{15}$	0.51, 0.73, 0.85	0.14, 0.37, 0.6	0.07, 0.27, 0.51	0.28	0.29	0.29	0.89	0.00
F2	$F2_{16}$	0.25, 0.49, 0.74	0.13, 0.35, 0.58	0.03, 0.17, 0.43	0.19	0.21	0.22	1.07	0.68
F2	$F2_{17}$	0.25, 0.49, 0.74	0.22, 0.46, 0.71	0.06, 0.22, 0.52	0.25	0.26	0.22	0.58	-0.86
F2	$F2_{18}$	0.28, 0.52, 0.77	0.2, 0.43, 0.68	0.06, 0.23, 0.52	0.25	0.27	0.24	0.74	-0.36
F3	$F3_{19}$	0.58, 0.82, 0.92	0.24, 0.46, 0.7	0.14, 0.37, 0.64	0.38	0.39	0.29	0.37	-0.99
F3	$F3_{20}$	0.55, 0.79, 0.9	0.25, 0.48, 0.71	0.14, 0.38, 0.65	0.39	0.40	0.30	0.42	-0.90
F3	$F3_{21}$	0.58, 0.83, 0.93	0.1, 0.33, 0.57	0.06, 0.27, 0.53	0.28	0.29	0.27	0.78	0.01
F3	$F3_{22}$	0.27, 0.49, 0.73	0.2, 0.43, 0.68	0.06, 0.21, 0.49	0.23	0.26	0.24	0.83	-0.23
F3	$F3_{23}$	0.24, 0.46, 0.71	0.09, 0.31, 0.55	0.02, 0.14, 0.39	0.16	0.19	0.21	1.23	1.31
F3	$F3_{24}$	0.54, 0.77, 0.89	0.24, 0.48, 0.73	0.13, 0.37, 0.64	0.38	0.38	0.29	0.41	-0.89
F3	$F3_{25}$	0.27, 0.51, 0.73	0.29, 0.51, 0.74	0.08, 0.26, 0.54	0.28	0.30	0.25	0.55	-0.99
F3	$F3_{26}$	0.27, 0.51, 0.75	0.1, 0.33, 0.58	0.03, 0.17, 0.43	0.19	0.20	0.20	0.82	-0.29
F3	$F3_{27}$	0.6, 0.85, 0.95	0.38, 0.62, 0.86	0.23, 0.53, 0.82	0.53	0.52	0.31	0.09	-1.14
F3	$F3_{28}$	0.51, 0.75, 0.88	0.14, 0.24, 0.48	0.07, 0.18, 0.42	0.20	0.26	0.32	1.19	0.23
F3	$F3_{29}$	0.32, 0.55, 0.78	0.11, 0.35, 0.58	0.04, 0.19, 0.45	0.21	0.22	0.22	1.00	0.61
F4	$F4_{30}$	0.29, 0.52, 0.76	0.15, 0.39, 0.62	0.04, 0.21, 0.47	0.22	0.25	0.24	0.98	0.42
F4	$F4_{31}$	0.25, 0.47, 0.72	0.11, 0.35, 0.6	0.03, 0.17, 0.43	0.19	0.21	0.22	1.09	0.73
F4	$F4_{32}$	0.57, 0.82, 0.93	0.27, 0.51, 0.75	0.15, 0.42, 0.7	0.42	0.43	0.29	0.30	-0.93
F4	$F4_{33}$	0.54, 0.77, 0.89	0.36, 0.6, 0.85	0.1, 0.46, 0.759	0.46	0.46	0.33	0.25	-1.13
F4	$F4_{34}$	0.3, 0.53, 0.76	0.13, 0.36, 0.6	0.04, 0.19, 0.45	0.21	0.23	0.23	1.08	0.78
F4	$F4_{35}$	0.59, 0.83, 0.93	0.27, 0.52, 0.76	0.16, 0.43, 0.7	0.43	0.44	0.28	0.25	-0.96
F4	$F4_{36}$	0.3, 0.55, 0.8	0.25, 0.49, 0.74	0.08, 0.27, 0.59	0.29	0.31	0.24	0.51	-0.95
F4	$F4_{37}$	0.3, 0.54, 0.77	0.09, 0.33, 0.57	0.03, 0.18, 0.44	0.20	0.21	).20	0.72	-0.39
F4	$F4_{38}$	0.29, 0.52, 0.75	0.07, 0.29, 0.53	0.02, 0.15, 0.4	0.17	0.18	0.18	0.74	-0.48
F4	$F4_{39}$	0.09, 0.20, 0.45	0.02, 0.1, 0.35	0.00, 0.02, 0.15	0.04	0.05	0.08	2.15	6.37
F5	$F5_{40}$	0.35, 0.6, 0.8	0.64, 0.89, 0.97	0.22, 0.58, 0.78	0.52	0.52	0.29	0.10	-1.12
F5	$F5_{41}$	0.32, 0.57, 0.8	0.26, 0.51, 0.76	0.08, 0.29, 0.61	0.31	0.33	0.24	0.54	-0.80
F5	$F5_{42}$	0.34, 0.59, 0.81	0.05, 0.30, 0.55	0.02, 0.18, 0.44	0.19	0.21	0.19	0.63	-0.56
F5	$F5_{43}$	0.25, 0.5, 0.74	0.44, 0.69, 0.92	0.11, 0.35, 0.68	0.36	0.38	0.28	0.53	-0.72
F5	$F5_{44}$	0.25, 0.5, 0.75	0.1, 0.32, 0.57	0.02, 0.16, 0.42	0.18	0.20	0.21	1.14	1.11
F5	$F5_{45}$	0.25, 0.49, 0.74	0.2, 0.43, 0.68	0.05, 0.21, 0.5	0.23	0.26	0.23	0.68	-0.66
F5	$F5_{46}$	0.24, 0.48, 0.73	0.04, 0.25, 0.5	0.01, 0.12, 0.37	0.14	0.17	0.17	0.80	-0.53
F5	$F5_{47}$	0.26, 0.51, 0.76	0.25, 0.49, 0.74	0.07, 0.25, 0.56	0.27	0.29	0.23	0.56	-0.84
F6	$F6_{48}$	0.61, 0.86, 0.95	0.63, 0.88, 0.96	0.38, 0.76, 0.91	0.72	0.68	0.29	-0.33	-1.13
F6	$F6_{49}$	0.32, 0.57, 0.81	0.07, 0.31, 0.55	0.02, 0.18, 0.45	0.19	0.21	0.20	0.69	-0.45
F6	$F6_{50}$	0.29, 0.54, 0.79	0.05, 0.28, 0.53	0.02, 0.15, 0.42	0.17	0.19	0.19	0.63	-0.88
F6	$F6_{51}$	0.52, 0.77, 0.97	0.46, 0.71, 0.92	0.24, 0.55, 0.9	0.55	0.56	0.31	0.07	-1.25
F6	$F6_{52}$	0.29, 0.54, 0.79	0.45, 0.7, 0.93	0.13, 0.37, 0.73	0.39	0.41	0.28	0.43	-0.93
F6	$F6_{53}$	0.29, 0.53, 0.77	0.48, 0.73, 0.94	0.14, 0.38, 0.72	0.40	0.42	0.28	0.37	-1.04

[u1 = 0.2 = 0.3]
[r1 = 0, r2 = 0.5]
[p1 = 0.3, p2 = 0.7]
[v1 = 0.5, v2 = 1]
[c1 = 0.7, c2 = 1]
[l1 = 0, l2 = 0.3]
[m1 = 0,   m2 = 0.5]
[h1 = 0.3, h2 = 0.7]
[v1 = 0.5, v2 = 1]
[c1 = 0.7, c2 = 1

In computation, (u1, r1, p1, v1, c1) = (0, 0,0.3, 0.5, 0.7)

First: = 1, last =5
δ- threshold: = $\lfloor 1 + 5/2 \rfloor = 3$
Hence, S = (0.3, 0.5, 0.7, 0.5, 0.7)

δs3 =

$$\frac{(0-0.3)*0.3+(0-0.3)*0.5+(0.5-0.3)*0.5+(0.7-0.3)*0.7}{0.3+0.5+0.7+0.5+0.7}$$

$$=\frac{0.14}{2.7}$$

= 0.051852
δs4 =

$$\frac{(0-0.5)*0.3+(0-0.5)*0.5+(0.3-0.5)*0.7+(0.7-0.5)*0.7}{0.3+0.5+0.7+0.5+0.7}$$

$$=\frac{-0.4}{2.7}$$

= -14815

Since δs3 > 0 and δs4 $< 0, then$

Left = f_L(l1,m1,h,1v2,c2) = P1 + δ2 (19)

= 0.3 + 0.05 = 0.35
Min F_L is 0.35.
Also, (u2, r2, p2, v2, c2) = (0.3, 0.5, 0.7, 1 and 1)
First: = last: = 5
$\gamma - threshold \coloneqq \lfloor (1+5)/2 \rfloor = 3$
S = (0, 0, 0.3, 1, 1)

$$\gamma 3 = \frac{(0.3 - 0.7) * 0 + (0.5 - 0.7) * 0 + (1 - 0.7) * 1 + (1 - 0.7) * 1}{0+0+0.3+1+1}$$

$$= \frac{(0.6)}{2.3}$$

= 0.26087

$$\gamma 4 = \frac{(0.3 - 1) * 0 + (0.5 - 1) * 0 + (1 - 1) * 0.3 + (1 - 1) * 1}{0+0+0.3+1+1} = 0$$

Since $\gamma 3 > 0$ and $\gamma 4 = 0$

Then, P2 = Fp(l2, m2, h2, v1, c1) (20)

= p2 + γ3 = 0.7 + 0.26 = 0.96

Therefore, the interval for $\propto = 0$ is [0.35, 0.96]

Similarly, for ∝ = 1, considering one values for α, such as 0 and 1, in the intervals of x_i and y_i yields the following:

[u1 = 0, 1],
[r1 = 0.25]
[p1 = 0.5]
[v1 = 0.75]
[c1 = 1]
[m1 = 0.25]
[h1 = 0.5]
[v1 = 0.75]
[c1 = 1]

In computation, (u1, r1, p1, v1, c1) = (0, 0.25, 0.5, 0.75, 1)
First: = 1, last =5
δ- threshold: = $\lfloor 1 + 5/2 \rfloor = 3$
Hence, S = (0, 0.25, 0.5, 0.75, 1)

$$\delta s3 = \frac{(0 - 0.5) * 0 + (0.25 - 0.5) * 0.25 + (0.75 - 0.5) * 0.75 + (1 - 0.5) * 1}{0+0.25+0.5+0.75+1}$$

$$= \frac{0.625}{2.5} = 0.25$$

$$\delta s4 = \frac{(0 - 0.5) * 0.3 + (0 - 0.5) * 0.5 + (0.3 - 0.5) * 0.7 + (0.7 - 0.5) * 0.7}{0.3+0.5+0.7+0.5+0.7} = 0$$

Since $\delta s3 > 0$ and δs4 = 0, then,

Then, t = f_L(l1,m1,h,1v2,c2) = P1 + δ2 (21)

= 0.5 + 0.25 = 0.75

Also, (u2, r2, p2, v2, c2) = (0, 0.25, 0.5, 0.75and 1)
First: = last: = 5

$\gamma - threshold \coloneqq \lfloor (1+5)/2 \rfloor = 3$
S = (0, 0.25, 0.5, 0.75, 1)

$$\gamma 3 = \frac{(0 - 0.5) * 0 + (0.25 - 0.5) * 0.25 + (0.75 - 0.5) * 0.75 + (1 - 0.5) * 1}{0+0.25+0.5+0.75+1} = \frac{0.625}{2.5} = 0.25$$

$$\gamma 4 = \frac{(0 - 0.5) * 0.3 + (0 - 0.5) * 0.5 + (0.3 - 0.5) * 0.7 + (0.7 - 0.5) * 0.7}{0.3+0.5+0.7+0.5+0.7} = 0$$

Since $\gamma 3 > 0$ and $\gamma 4 = 0$

Then, P2 = Fp(l2, m2, h2, v1, c1) (22)

= p2 + γ3 = 0.5 + 0.25 = 0.75

Therefore, the interval in this case for $\propto = 0$ is [0.75, 0.75]

Resultant fuzzy triangle of the computed weighted average of the aggregated probability and consequence of occurrence of all the risk variables is (0.35, 0.75 and 0.96) and depicted in Fig. 7. This represents the cumulative pessimistic, probable and optimistic fuzzy values of the overall marginal field risks which results in total risk of 0.71 in crisp terms.

Coefficient of concordance: The computed value for coefficient of concordance (W) is 0.71, while the associated chi-squared value (χ^2) is 546 which are greater than 27.69 recorded in the statistics table at significance level of 0.01. The import of this is that the 42 judges were consistent in their ranking of the 53 variables. Further, our study data provided paucity of evidence for us to accept a null hypothesis of lack of discordance of ranking among selected judges. In other words, the null hypothesis was rejected at a p-value of 0.01.

Investment appraisal-pessimistic case: To compute the cumulative impact of the risk, we used the worst case scenario of Low Case Expectation from Fig. 3. The NPV curve presented in Fig. 8 showed a breakeven value at 33.5% discount rate, above which any investment becomes unprofitable. This assumed fixed taxation and royalty rate, as well as controlled operating cost. In this case, the risk value above the profitable

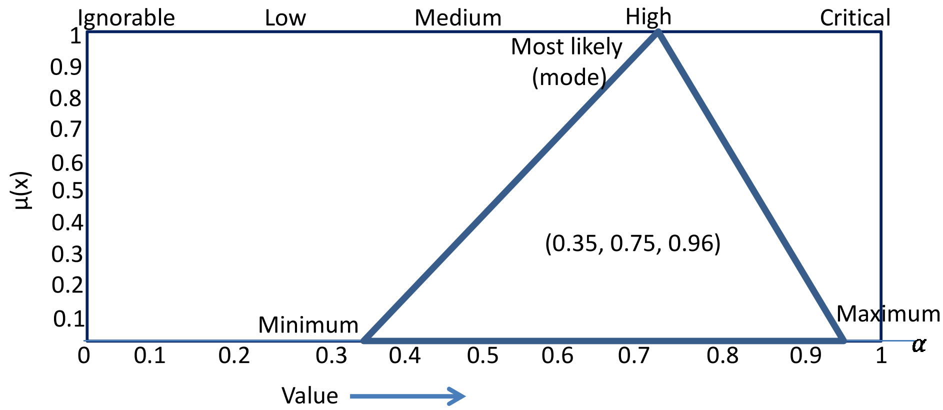

Fig. 7: Overall fuzzy triangular rating of the marginal field risks

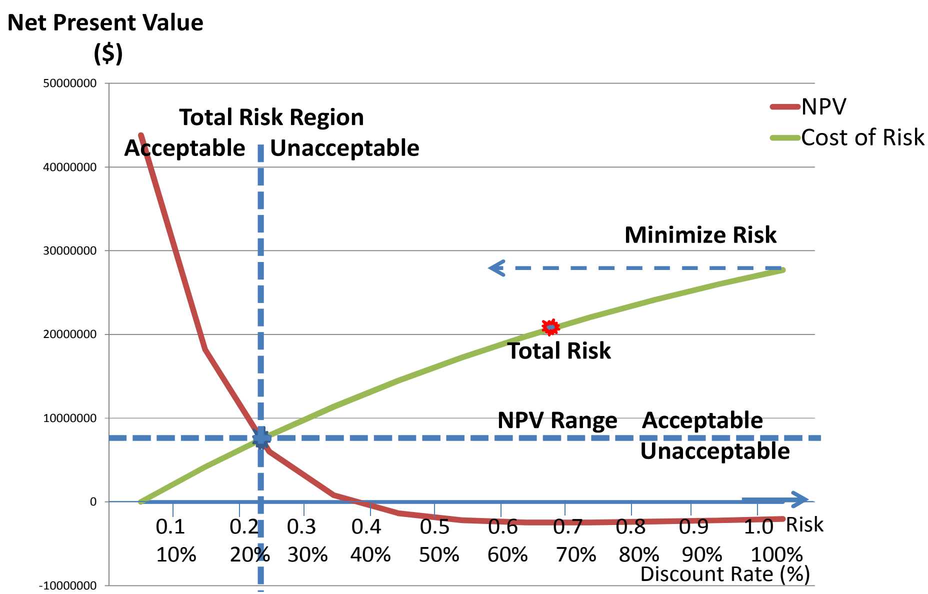

Fig. 8: Investment returns profile

threshold of 0.25 will give room for disaster in such investment. Already the risk analysis result tabled in Table 3 has identified F61, Security of Personnel and Property with defuzified crisp rating of 0.72 as the greatest risk followed by Community Restiveness, Operating Cost and Regulations posting risk ratings above 0.5 crisp values each.

CONCLUSION

A clear understanding of the risks helps to correlate and stratify the expected net returns through efficient planning for and allocation of right resources as well as selecting an optimum alternative. Here, the risk factors become variable cost elements that have the potential to sway the direction of investment profitability, especially when faced with multivariate scenario or sensitivity variance of what ifs. The overall result of this study has successfully clarified issues relating to risk profile in the marginal field to confirm that risk lurks or skulks in uncertainty as surprise lies in wait in ambush. However, these are some pertinent areas of ambiguity with potential to considerably reduce the overall risk below the acceptable level and swing the risk profile:

- How far are the local investors and government ready to partner with the host communities in the oilfield exploitation to stem security problems and minimize host community restiveness?
- Is the government willing and ready to regulate and guide the operations of marginal fields in Nigeria without adding unnecessary regulatory burdens?
- To what extent are the venture capitalists ready and willing to collaborate with each other in the sharing of information and technical/operational experience to cut down on operational cost?

- To what extent are the independent oil companies willing and ready to play along in providing necessary operational and technical supports as may be needed?
- How are the venture capitalists ready to optimize their relationships with foreign partners to secure the much needed technical and financial supports?

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