PROCEEDINGS
JOINT CONVENTION BANDUNG (JCB) 2021
November 23rd – 25th 2021

Uncertainty Analysis Workflow to Estimate Oil and Gas Reserves as A Guideline for Field Development Planning

Arya Disiyona, SKK Migas

Abstract

It is common practice that estimating resources and reserves for exploration activities is different from the development stage, since has high uncertainty, lack of available data and information, so the method that is often used to estimate resources is probabilistic. However, in development or exploitation period since it is presumed it had more data, the evident of oil & gas discovery, and the presence of commercial hydrocarbons that can be produced, the deterministic method is preferred to be used.

In this paper, the discussion will focus on deterministic applications for field development. Geoscientists assume that the uncertainty at this stage is very low and even tends to be ignored so that the reserve figure used is only a single number. While in this period, uncertainty still exists covering technical aspects, technology application, and commercial valuation with different levels depending on subsurface variables to estimate hydrocarbon reserves. Since 2010, all reserves booked for any field development proposal have always used the deterministic method, however starting in 2018 SKK Migas released the 2nd Revised Pedoman Tata Kerja (PTK) No. 37 on the Plan of Development (POD) and one of its points contains that all subsurface evaluations require to obtain uncertainty analysis & risk management and as well as use multi-scenario methods in calculating hydrocarbons in place. Multi-scenario is a incorporation of probabilistic and deterministic methods for the use of uncertainty analysis of multiple subsurface parameters such as seismic interpretation, petrophysical evaluation, conceptual geology and static modelling. The expected results, for example, are several low case, base case, and high case geological models and are able to provide geological maps for each case.

As a derivative of the PTK-POD implementation, an uncertainty analysis workflow is required to support the use of a multi-scenario method in order to capture all variations of subsurface parameters that have the potential to have an effect on project maturation. The deterministic method is still used as an initial reference in identifying the uncertainty of geological and reservoir parameters through the Tornado Chart. This step is able to reveal which subjects are most sensitive to the Hydrocarbon In-Place value. Once the parameter is selected, the probabilistic calculation will provide a normal distribution curve and show the stability of the parameter distribution in the geostatistical model. In conclusion, the results of the multi-scenario model of low case, base case, and high case in the calculation of reserves are a reflection of the possible risk-outcome that should be considered for decision making in oil and gas projects.

Keywords: Uncertainty Analysis, Field Development, Reserve, Geostatistical Model

Introduction

Exploration and exploitation activities are high-risk businesses. Geological concepts are always uncertain regarding structure, reservoir, seal capacity, facies distribution, etc. Meanwhile, the evaluation of the exploitation and commerciality of hydrocarbons has their respective uncertainties for costs, probability of finding an economical reservoir, technology, and oil/gas prices. The two main different mindsets for the two activities are reflected in the objectives themselves. In exploration is how to find hydrocarbons however in exploitation is how to define the distribution of reservoirs that have economic value.

There are several methods for estimating hydrocarbon resources. In general classification, it can be divided into conventional and geostatistical methods. Conventional methods usually use normal volumetric equations in which each parameter has been determined simply in single number, namely: a). Gross rock volume (GRV) is obtained from a single depth structure map, b) from petrophysical analysis namely average porosity, net to gross ratio, and water saturation numbers, then c) based on the laboratory PVT analysis result that is the average oil/gas formation volume factor. This method has been commonly used in two-dimensional models over the past few decades, but as statistics advances and becomes embedded in the resource calculation process, 2D methods become more precise in estimating hydrocarbon resources.

On the other hand, an explorationist usually uses the conventional method using Monte Carlo Simulation where the process combines probabilistic and deterministic to predict the potential resources in the reservoir. However, this method is only be taken for initial project predictions as a reference for investors to capture the potential revenue they will receive in the future. Since the objective is to deliver results for high-level decisions, we need to calculate in a simple way and the results are rough numbers. Sometimes, all parameters used to be simulated in a probabilistic process are divided into low values, base values, and high values to create a yield distribution curve.

In geostatistical methods, deterministic and probabilistic processes can be used, especially when combined. The fundamental improvement of this method compared to conventional methods is that we can create three-dimensional models. Recently, three-dimensional modeling is the best method that is popular with all major oil companies and has become an essential part of normal exploration and exploitation activities. Kamali et.al (2013) stated that 3D reservoir models play an important role in geology and petroleum engineering, where each method utilizes geological, mathematical, and statistical information. Modern specialized software programs can model complex and irregular geological volumes in three dimensions. This is done by using geological maps and construction information to create precise models.

Understanding to Uncertainty and Risk

Normally, in the calculation of hydrocarbon resources, the expected number that we will achieve is derived from the average value, although it is possible to get a large variance result. Determining the average number for each parameter is a normal thing for Geologists and Engineers, they sometimes do not take into account the risks that may occur because they do not acknowledge the uncertainty in the distribution of parameters. Savage (2009) says Plans based on the assumption of averages are wrong. An apocryphal example concerns the statistician who drowned while wading through a river whose average depth was only three feet (Figure-1). In Planning for the future, uncertain outcomes are often replaced by a single prediction, called the average. This leads to a class of systematic errors called Flaw of Average, which explains among other things why estimates are always wrong.

In the preparation of development plans, field management decisions are usually made using a deterministic approach. The procedure is to select a single value for each parameter to enter into the appropriate equation and to obtain a single number. Although this approach is very fast, it often leads to one answer and is likely to be a miss leading decision. Since the number of outcomes is only one, the potential risk cannot be measured either. Following provided reserves/resources can be classify to 1P, 2P, and 3P category. Probabilistic procedures are used in some cases for reserve assessment, considering geological uncertainties, or in field evaluations, using Monte Carlo simulations or similar techniques to incorporate economic uncertainties. Probabilistic approach is a rigorous method with comprehensive process, it needs more time consuming since building a robust model. As the uncertainty range parameter input to the software, the outcome will be a distribution model. This approach is quantifying the risk, therefore result numbers of range really informed for decisions.

Figure-2 describes those two main approaches that geologists and petroleum engineers always use to estimate hydrocarbon resources. The two methods have differences in the process and purpose of their application. The Society of Petroleum Engineers (SPE) defines this method as a guideline in the Petroleum Resource Management System (PRMS) document.

People always mix up the terms uncertainty and risk, but they shouldn't. There is nothing uncertain about reality, it is our vision of reality which is about uncertainty. Therefore, uncertainty is not an intrinsic property of the system; it is the result of incomplete knowledge by the observer. Uncertainty is a situation where there is limited knowledge and information that can lead to the target, in this case sometimes there is no key information to understand the possible outcomes to anticipate the worst-case scenario. Risk is a variety of possible conditions as an impact that arises from a situation of uncertainty. Another understanding of risk reflects how uncertain outcomes lead to high potential missed opportunities. Uncertainty cannot also be estimated, it is modeled. Therefore, stochastics takes on its role.

Often there is significant uncertainty in many subsurface input parameters early in the project life cycle. Uncertainty arises since most subsurface parameters are estimated from a small sample of reservoir properties from discovery and appraisal wells. The methodology for measuring the impact of uncertainty is still not well established due to of the amount of variables that have to be considered. Basically, development risk is a function of geological, economic, and technological uncertainty. In this paper we focus on geological uncertainty. In geostatistical models, volume in place and recovery factors are sufficient in risk analysis as a reflection of uncertainty in seismic interpretation, petrophysical evaluation, PVT behavior from laboratory analysis, reservoir pressure data, core analysis, well test results, etc. Recently, the quantification, understanding, and management of subsurface uncertainty has become increasingly important for oil and gas companies as they strive to optimize reserve portfolios, make better field development decisions, and improve day-to-day technical options such as well planning.

As we are very knowledgeable about range of uncertainties in every stage of the oil and gas industry regarding the quality and amount of data at each stage or time. In general, at the exploration stage the range of uncertainty is wide. Analog data usually comes from adjacent fields and the method used is simple Monte Carlo probabilistic which is classified into Low (P90), Best (P50) and High (P10) estimates. Then at the Appraisal and Production stage, additional data were obtained, including over-appraisal wells, additional seismic surveys, and even production data so that the reserve figure becomes more certain and reduces the range of uncertainty. This explanation can be summarized in Figure-3 and the estimation of reserves in the oil and gas field can be more firm when it comes to the abandonment stage.

Multiscenario Concept

The two major approaches in recent reserve prediction are deterministic and probabilistic methods with individual improvements. This method is very common, especially in Indonesia where the deterministic method is included as standard procedure in field development planning before 2018. The advantage of this method is that it is simple, fast, and does not require sophisticated computers. But nowadays, the case of field development is becoming more costly, complex, and unique. Uncertainty is reflected in the challenges and risks and inherent in the complexity of the project, so it seems a must to transform the methodology to a more comprehensive process that is able to capture these difficulties to anticipate any possible impacts in the future.

The probability of uncertainty should be quantified when estimating reserves, and the method that can account for all uncertainties is the Probabilistic method. This method has some inherent problems. They are affected by all input parameters, including the most likely and maximum values for those parameters. However, in one method, it cannot calculate back the input parameter associated with the reserve, only the end result is known but it does not know the exact value of any input parameter. On the other hand, deterministic methods calculate reserves using tangible and explanatory values so that all parameters are exactly known. Susceptibility to deterministic sometimes ignores variability and uncertainty in the input data compared to the probability that it is possible to include more variance in the data. Considering the challenges in such methods, the combination of deterministic and probabilistic methods allows geologists and engineers to solve the problem of reserve estimation. The name of the combination method is the multi-scenario method.

Multiscenario or sometimes called scenario method or multirealization method in PRMS 2011 essentially defines an extension of the deterministic method but range of possible deterministic outcomes or scenarios are described. The scenario method combines elements of a deterministic approach and a fully probabilistic method. It describes a range of possible outcomes for the reservoir, which is consistent with the observed data. The distribution of low case, best case, and high case is made up of several deterministic cases. One result that is physically consistent within this range with in-place volume estimates is called subsurface realization. For the purpose of obtaining recovery factors, we can then define a development scenario for each subsurface realization and subsequently book the recoverable volume in the appropriate category. In the end result, the multi-scenario method makes it possible to select parameters to derive a tornado chart and then utilize the distribution curve that produces statistical calculations, such as minimum and maximum values, mean, most likely value, standard deviation, and percentile (Figure-4). In any scenario, we can extract maps/models for each parameter, such as vshale map, porosity map, sw map, hydrocarbon pore volume, etc.

Uncertainty Analysis Workflow

The availability of data for oil and gas fields is generally insufficient to minimize the uncertainty related to the construction of geological or reservoir models. An understanding of the uncertainties involved in geological modeling is an essential tool to support decisions in field development as they are present in the process. The process is even more critical because most investments are made during the stage when uncertainty is greater (Schiozer et.al., 2004). Deutch (2002) mentions that a geostatistical reservoir model is a “set” of spatially distributed of parameters including (1) structural definition of each stratigraphic layer, (2) facies within each stratigraphic layer, and (3) petrophysical properties such as porosity, permeability, and the residual saturation on a by layer and by facies basis. Each model consists of one realization that is not built for the same facies realization; one porosity realization is associated with each facies realization. The uncertainty created by multiple realizations is realistic when the geological conceptual framework and statistical parameters, such as the variogram and size distribution, are well known. This parameter is not well known early in the reservoir life cycle; therefore, there is more uncertainty than is measured by a set of geostatistical realizations generated with the same of underlying parameters.

A more realistic space of id uncertainty is determined by a combination of scenario-based approaches and conventional geostatistical modeling. As a schematic illustration in Figure-5, the reservoir can fit in any of different conceptual models (M-I, M-II, or M-III) with probabilities 0.5, 0.3, and 0.2. In scenario-based, there may be different sets of modeling parameters (e.g.: variogram) and some derivations of 3, 2, and 3 sets of possible parameters for a conceptual geological model. After setting specific parameters, geostatistical realizations are generated for each of the eight scenarios.

Meanwhile in the geostatistical uncertainty process, there is a realization of L and equally probable to gives the set of parameters used to create it. Bayes' law, the probability of each realization is calculated by multiplying the probability of each realization (1/L) by the probability of each scenario. A reasonable definition of a scenario and the assignment of conditional probabilities are critical. Scenarios can reflect different aspects of uncertainty, for example, direction of deposition, fault seals, facies quality and fracture density. Scenarios can also reflect uncertainty in critical statistical parameters such as the net-to-gross ratio (low, medium, high) or the range of the variogram. Aspects of large-scale discrete uncertainty are qualified by scenario-based approach, while uncertainty due to incomplete data is quantified by multiple geostatistical realization.

Normally in geostatistical modeling, regardless of whether the method is deterministic, stochastic, or a combination of both, the objective of the process is to have a number of hydrocarbons in place. The integration of work in geostatistical modeling is the result of geophysical interpretation, petrophysical evaluation, and geological interpretation. Through specific processes and certain methodologies, several maps/models will be produced vshale, porosity, water saturation, permeability, hydrocarbon pore volume, etc. In general, geologists or engineers only make one model of each parameter because they think the results are the most correct, but they do not realize that many uncertainties in the model can affect the success of field development. Decisions related to field development and reservoir management are always associated with the risks involved due to the uncertainty present in the process.

The conceptual workflow explained by Deutch (2002) needs sophisticated hardware and applications to capture all these uncertainties. The challenge for calculating uncertainty is that it is time consuming, the more complex the model and the uncertainty, the more time it will take to solve the problem. To manage ambiguity, we need to divide the main parameter groups into two. The first group is large-scale discrete parameters, such as depth structure maps, seismic attributes, seismic inversions, and fracture distributions. Ideally these parameters are used as scenario based however the best possible model is usually been selected. The second group of parameters is part of the uncertainty analysis such as petrophysical parameters (including cut off), statistical variogram, facies shape, fluid contact, formation volume factor, seeds number, and rock typing. This group will be used when the probabilistic process starts.

Figure-6 shows an uncertainty analysis workflow that can be used for geomodelers as a way out of reducing the time required to create geostatistical models while maintaining the quality of the results. This workflow consists of two stages, namely (1) performing a normal deterministic geostatistical modeling to produce hydrocarbons in place then followed by (2) a probabilistic method which include define the uncertainty of the parameters, heavy hitter selection based on the tornado chart, and deciding how many realizations may be required to form the best normal distribution curve.

The most critical to review the uncertainty is when defining incomplete information to some of the parameters used in geostatistical modeling. By heavy hitter selection by using a tornado chart can make it easier for geomodelers to select which parameters may influence the probabilistic process (Figure-7). The objective of heavy hitter selection is to screen out less parameter ranges due to (1) to reduce hardware time consumption to run the application when the number of parameters is few, (2) to avoid ambiguity of the best model number due to the spiky normal distribution curve as a result of statistically very dominant value. Unreal values populated in a certain number can form a "strange" shaped curve due to the narrow range of parameters distribution included in the calculation. The selected 5 to 7 parameters used in the uncertainty analysis yielded a significant impact in reducing almost half the running time of the total 20 parameters.

The required of realization amount depends on the "precision" for uncertainty assessment required. A large amount of realization is required to assess the 1% to 99% percentile of the hydrocarbon in place distribution, but not always. The basic concept, if the running process has reached a solid model, sometimes the number changes are not significant when increasing the realization, and produces a smooth normal distribution curve shape (Figure-8). The best model should have both conditions because they are interrelated. Therefore, there is actually no specific formula that can estimate how much realization is needed.

One of the advantages in the multi-scenario method, based on normal distribution curves, is that the decision to select a certain model is extracted only from the required map, e.g., hydrocarbon pore volume and any petrophysical model at a certain percentile. And another benefit is that iteration from static to simulation can be started earlier because in uncertainty analysis multi-scenario workflows are able to capture incomplete information of dynamic reservoir modeling.

The output of uncertainty workflow analysis is to select which probability models that able to use for simulation modeling, there are low (P90), best (P50), or high case (P10). However, in normal condition the recommended model is best case as an optimum case which equal to 50% percentile. However, at several conditions when according to the technical evaluation stated reveals (1) the availability data is not sufficient, (2) fewer quality data provided, and (3) remotely location of potential gas buyer can be as one of parameter for choosing of development strategy, the possibly recommended model for simulation is low case model (P90 or 10% percentile) as a part of risk management. In simulation model, engineer will always to assess the uncertainty dynamic data based neither but will not be discussed in this paper.

Discussion and Conclusions

The aim of geostatistical modeling is to utilize a wide variety of data at different scales and accuracy, to build a reservoir model capable of representing geological heterogeneity and also quantifying uncertainty by generating a number of equiprobable models. In the preparation of development plans, management decisions are usually taken using a deterministic approach. The probabilistic approach is often not used because of the amount of time and computational effort required. However, recent hardware and software improvements have made it possible to incorporate more accurate production predictions in the process. Furthermore, uncertainty analysis can also be carried out as one of the workflows of the process itself.

The proposal workflow for uncertainty analysis is important to include a multi-scenario approach to quantifying the impact of uncertainty in the development process. The low, best, and high cases on the results of the multi-scenario method do not always represent the 1P, 2P, and 3P reserve classifications. This condition should also be considered for the type of field, related to its complexity and uncertainty. Usually, cases from multi-scenarios are reflected in the range of reserve numbers from low, best, and high estimates. For green or developing fields, the range may be reflected in the 2P or 3P reserve category, while in mature fields the range may be in the 1P reserves category. This situation describes of uncertainties exist in the field. The green fields due to limited data available possibly need more additional information, such as infill wells, seismic survey, or production data. However in mature fields, probably reservoir pressure itself is depleted, development wells located at optimum position to drain hydrocarbon, and many update dynamic reservoir information are collected, so range of information is narrow reflected proven reserves indicates to entire field.

In addition, recommended model either P90 or P50, from certain selected realization model it can be extracted the map of properties, for example vshale, porosity, permeability, or even HCPV. And the map resulted is typical with deterministic approach.

Meanwhile for deterministic approach, recently since sophisticated hardware easily provided, also can use using geostatistic method, based on stochastic calculation single input properties reservoir in the wells will be distributed through the area but only get single output distribution model either. It takes simple process, fast, single answer but does not quantify the risks. The result model directly able to classified 1P, 2P, or 3P reserves category.

A combination of deterministic and probabilistic approaches with several simplifications in the workflow is allowed based on the required precision, the most common and usual approach is the selection of critical variables through sensitivity analysis. This new proposal approach is already applicable to several fields in Indonesia as a part technical assessment to capture subsurface uncertainties. Accountability of management decisions regarding risk analysis can be accommodated in the uncertainty analysis process. The analysis steps start from selecting scenarios, running multiple realizations, ranking models, then selecting the final model that will be the basis for field development. The methodology described in this paper is applied to geological uncertainty which is the most important parameter of the process; however, research is still needed to address operational and technological uncertainties and also for better reservoir characterization procedures when uncertainty exists.

References

Deutch, C.V., 2002. Geostatistical Reservoir Modeling. Oxford University Press, New York.

Kamali, M.Z., Omdivar, A., Kazemzadeh, E., 2013. 3D Geostatistical Modeling and Uncertainty Analysis in Carbonate Reservoir, SW Iran. Journal of Geological Research, Vol 2013.

Savage, S.L., 2009. The Flaw of Average: Why We Underestimate Risk in the Face of Uncertainty. John Wiley & Sons Inc, Hoboken, New Jersey.

Schiozer, D.J., Ligero, E.L., Santos, J.A.M., 2004. Risk Assessment for Reservoir Development Under Uncertainty. Journal of the Brazilian Society of Mechanical Sciences & Engineering, Vol XXVI.

Acknowledgements

The author would like to thank SKK Migas for approval to publish this paper. Highest appreciation should also be given to the subsurface team who provided useful data and fruitful discussions as well as comprehensive insights on creating uncertainty analysis workflows for field development.

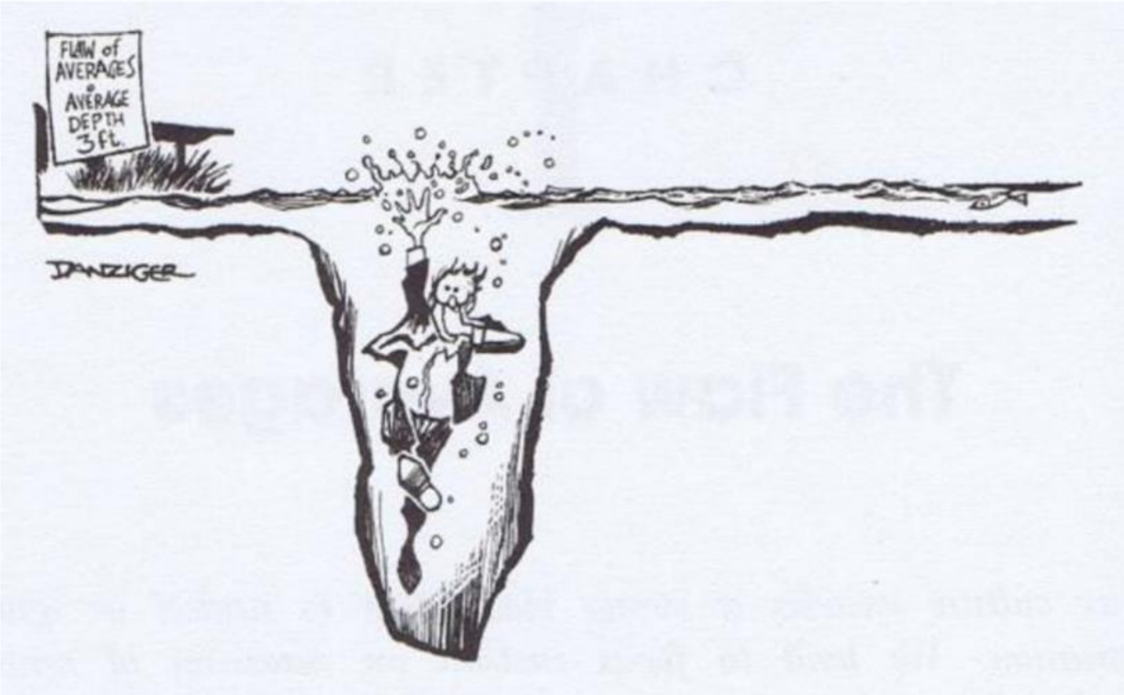

Figure-1: An apocryphal example concerns the statistician who drowned while fording a river that was, on average, only three feet deep, as depicted in the sensitive portrayal by cartoonist Jeff Danziger (Savage, 2009). Miss leading to anticipate for uncertainty in average statement of depth.

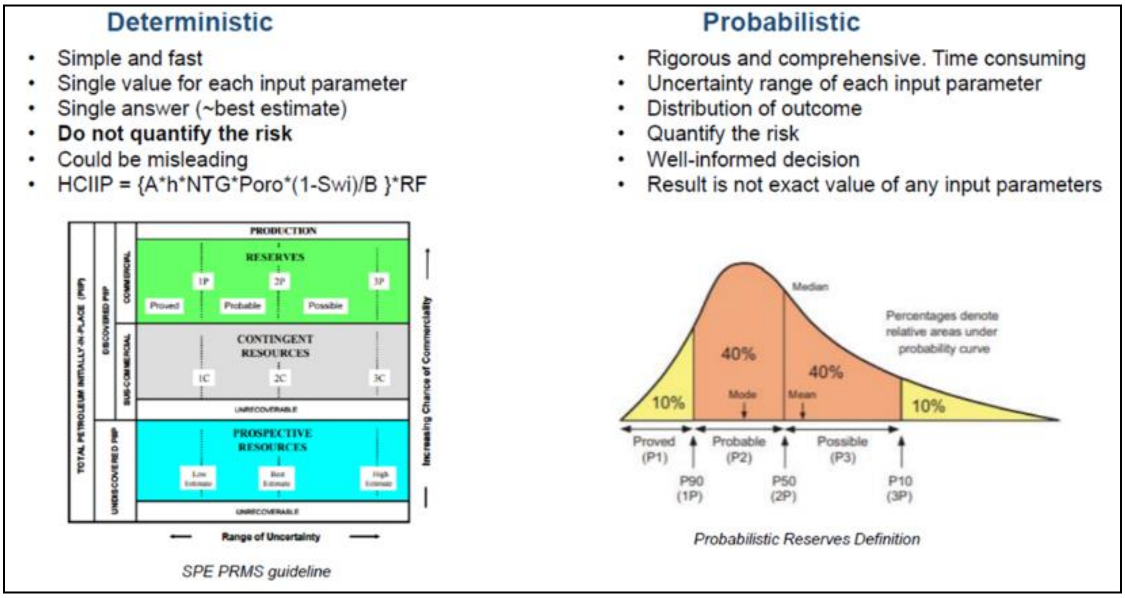

Figure-2: Two general approaches of reserves estimation method with pro and contra. In context of uncertainty analysis will be considered in probabilistic method and more robust process, while deterministic is fast and simple equation.

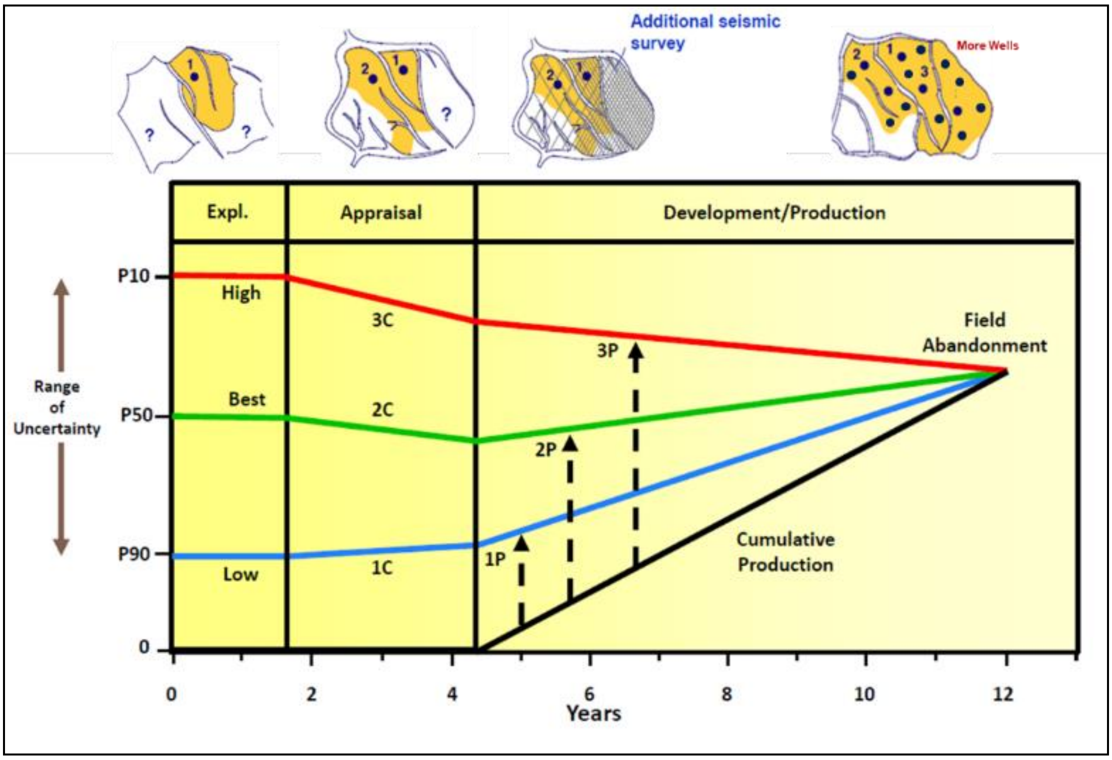

Figure-3: The image gives an understanding of the progression of reserves number during the time. Figures above table describes availability data during each of stage, for example: number of wells, seismic survey, and production data. The uncertainty has the highest range in exploration period with minimum data and will be decreased when the data acquired for appraisal, then the "real" reserves number may be more firmed on abandonment stage.

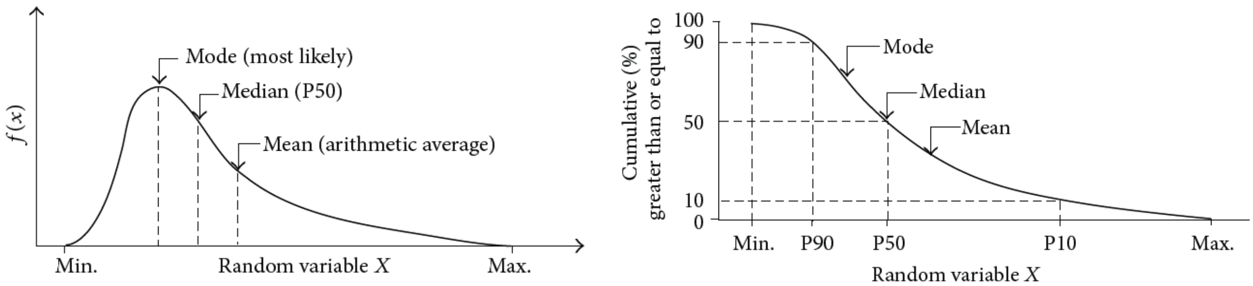

Figure-4: In probabilistic method, we able to see the distribution of number from minimum to maximum with its probability cases as the result of statistical calculation. Left figure is normal distribution curve describes the position of mode, median, and mean variables. Right figure is probability distribution curve describes percentiles variable for any possibility's outcome.

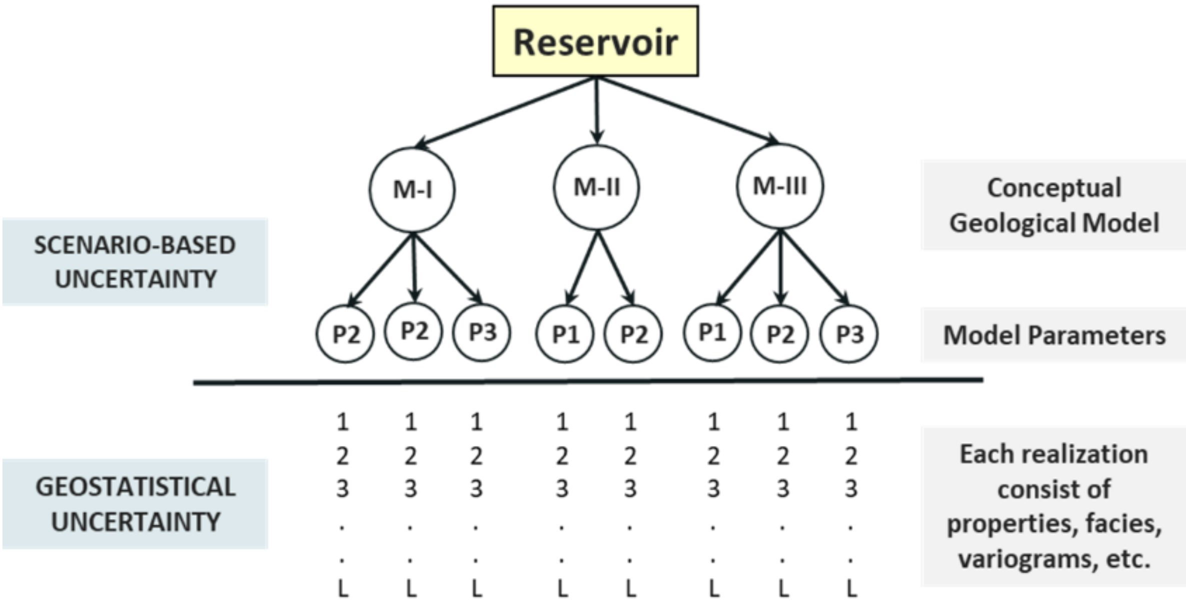

Figure-5: Schematic illustration of combining scenario based and geostatistical based of uncertainty that accommodated in the process of multiscenario method (modify Deutch, 2002).

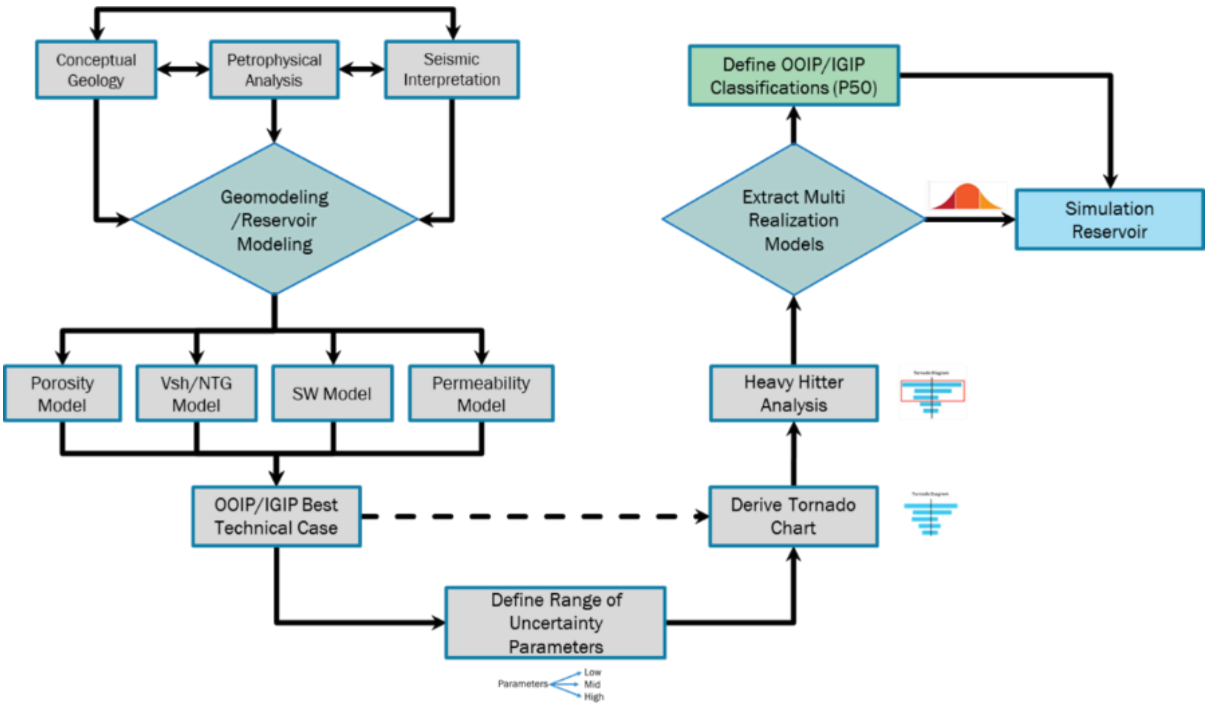

Figure-6: The uncertainty workflow guides to estimate of reserves in geostatistical modelling. Recent hardware able to obtain both deterministic and probabilistic methods. Multiscenario combines these methods to capture scenario base in deterministic and distribute variables to probabilistic process. Common geostatistic modelling with deterministic process resulting a model of porosity, Vsh/Ntg, Sw, permeability, and hydrocarbon in-place. Probabilistic process initiated by defining parameters uncertainty through tornado chart and resulting hydrocarbon distribution numbers in normal distribution curves.

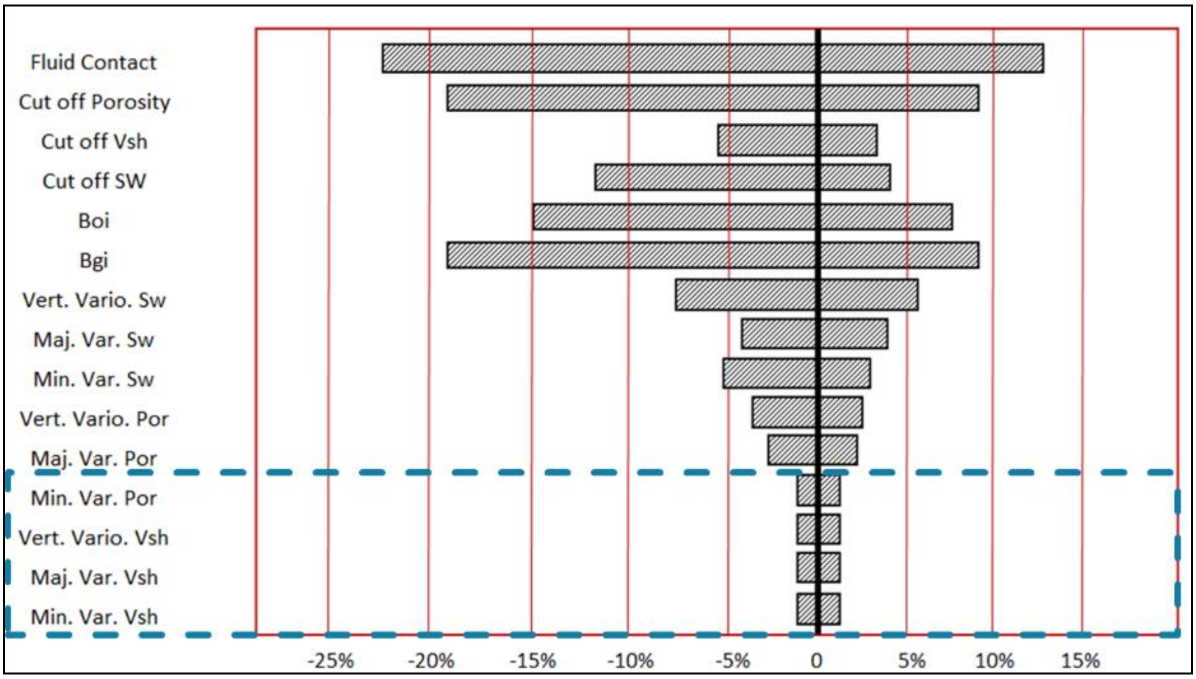

Figure-7: Tornado chart informs the range of variables of geostatistic before to obtain probabilistic Monte Carlo. In order to time effort reduction, unsignificant impact of variables with small range can be screen out and not to be included in running process (dash blue box).

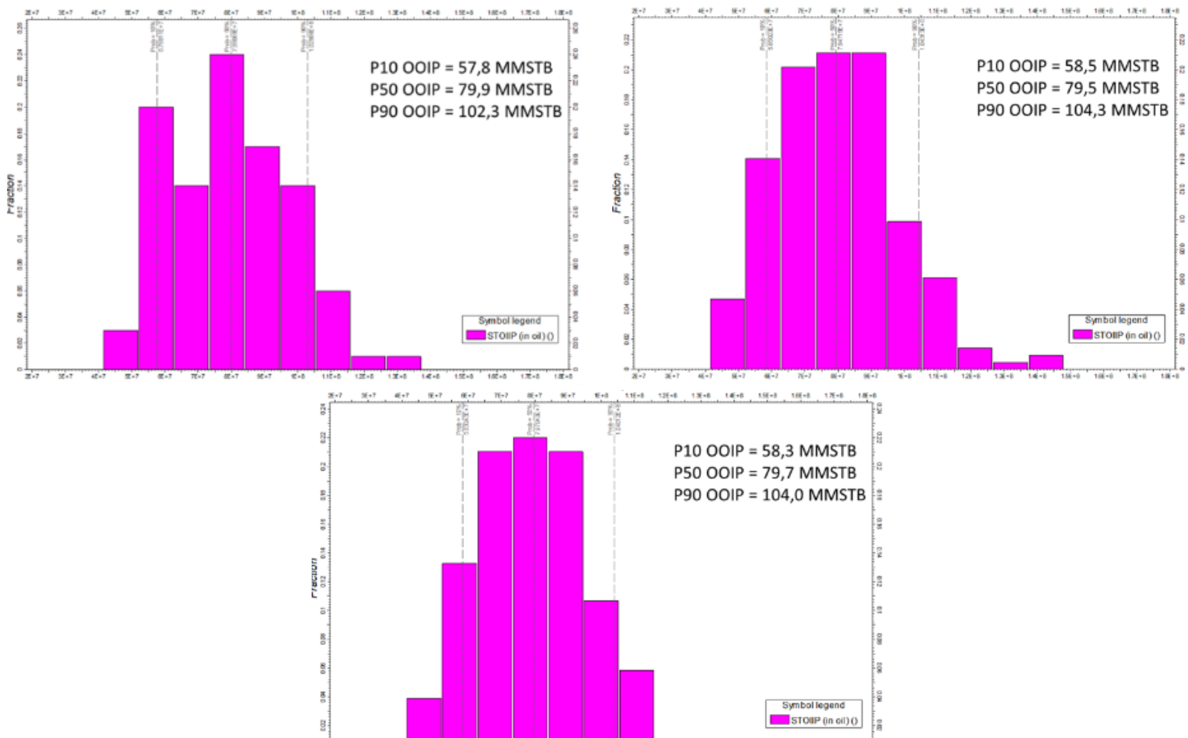

Figure-8: Three figures above describe the amount of realizations or iterations: upper left 100x, upper right 200x, and below 300x. Although each realization gives narrow discrepancy value but better curve indicates better parameter models in geostatistic distribution. 300x iterations are the best curve and model, therefore it can be proceeded to dynamic modelling.