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SENSITIVITY & UNCERTAINTY ANALYSIS OF ORIGINAL OIL-IN-PLACE IN CARBONATE RESERVOIR MODELING, A CASE STUDY

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Abstract

A systematic quantification of technical risks is crucial for decision makers to be able to compare or rank possible projects of a global portfolio, or understand the risk level they are taking on any new field development. A quantification of the impact of various subsurface uncertainties on economic may also help justify the acquisition of further data, in order to reduce the uncertainty before major decisions are made. All geostatistical methods used in estimation of reservoir parameters are inaccurate, modeling of "estimation error" in form of uncertainty analysis is very important. Consequently, the application of sensitivity analysis on stochastic models of reservoir horizons, petrophysical properties, and oil-water contacts, also their effect on reserve, clearly shows any alteration in the reservoir geometry has significant effect on the oil in place.

The studied reservoir is located at carbonate sequences of Ilam formation, Iran; it comprises Four Zones. Zone 1-2 and zone 1-4 are main reserve and other zone have a little oil. Average porosity and water saturation of the reservoir is about 25% and 43%. the uncertainty analysis result P90, P50 & P10 are about $415*10^6$ bbl, $600*10^6$ bbl & $800*10^6$ bbl.

Key Words: Original oil-in-place; Sensitivity; Uncertainty; Carbonate; Reservoir modeling.

1. Introduction

The decision to go for the project or not, or the choice between different field development concepts, are made on mean values and not on deterministic reference values. Hence it is important to estimate mean production, mean net present value, mean cash flow etc. for the different alternatives and decisions. Understanding the volume uncertainty and estimating the volume uncertainty range are important input for risk mitigation actions such as defining flexibility in the field development plan and finding robust solutions that are optimal over a range of outcomes rather than optimal on the reference case understanding of the field.

Uncertainty exists everywhere, such as (1) raw data measurements, (2) data processing and interpretation,(3) structural modeling, (4) facies modeling, (5) petrophysical modeling and (6)PVT analysis, which affects the ability to understand the reservoir behavior, making reliable production forecasts and risk-free decisions.

Throughout the life of a hydrocarbon reservoir, from discovery to abandonment, a great number of decisions depend on incomplete and uncertain information [2].Uncertainty is not an inherent feature of our reservoirs; it is due to our lack of knowledge and understanding about the reservoir [3]. This data shortage is mainly due to reservoir complexity and to the high cost of data acquisition. Therefore, the prediction of oil-in-place mostly is uncertain [4].

2. Methodology

For volumetric computations, different types of volumes that can be computed are: the gross rock volume (GRV), the net rock volume (NRV), the net porous volume (NPV), the different fluid volumes (OIP and GIP), and the connected volumes using various connectivity criteria. These volumes should be reported not only for the whole model but also for any regions defined on the model.

Equation for Oil in Place at reservoir conditions (no gas):

$$STOIIP = GRV * NTG * \phi * (1 - Sw)$$.

The major elements here are the Gross Rock Volume (GRV), consisting of a structural piece: horizons and faults - properly connected together - and fluid contacts; the Net-to-Gross (NTG); the net Porosity (Φ), and the Water Saturation(Sw).

Identifying which of these elements is more important than the others will help focus resources on relevant issues, stay at the right level of technical detail, and in turn save time and money.

The main objective of this study is to uncertainty quantifying of the objective function. To meet this goal, the following procedure should be done.

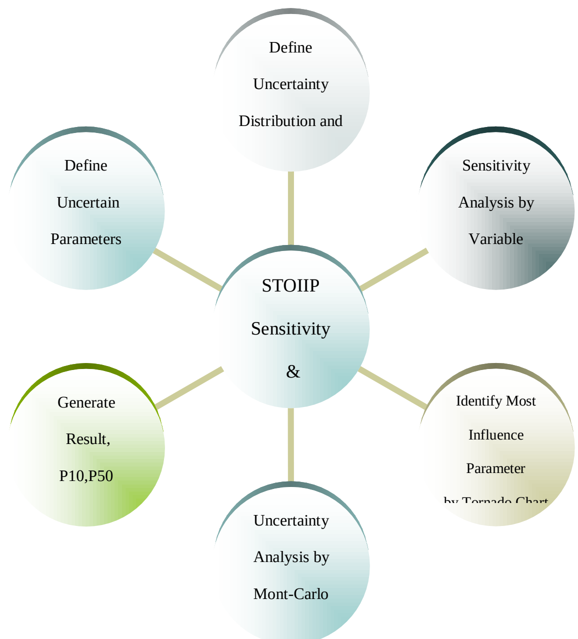

Figure 1 Sensitivity & Uncertainty Analysis workflow of STOIIP, in six steps

3. Uncertain Parameters

When building a geological model one has to go through a thorough subsurface evaluation including interpreting seismic data, performing time-to-depth conversion, interpreting log data, establishing geological conceptual models, building a 3D reservoir model, and estimating fluid contacts and fluid types in the different areas. Then it is important to acknowledge that at each step there are uncertainties, both in the data that are used, the selection of which data to include, and in the interpretation of the data. In an integrated uncertainty analysis it is important to include all these uncertainties in the value chain from seismic interpretation to volume and value calculation.

The uncertainties included in the uncertainty analysis of in-place volumes are:

1. Structural Uncertainty
2. Fluid contacts
3. Petrophysical Properties
4. PVT as Bo, Bg

3.1 Structure Uncertainty

The main sources of structural depth uncertainty include (1) velocity model; (2) time interpretation pick; (3) isochore thickness; and (4) fault interpretation. Uncertainty in velocity model can be defined by assigning probability distributions to the parameters of the model (V0, k, etc). The input parameters can be constants, functions or maps. Velocity uncertainty maps are particularly useful for incorporating realistic lateral variations such as increased uncertainty away from well data and down dip. These maps can be based on well miss ties, analysis of stacking velocities and general time interpretation uncertainty is usually defined by small time shifts of interpreted horizons. The time shift can either be a constant or can vary laterally to reflect varying quality of the seismic response or increasing uncertainty over major faults.

Isochore uncertainty is handled in a similar manner to the time interpretation uncertainty. Constant thickness multipliers or thickness uncertainty maps are applied to "base case" isochore.

Horizon depth uncertainty also needs to be linked to the fault model and uncertainty in velocities and depth conversion should be handled in a consistent manner for both depth horizons and fault surfaces.

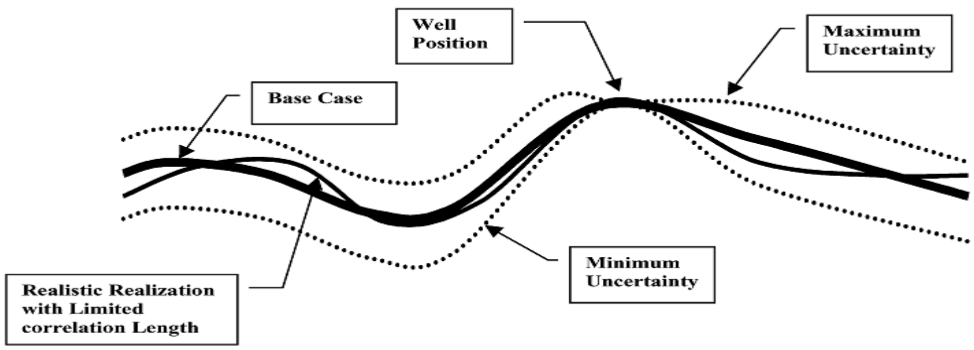

Figure 2 An uncertainty map has been added and removed (dotted lines) to a reference map (thick continuous line)

3.2. Fluid Contact

It is important not only to include the uncertainty in the contact given the underlying assumptions, but also the uncertainty in the underlying assumptions.

1. If an oil-down-to is observed the maximum contact depth is the spill point. However, the depth (and position) of the spill point is uncertain due to uncertainty in the depth conversion model. Presence or absence of sealing faults may change the definition of spill point drastically.
2. In some cases the gas-oil contact is observed and pressure measurements and fluid samples are taken from the oil zone but no samples or measurements are made in the water-zone. If the neighboring segment has pressure measurements in the water zone it is assumed, as a reference case, that the water zones in these two segments are in pressure communication. Then the oil-water contact can be estimated with the uncertainty defined by the uncertainties in fluid density and pressure measurements. However, the assumption that the water is in pressure communication should also be challenged and included in the uncertainty evaluation giving a complex uncertainty picture and large spans.

3.3 Petrophysical Properties Uncertainty

Reservoir model porosities were derived from log porosities calibrated to core measurements. Uncertainty resulting was obtained by considering an areal distribution of porosities. The porosities considered are vertical averages over reservoir thickness. Porosity is a key component of reservoir Pore Volume and hence of the resource base for the field. Since the porosity defines the volumes of moveable fluids in the reservoir, measurements of the effective porosity of the reservoir rock is also required. There are two important sources of porosity uncertainty. The first is related to logging tool measurement, processing and interpretation. The second is related to the sampling of wells. Additionally, the impact of internal porosity trends is independent of the relationship of the trends to the structure and contacts, so they need to be quantified separately.

As with porosity related uncertainty, there are two main sources of water saturation uncertainty.

3.4. PVT as Bo, Bg

Fluid samples are retrieved from most of the segments with wells. Here the uncertainties in the expansion factors Bo and Bg are relatively small and mainly due to uncertainty in the lab-results. The fluids change significantly across the field, and there is a large uncertainty in segments with no fluid samples. This uncertainty is estimated using information from the drilled wells and the variation in fluid properties across the field.

4. Sensitivity analysis

Design sensitivity analysis plays a critical role in inverse and identification studies, as well as numerical optimization, and reliability analyses. Before Uncertainty analysis and determine most influenced uncertain parameters, it is important to make sensitivity analysis. Sensitivity analysis is frequently performed to gain a better understanding of the influence of variables or parameters on the distributions of uncertainty. The purpose of sensitivity analysis is to identify those parameters and/or processes that strongly influence simulated results of the given model, and further analyze the trends of these correlations. Tornado chart is sensitivity analysis result and show that the major elements. Petrel offers two separate sensitivity tasks in the Uncertainty and optimization process:

4.1 Sensitivity by variable (Uncertain, SEED)

The variable-based sensitivity of the given model is determined by successively selecting one variable at a time from the set of all uncertain variables, and changing its value while keeping the others fixed at their Base values. This is done for each uncertain variable in turn, so the total No. of runs thus equals to the number of uncertain or SEED variables multiplied by the No. of samples per variable that has been entered by the user. Note that Expression-type variables are not directly sampled to test their sensitivity because they may depend on other $-variables that are tested.

4.2 Sensitivity by process

The process-based sensitivity of the given model is determined by altering the variables of one process at a time. This differs from Sensitivity by variable as several parameters may be defined within a single process. When this task is chosen, the total No. of runs equals to the number of parameterized processes multiplied by the value entered in the No. of samples. If multiple variables are defined in one process, all these variables will be active together.

5. Case study sensitivity & uncertainty analysis

Spatial 3D modelling was performed with the use of the Petrel software. This case data only one exploration well with full sets logs and three fluid samples. Structural model was created by interpreted UGC with 100 x 100 m grid increment. Five proportional inner layers were set, in order to divide the model into over 297460 cells. The studied reservoir is located at carbonate sequences of Ilam formation, Iran; it comprises Four Zones. Zone 1-2 and zone 1-4 are main reserve and other zone have a little oil. In this case oil-water contact is oil-down-to and the Spill Point value were selected to be -3475 m. Average porosity was counted from Deterministic(Moving Average) porosity model. The same procedure was used to count water saturation and permeability distribution. Average porosity, water saturation and permeability of the reservoir are about 25%, 43% and 28 md.

Basic volume parameters were calculated by the Volume calculations module in Petrel. These parameters include Bulk volume, Net volume, Pore volume and Hydrocarbons Per Volume (oil in our case) (HCPVo).

Using the Uncertainty and optimization module in Petrel, first define uncertain parameter such as Structure, oil-water contact, petrophysical model(porosity & water saturation) and Bo. Second define uncertain parameter distribution and ranges, third analyzed sensitivity by variable and obtain more influenced parameter in volumetric uncertainty. For oil-water contact select triangular distribution and define three depth, spill point(-3475 TVDSS), base Ilam reservoir(-3391 TVDSS) and reference depth (-3440 TVDSS) to reduce volumetric uncertainty. Using Monte-Carlo sampler(Latin-hypercube sampling) with 2000 No. of samples from their assigned distributions was used for this purpose.

Table 1 contains a summary of the input distributions type and their ranges for case Model. Low and high values of factors were obtained.

Implementation of Sensitivity analysis on case model using uncertain parameter described before would yield the tornado chart of figure 3 where it is confirmed that oil-water Contact (WOC) and petrophysical parameters (porosity and water saturation model) have largest impact on our original oil-in-place calculation. Tornado charts are great to visually summarize information and more precisely the impact of various plotted parameters. They are excellent decision-support tools for that reason.

Table 1 Uncertainty and sensitivity analysis variable distribution and ranges

Uncertain Parameter	Base Value	Distribution	Arguments					
$Structure	$SEED(Std Dev. 2.0)							
$WOC	-3475	Triangular	Min	-3475	Mode	-3440	Max	-3391
$Petrophysical Parameter	0	Triangular	Min	-0.2	Mode	0	Max	+0.2
$vertical variogram	4	Triangular	Min	3	Mode	7	Max	11
$Bo	1.351	Normal	Mean	1.351	Std.	0.01		

Monte-Carlo sampler(Latin-hypercube sampling) with 2000 No. of samples from their assigned distributions was used for uncertainty analysis. It investigates the effect of the various variables simultaneously in a series of experimental runs.

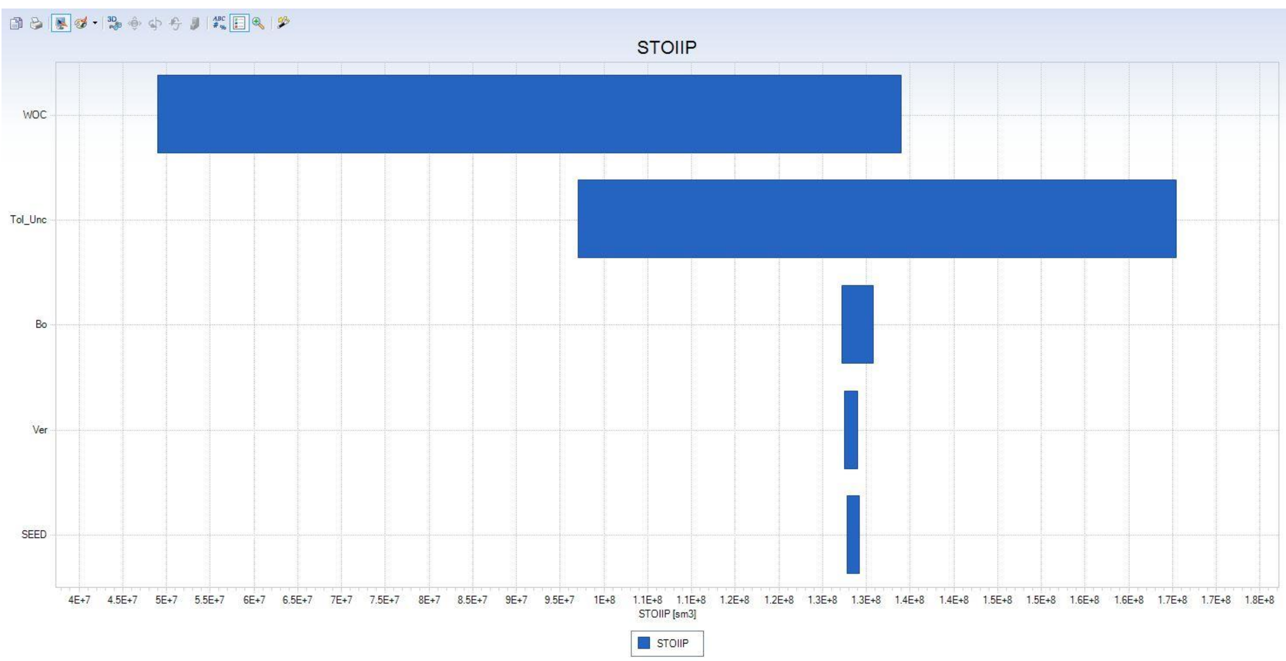

Figure 3 Sensitivity analysis result in tornado chart

A specific combination of properties (input variables) at different levels that make up multiple realizations of the volumetric reports. The results were analyzed to obtain the relationship between the input variables and the output responses.

The results can be shown in histograms (figure 4) and table (table 2Table 2) in which probability level of 10%, probability level of 50% (reality-oriented model) and probability level of 90% have been identified and CDF curve can be depicted. This way we can study performance of that parameter on the amount of oil.

Table 2 Volumetric uncertainty analysis result

P90	66.10^6 sm^3	415.10^6 bbl
P50	96.10^6 sm^3	600.10^6 bbl
P10	127.10^6 sm^3	800.10^6 bbl

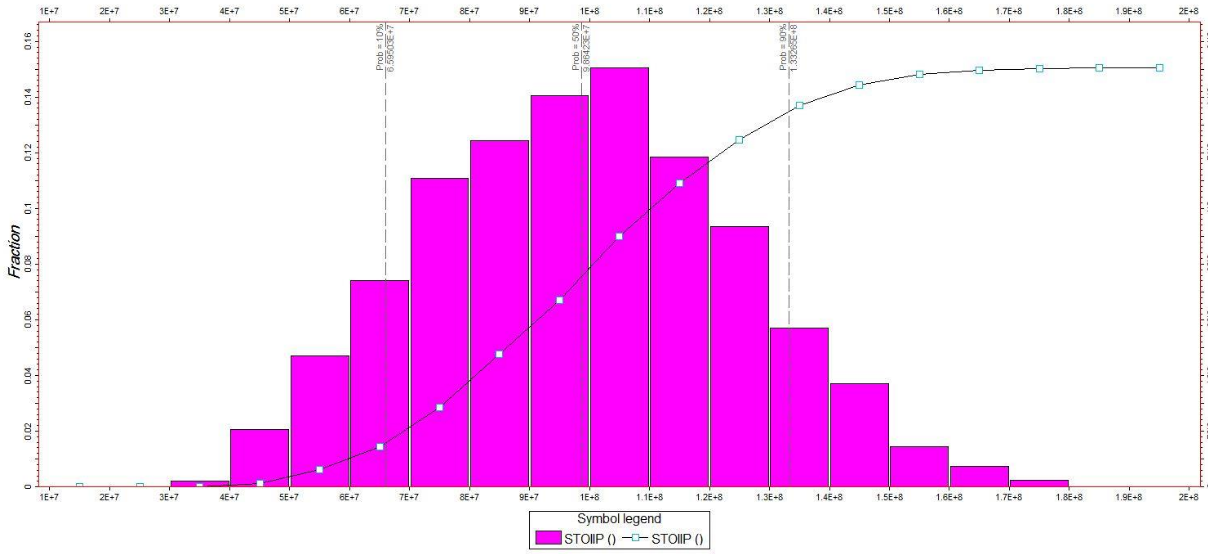

Figure 4 STOIIP CDF curve of different runs for Ilam reservoir volumetric calculation

6. Conclusion & recommendation

Sensitivity analysis on case model using uncertain parameter described that oil-water contact (WOC) and petrophysical parameters(porosity and water saturation model) have largest impact on our original oil in place calculation.

The results can be shown in histograms in which probability level of 10%, probability level of 50% (reality-oriented model) and probability level of 90% have been identified and CDF curve can be depicted. This way we can study performance of that parameter on the amount of oil.

It is necessary to rapidly know what actions are required to reduce their uncertainty to an acceptable level. For a reservoir modeling point of view, that would mean: (i) refining the interpretation, (ii) refining the model, or (iii) gathering more data because interpretation and modeling uncertainty cannot be refined any further with existing information.

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