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Rethinking Probabilistic Reserves Estimation

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Abstract

Petroleum reserves assessment is a routine exercise performed by every oil and gas company. The reserves estimation could be achieved using deterministic or probabilistic methods. Depending on the type of data available, different assumptions and data are used at various stages of the assessment throughout the E and P life cycle, i.e., exploration, appraisal, development, depletion and so on. The accuracy of the reserves estimate is highly dependent on the amount and quality of data available and experience of the evaluator. The estimates become more accurate and refined as more and more data become available.

The objective of this paper is to urge the industry to rethink the terminology used for categorizing probabilistic reserves (P90, P50 and P10). As a routine practice, we consider 1P=P90=proved reserves, 2P=P50=proved +probable reserves and 3P=P10=proved+probable+possible reserves. The reserves categories depend on the range of uncertainty. It is shown here that P50 (or mean/median/expected value) is a more robust and logical value to be used for categorizing reserves. The P90 and P10 demonstrate confidence levels but not the magnitude/range of uncertainty. Some examples are presented in this paper to show that P50 (or mean) with its corresponding standard deviation (indication of uncertainty) could be more appropriately used to book and categorize reserves. The concept of Expected Value (EV) is also revisited as this is not correctly reported in some publications.

Keywords: PRMS; Reserves assessment; Probabilistic reserves; Expected value; Proved reserves

Introduction

The Petroleum Resources Management System (PRMS), revised in 2018, provides guidelines that are followed by the industry for the assessment of hydrocarbon resources. The objective of PRMS is to provide consistent and reliable definitions, classification, and estimation of hydrocarbon resources. The document was prepared by the Oil and Gas Reserves Committee under the auspices of the Society of Petroleum Engineers (SPE). The PRMS has been broadly adopted by the oil and gas industry as the international standard reference for the classification of oil and gas reserves and resources.

The oil and gas accumulations are classified as (a) reserves, (b) contingent resources and (c) undiscovered oil and gas volumes. Reserves are categorized into proved (1P), probable (P2) and possible (P3). The combination of proved plus probable is 2P and proved plus probable plus possible is 3P. Proved (1P) and proved plus probable (2P) reserves are commonly used throughout the oil and gas industry for reporting purposes [1]. Reporting the 3P reserves is relatively scarce but can be used for internal decision-making and strategies. Deterministic or probabilistic methods can be used to calculate reserves.

The deterministic estimates are based on qualitative assessment of relative uncertainty using discrete variables and consistent evaluation guidelines (PRMS 2018; Mian 2011a). The confidence level of the estimates is based on the available data and the estimator's best professional judgement and experience. The estimates are presented as low (1P), best/most likely (2P) and high (3P). The range of uncertainty of these cannot be quantified as its successful application is often relying on the expert knowledge of the evaluator and the selection of variables could be biased depending on the risk perception of the evaluator (Figure 1).

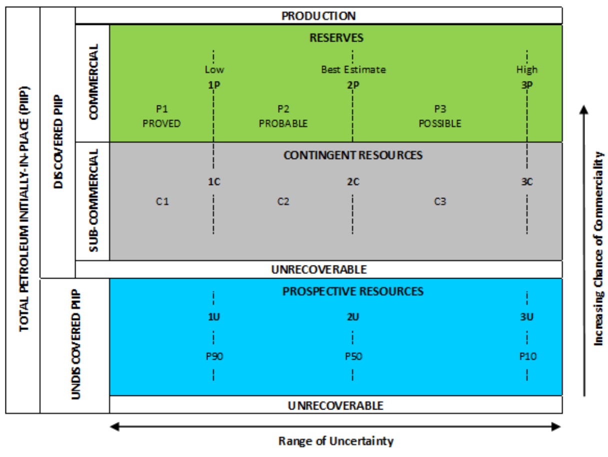

Figure 1: *Petroleum resources classification framework.*

In probabilistic estimates, the range of uncertainty is represented by probability distributions of each variable and the resulting outcome as a probability distribution (Mian 2011b). The outcome is represented by a Probability Density Function (PDF) and a corresponding Cumulative Distribution Function (CDF). Monte Carlo simulation is used to perform the analysis, which will result in various statistical

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outcomes such as mean, mode, median, standard deviation and percentiles.

Materials and Methods

These categories are normally treated as equal/synonym, i.e., 1P = P90, 2P = P50 and 3P = P10 as shown below.

- 1P = Proved Reserves (low case) = P90 (90% probability that actual reserves are greater than the P90 quartile).
- 2P = Proved + Probable (best case) = P50 (50% probability that actual reserves are greater than the P50 quartile).
- 3P = Proved + Probable + Possible (high case) = P10 (10% probability that actual reserves are greater than the P10 quartile).

Although we routinely refer to the above relationships, they are not correct. These relationships will depend on the assumptions used and how the calculations are performed. The probabilistic estimates may be quantitatively different for 1P vs. P90 and 3P vs. P10. Depending on the type and combination of probability distributions and related parameters used in the Monte Carlo simulation, only the 2P and probabilistic mean or median may be same or close,

In probabilistic analysis the 1P, 2P and 3P will individually also have P90, P50 and P10 as each one of these have associated uncertainties. A question here is: which P90 = 1P = proved reserves (i.e., P90 of 1P, P90 of 2P or P90 of 3P)? A set of data are used to show that the P50/median or mean with its corresponding standard deviation shall be used to categorize reserves. The calculation and interpretation of the Expected Value (EV) is also clarified.

Expected Value (EV)

It is important to first understand some basic calculations requiring probabilities. The simplest distribution pattern is a flat distribution, such as the outcome from a rolling of a single die or flip of a coin. Each side of a single die is equally likely to come up when rolled, i.e., the probability of getting an even number is 50% and the probability of getting an odd number is 50%. Similarly, in flipping a coin the probability of head is 50% and the probability of tail is 50%. However, this does not mean that first time we flip a coin we will get head and the second time we will get tail. The 50% probability materializes after repeated trials, the key word is the repeated trials.

A person goes to a fair and sees a guy sitting and asking the visitors to roll a die and call a number. He charges USD 2 to let a visitor roll a die – if the visitor calls even number and the die comes out to be even, he gets USD 3 (net) but if the die turns out to be odd then he loses the USD 2 paid for rolling the die.

EV is the probability-weighted average value of all possible outcomes. An experiment is manually performed by flipping a coin 30 times and each time recording the cumulative gain/loss. The EV is the cumulative gain/loss divided by the number of trials. It is shown that the experimental EV converges to the theoretical EV as we increase the trials. This understanding is very important for what is proposed in this paper.

Monte Carlo simulation is also used to simulate this experiment, the outcome of 300 iterations is shown. The figure clearly shows how the simulated values converge to the theoretical EV of 0.50. It is interesting to note that the P90 for this game is -2.0, P10 is 3.0 and EV = Mean = 0.50 (Figure 2).

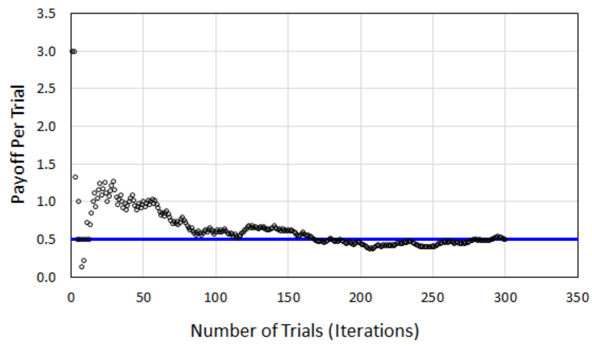

Figure2: *Simulation outcome for rolling a die (EV = 0.50).*

Where Xi is a random variable and P (Xi) is the probability of occurrence of the random variable. The sum of the probabilities must always add to 100%. Some examples given in oil and gas industry publications show the sum of probabilities to significantly exceed the 100% rule (Patricelli = 178% and PRMS = 197%).

Results and Discussion

Deterministic estimates

Figure 3 shows a typical structural cross section AA' after drilling of an exploration well and two appraisal wells. Based on the available data, the reservoir is divided into proved (1P), proved plus probable (2P) and proved plus probable plus possible (3P) categories. The data representing the structural cross section AA', are used to estimate the technically recoverable oil (EUR) using the deterministic estimation.

The Low and High are predominantly due to insufficient control over the reservoir size and formation thickness and to somewhat lesser extent due to uncertainty of the other variables [2]. The logic used to call 2P as "Best Estimate" also need to be revisited. The 2P is a combination of Proved (1P) with higher probability and less uncertainty while Probable (P2) is associated with lower probability and higher uncertainty. Only the EV of 1P and P2 could be considered as best estimate but not 2P. This is apparently due to the confusion of equating 2P = P50. In reality, the P50 of 1P could be considered as "Best Estimate" (Figure 3 and Table 1).

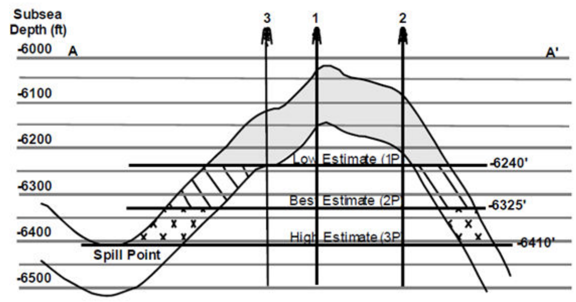

Figure 3: *Structural cross section AA.*

Estimated Parameters	Units	Low (1P)	Best (2P)	High (3P)
		Estimate	Estimate	Estimate
Bulk Reservoir Pay Volume	M acre-feet	821	1371	1918
Average Porosity	%	19	18	17
Average Water Saturation	%	20	22	24
Average FVF (Boi)	RB/STB	1.33	1.33	1.33
Recovery Factor	%	0.45	0.4	0.35
Oil Initially in-Place (OIIP)	MMSTB	728	1123	1445
Recoverable Oil (EUR)	MMSTB	328	449	506

Table1: Volumetric Assessment of Technically Recoverable Oil.

Probabilistic estimates

The following two scenarios of probabilistic resource estimates are presented.

- Volumetric calculations using the data and Monte Carlo simulation.
- Pilot wells' performance using an existing analog field performance developed using Monte Carlo simulation.

Volumetric calculations

For illustration, the 1P, 2P and 3P data are simulated using probability distributions. The uncertainty in data is shown. In reality, a combination of probability distributions will be used depending on the variable. The popular probability distributions typically used are (1) triangular, (b) uniform, (c) normal and (d) lognormal. The probability distributions are selected using experience, typical probabilistic behavior of certain variables or fitting distributions to actual historical analogous data. The following three cases are simulated.

Case 1 (1P): Note that 1P is also not 100% certain.

- Bulk reservoir pay volume = Lognormal(μ = 821,σ = 41)
- Average porosity = Triangle(17%,18%,19%)
- Water saturation = Triangle(20%,22%,24%)
- Average FVF (Boi) = Uniform(1.33, 1.35)
- Recovery factor = Triangle(35%,40%,45%)

Case 2 (2P):

- Bulk reservoir pay volume = Lognormal(μ = 1371, σ = 69)
- Average porosity = Normal(17%, 18%,19%)
- Water saturation = Normal(20%,22%,24%)
- Average FVF (Boi) = Uniform(1.33, 1.35)
- Recovery factor = Triangle(35%,40%,45%)

Case 3 (3P):

- Bulk reservoir pay volume = Lognormal(μ = 1918, σ = 96)
- Average porosity = Normal(17%,18%,19%)
- Water saturation = Normal(20%,22%,24%)
- Average FVF (Boi) = Uniform(1.33, 135)
- Recovery factor = Triangle(35%,40%,45%)

After running 15,000 iterations of simulation, the results are shown. Note that the 1P ≠ P90, 3P ≠ P10 and only 2P (449) ≈ P50 (446) of Case 2. By the definition of PRMS, which of the values shall be Proved (P90), Proved + Probable (P50) and Proved + Probable + Possible (P10)? In line with the x-axis of the Petroleum Resources Classification Network, categorization of 1P, 2P and 3P reserves as per their respective range of uncertainty. Note that a P90 is not an average number like the P50/mean/median, i.e., 90% of the iterations give value above this number.

Note carefully that the x-axis "Range of Uncertainty" and not "Confidence Level" [3]. The percentiles represent confidence levels and not uncertainty. Uncertainty is the standard deviation surrounding the mean of each category as shown. Each of these reserves categories will be subject to commerciality assessment in order to be classified as reserves (Table 2 and Figure 4).

	Deterministic	Probabilistic		
Category	From Table 1	Case 1	Case 2	Case 3
1P or P90	328	241	403	563
2P or P50	449	266	445	622
3P or P10	506	294	491	686
Mean	428	267	446	624
Median		266	445	622
Standard Deviation		20.24	34.1	47.34

Table2: *Volumetric assessment of technically recoverable oil.*

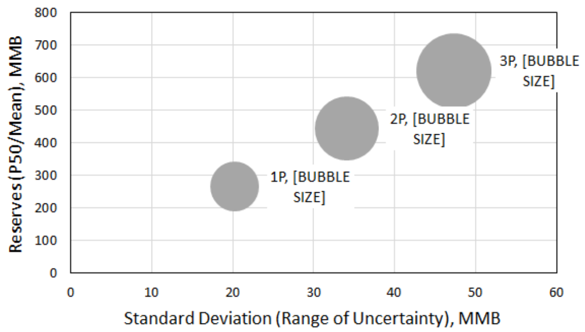

Figure4: Reserves classification as range of uncertainty.

Using Analogy to Assess Proved Reserves

Reserves for 100 Barnett shale gas wells, with established productions history, are calculated using Arps' decline curve analysis and 7% terminal decline rate [4].

Probability distributions are then fitted to the resulting Arps' decline parameters (qgi, Di and b).

The resulting probabilistic parameters are shown. These parameters are then modelled to run through Monte Carlo simulation using 10,000 iterations. The simulation resulted in the probabilistic production forecasts shown (Table 3 and Figure 5).

Decline Parameters	Minimum	Maximum	P90	P50	P10	Distribution
qgi	15873	198752	29322	58253	120188	Lognormal
Di	0.0184	1.5159	0.0548	0.1851	0.6607	Lognormal
b	0.1539	2.9901	0.8542	1.5356	2.1944	Weibull

Table 3: *Probabilistic decline curve parameters obtained from 100 Barnett shale gas wells.*

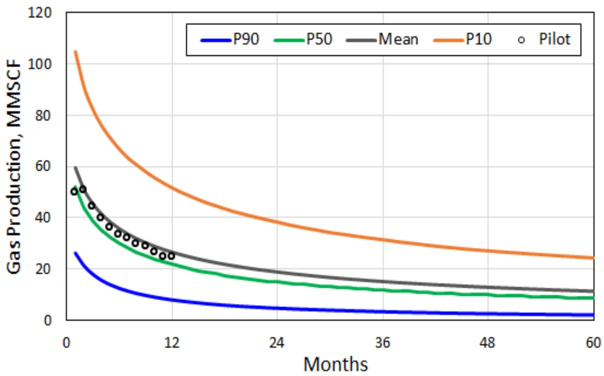

Figure 5: Pilot performance super imposed over probabilistic analog production forecast.

This probabilistic forecast is used as an analog for assessing reserves for a new field with performance from pilot wells. The pilot wells are aerially spread in order to sample a larger area of the shale gas accumulation. The average pilot wells' performance is superimposed on the analogous production forecast. The pilot performance lies between the P50 and mean of the probabilistic analogous production performance. Therefore, in this case the P50 or mean (not the P90) will be reported as proved reserves if commercial.

The commerciality will be evaluated by defining a project with a long-term field development program. Based on the P50 production profile, a 15-year development plan is formulated as shown. Some 315 wells will be required to develop 716 BSCF of gas reserves (2.27 BSCF/well) in the first five years. An average of 63 wells will be required to be drilled in each of the five years.

In the following 10 years, 262 wells are drilled in the first half to develop 594 BSCF and 179 wells in the second half to develop 407 BSCF. Enough acreage has to be available in order to accommodate drilling of the total of 757 wells to develop 1,717 BSCF of gas reserves over the 15-year period. Since the PRMS requires a 5-year development plan, the plan will develop 1P = 716 BSCF, 2P = 1,310 BSCF and 3P = 1,717 BSCF. Depending on the availability of acreage, funds and drilling logistics (i.e., number of wells that can be drilled per year), the plateau production can be increased and then maintained for as long as technically possible to increase the booked reserves. This example is a typical case of repeated trials [5]F. The drilling of number of wells represents repeated trials. Note that the P90 (proved as per PRMS) in this case cannot be used to arrive at the field plateau rate and then maintain the plateau for as long as technically possible. The reason being that 90% of the wells will generate higher production forecast than the P90 (Figure 6).

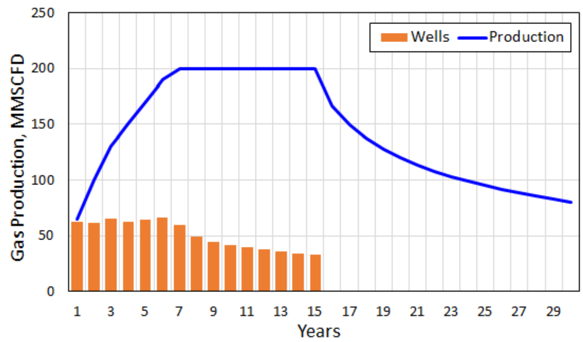

Figure 6: *Gas field development plan.*

Conclusion

While using probabilistic reserves estimation, P50 of 1P, P50 of 2P and P50 of 3P and their associated standard deviation (range of uncertainty) shall be used to categorize 1P, 2P and 3P reserves respectively. Percentiles (P90, P50 and P10) represent confidence levels and not range of uncertainty. Therefore, the method given in this paper is more in line with the x-axis title of the petroleum resources classification framework. The calculation of expected value mathematically requires the probabilities of the random variables to sum to 100%. This condition is also applicable to calculating the expected value of reserves or expected monetary value in the oil and gas industry. As mentioned in PRMS, the P90 and P10 can be only used as lower and higher sensitivities. The 5-year development plan should be relaxed for the development of the unconventional resources if enough funds, logistic resources and acreage are available. Otherwise, the reserves developed in the first 5-year plan should be classified as 1P, second 5-year plan as P2 and third 5-year plan as P3.

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