Sidetrack/Recompletion Time Evaluation by Proxy Model

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Abstract: Sidetrack during field development and ongoing production arises to exploit bypassed reserves, unexploited zones and to tackle unforeseen conditions that are likely to occur due to uncertainties and heterogeneity in initially characterizing a reservoir. Whereas recompletion is due to sequential production of stacked reservoirs or multiple pay zones that is caused by regulation on commingling. The purpose of this paper is to investigate the application of experimental design (ED) in optimizing sidetrack/recompletion time of multiple pay zones in view of maximizing returns on investment by net present value (NPV) and expected monetary value (EMV). A hypothetical reservoir of two pay zones with uncertainties associated with pay thickness, porosity, permeability and time to perform the sidetrack was considered. The ED method of Box-Behnken response surface design was used to reduce the number of runs made by generating the most effective combination of variables for the experiment. Experimental runs were conducted with a Black Oil reservoir simulator to give production profile and the computed NPV was used afterwards to produce the Proxy model in ED. NPV computed from the Proxy Model was reasonable compared to that of the production profile from the simulator. However, a higher level D-Optimal or factorial design may be required for a reasonable match of EMV with respect to obtaining a realistic sidetrack/recompletion time.

Keywords: Sidetrack time, proxy model, experimental design, stacked reservoirs, net present value.

1. Introduction

The reasons for sidetracking from an existing well vary from well to well. Such as, to bypass an obstruction in the well that cannot be removed or can damage the well, to deepen a well or to relocate the bottom of the well in other to capture additional hydrocarbon reserves which is often horizontally removed from the original well. Whatever the reason is for a sidetrack, it always comes down to one point, which is, the economics. Restoring or increasing production from an existing well using a sidetrack is usually a quicker and significantly cheaper way to accessing a new horizon or a better spot in an existing horizon, while using the same wellbore especially when the existing zone is depleted or no more prolific. In some cases, the depleted zone is either plugged back or abandoned and commences from the new zone. This is the most common type of sidetrack procedure. However, a situation may exist where it is desired to sidetrack from an existing producing well which is still prolific to a new zone with the aim of producing both zones simultaneously. This is done in order to maximize recovery from an asset. For example, when the field lease life runs out in a few years without any chance of renewal. Development in the drilling and completion technology have made it possible to access these additional targets without losing the existing production interval. However, such procedures are not without risks.

Previous papers in this series [1] describe the basic decision-tree patterns for both sidetrack and recompletion developments of an oil field in terms of cash worth to date of a producing area, anticipated future worth, and also the likely worth of the potential development. In addition, the probability of how a new development could kill current production has a significant influence on the worth of going ahead with the sidetrack job. Previously, the investigation for a sidetrack had been evaluated only in terms of accumulated cash and potential gains and costs for the future. Presently, the element of time (i.e. when to undertake a sidetrack), is also of primary concern in developing an oil field to its maximum profit potential as evaluated by Lerche and Mudford [2]. Hence, it is necessary to convert estimates of total cash flow and total costs to a prescription involving the rate with time of such costs and gains. This research shows how such a matter can be handled for the case of deciding the optimal time to undertake a sidetrack job.

Sidetrack or recompletion of an unexploited would be productive zone (see Figure **1** for illustration) comes up with possible or likely scenarios that should be taken into consideration to solve the optimal sidetrack time. These likely scenarios are [2];

Case-1: If one can successfully do a sidetrack to the upper horizon (Zone-1), without lowering recovery from the producing lower horizon (Zone-2), what time is the sidetracking project most profitable?

Case-2: If one fails during recompletion (sidetrack), that is, no production from the upper horizon (Zone-1) yet has a successful production from lower horizon

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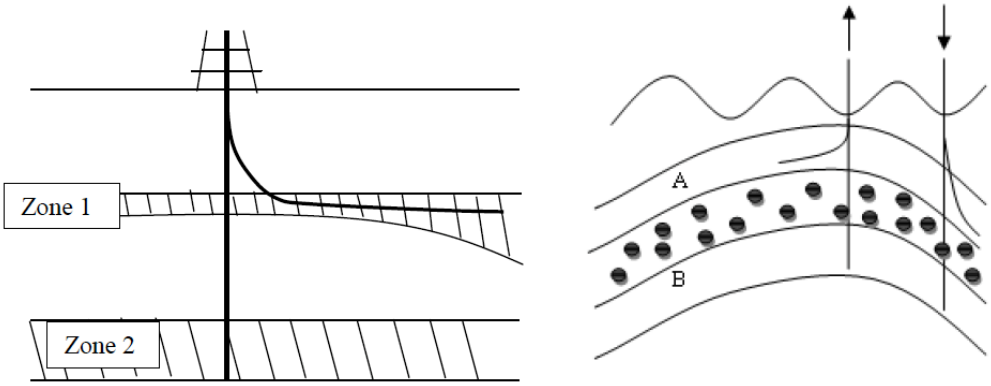


Figure 1a: Schematic of subsurface configuration (similar to Lerche and Mudford, 2001) [2]. **1b**: Schematic of subsurface configuration for both sidetrack from production and injection wells; source Orodu *et al.* (2011) [3].

(Zone-2), what time will the sidetracking project be most profitable?

Case-3: If one can successfully recomplete the upper horizon (Zone-1) and in the process of doing so kills the lower horizon's (Zone-2) production, what time will be most profitable for sidetracking?

Case-4: If one fails to successfully recomplete the upper horizon (Zone-1) and in the process kills the producing horizon (Zone-2), what time will the sidetrack project be most profitable?

Several challenges might be encountered during and after recompletion/sidetrack operation of an existing field. These unforeseen occurrences make it impossible to easily decide which of the four scenarios stated above might be encountered. The challenges associated with the sidetrack may be due to low or minimal recovery due to poor quality reservoir; a case of rapid pressure depletion due to isolation of the upper horizon or unknown connectivity of the upper horizon with the lower horizon and as such the upper horizon is already pressure depleted; poor recovery necessitated by natural drive mechanism and unconventional or highly viscous crude oil reservoir. Other issues may generally be connected to reservoir characterization studies and drilling challenges. The major question now becomes what time within the life span of the field, considering the chances of failure or success of one or both zones should the sidetrack job be done?

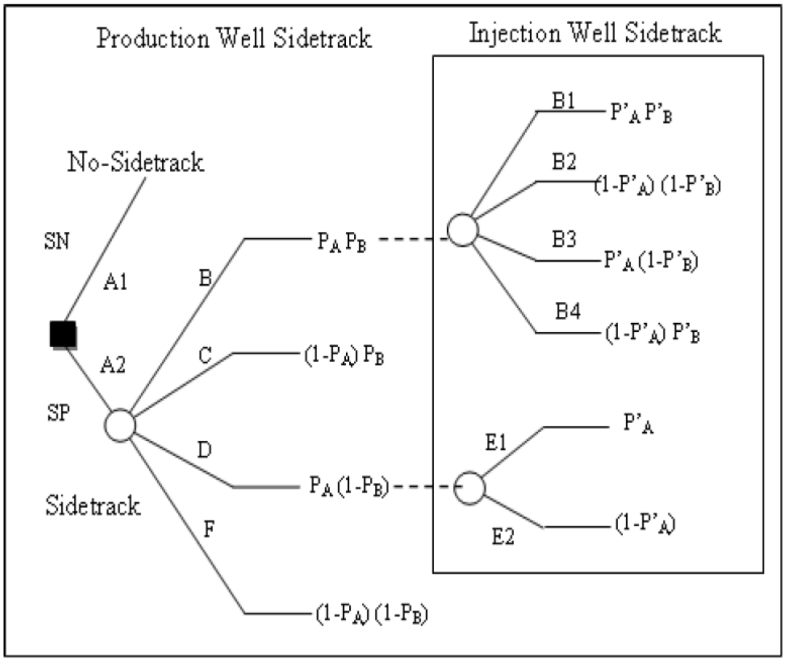


Figure 2: Schematic decision tree of only production well sidetrack and both sidetrack in production and injection wells; source Orodu and Tang (2011) [4].

One of the aims of this study is to examine the various decisions that can be taken if the need arises to produce simultaneously from two oil bearing zones. This can be achieved by a function of NPV with respect to reservoir parameters and the particular time at which sidetrack/recompletion will take place. By using the function, sidetrack time can be varied (alongside the reservoir parameters) to obtain NPV for the assessment of optimal time. Earlier studies have used analytical techniques to estimate production by exponential decline with uncertainty of success of sidetrack operation through probability of success and optimization of expected monetary value (EMV) to obtain optimal sidetrack time based on the schematic of Figures **1** and **2** [2]. Orodu *et al.* and Orodu and Tang [3, 4] previously, extended the application of obtaining optimal sidetrack time to a pair of production and injection well scenario and uncertainty of analytical production prediction parameters (see Figures **1b** and **2** showing either simultaneous or sequential sidetrack from both production and injection wells). This study employs a proxy model to estimate net present value (NPV) and EMV to the study of [2] as a function of time of sidetrack/recompletion and basic reservoir parameters. This suggests the application of design of experiments that is widely adopted to analysis of uncertainty of some parameters to production performance trend matching by the use of numerical reservoir simulators [5-8].

Since this study is based on a hypothetical field, it is important to establish basic assumptions. Some of the hypotheses which emerged are listed below:

- The field lies in an onshore location, housing two oil bearing Zones.
- The reservoirs are taken to be Undersaturated.
- Upper Oil bearing zone is inaccessible by the original wellbore penetrating Zone 2.
- Sidetracking must be carried out before Zone 2 becomes unprofitable.
- Sidetrack is stipulated to last 30days.
- The option taken to drill/complete the sidetrack is the selective re-entry tool. This allows the use of larger production tubing as opposed to the alternative methods but requires that the production fluids be commingled.
- Lower horizon is assumed to have a life span of 10years.

2. SIDETRACK OPTIMIZATION

According to Orodu *et al*. [3], maximizing recovery of existing producing field is pertinent to improving return-on-investment. Hence, maximizing recovery by either recompleting a well to adding more drainage points (extension of perforation zones) or sidetracking through an existing well to establish a secondary well bore for commingled production should be considered.

The optimal recompletion time was considered by maximizing the risked NPV or EMV [1, 2].

It is common knowledge that a shallower zone should be recompleted when production from a deeper zone or horizon fall below an economic limit or threshold. This may be followed by commingling production from both zones or as the case may be as detailed under the four case scenarios of the previous section.

Orodu and Tang and Lerche and Mudford [2, 4] had in the past evaluated optimal sidetrack time under risk to exploit a less productive horizon with the continued production scenerio of the highly productive horizon under production. Orodu and Tang studied secondary recovery mechanism under water flooding while Lerch and Mudford did primary recovery. The optimal time for a sidetrack was evaluated to maximize the EMV that is affected by the technical and geological risks involved with the sidetrack operation and uncertainties associated with production forecast.

2.1. Experimental Design

Experimental design (ED) as a *scheme* is aimed at maximizing the quantity of data that is useful through the application of a limited set of experiments from all possible experiments. It reduces the number of experimental trials required. Hence, it is economical and finds the combination of factor levels (subsurface variables) at which the response variable (NPV in this case) is optimized. Due to the lack of substantial reservoir description data, it will be very difficult to determine the optimum recovery of a development plan. The application of ED helps to map out uncertainties and develop a range of feasible geologic models and other variables including, permeability, porosity and net thickness. The ED technique basically helps in developing an optimized and proven plan over a wide range of subsurface uncertainties.

2.2. Selection of the Uncertain Reservoir Properties

The uncertainty of reservoir variables that applies to this study originates from the need to simulate the productivity of the two zones based on the influence of flow capacity and storativity. The key variables selected to significantly impact the desired output are highlighted below in Table **1**.

Table 1: Selected Uncertainty Attributes

Key reservoir uncertainties
Porosity of horizon 1 (PORO 1)
Porosity of horizon 2 (PORO 2)
Permeability of horizon 1 (PERM 1)
Permeability of horizon 2 (PERM 2)
Pay thickness of horizon 1 (H1)
Pay thickness of horizon 2 (H2)
Time of sidetrack (T)

Table 2: Range of Values for each Parameter

LEVEL	H1	H2	PORO1	PORO2	PERM1	PERM2	T
	(ft)	(ft)	(p.u)	(p.u)	(mD)	(mD)1	(yrs)
LOW CASE	5	17	0.2	0.223	100	100	0
HIGH CASE	50	178	0.353	0.288	1000	1000	9

2.3. Box-Behnken Response Surface Design

The values obtained are typical of Niger-Delta reservoirs. They were obtained by taking an average value of each of the properties of a shallow reservoir and a deeper reservoir on the same field. Since the Box-Behnken requires the input of low and high values to create a 3-level response surface design, the best and worst values of uncertain parameters were taken as shown below in Table **2**.

2.4. Experimental Runs

The values tabulated in Table **2** above for the uncertain attributes were plunged into an experimental design software to generate the factorial combinations which would mostly affect the output. This gave a total of 57 experimental runs representing all combinations of reservoir uncertain parameters, which saves time when compared to a three level full factorial design that would involve 2187 experimental runs. Since the number of attributes involved is high, the ED methodology simplified the experiment as much as possible reducing the necessary simulation runs.

The reservoir simulation runs designed by Box-Behnken were used to generate the 57 production histories using the corresponding properties of each run from the stipulated start of history to end of history. The time of sidetrack which is when the upper/shallow zone is open for production is also scheduled in the built models using the black oil simulator.

2.5. Economic Analysis

In order to generate the NPV proxy model using Box-Behnken design, estimates of the likely NPV for each combination of the uncertain variables are required. The NPV for each simulation run was computed mathematically using the generally accepted economic formula. This formula requires some economic parameters such as the price of crude oil, OPEX, CAPEX (i.e. the cost of drilling and completion activities for both zones depending on the time of sidetrack) etc (see Tables **3** and **4**, these estimates are typical of Asia). Since a monthly report was scheduled, the nominal interest rate method of discounting was used.

Table 3: Capital Expenditure Estimates

Activity	Cost $MM	
	Horizon 1	Horizon 2
Drilling	0.4	0.8
Completion	1.5	2.0

The NPV of a project is basically the measure of how much a future investment in a project is worth today. The equation below is a typical form of NPV computation that is used for this study.

Table 4: Economic Parameters

Required Parameter	Economic Cost/Value
Fixed Operating Rate	0.25% CAPEX/month
Oil Price	$75/bbl
Nominal discount rate	1.005%/month
Variable operating rate	$5/bbl

$$NPV(i,t)=\sum\frac{CF}{(1+i)^t}-\sum\frac{CI}{(1+i)^t}$$

where it *t* is time in years; *i*, discount rate; CF; cash-in-flow and CI capital investment for a given time.

2.6. Building Proxy Model

Using the simulated production results from the reservoir simulator, NPV is calculated from each experimental run and a proxy was generated for the four decision scenarios discussed above. The proxy model constitutes NPV as is a function of the inputs (uncertain reservoir parameters) for each of the scenarios. This equation was validated using a hypothetical Niger Delta data, the result section further presents the relationship between the time of sidetrack and the NPV of such a project for all assumed scenarios i.e. the failure or success of one or both zones.

Sub Section 2.6. Building Proxy Model: NPV = f (time, pay zone thickness – zone1, pay zone thickness – zone2, porosity zone1, porosity zone2, permeability zone1, permeability zone2)

3. RESULTS AND DISCUSSION

The 3D reservoir model for this study is made up of 5 layers of which the top 2 layers make up the shallow zone or Zone-1 of 2.5ft thickness while layers 4 and 5 make up the deeper zone or Zone-2 of total thickness of 48.75ft. Finally, Layer-3 is an impermeable zone of thickness, 50ft. Top depth for layer 1 is 5905.52ft; and Δx and Δy are uniform with 328.08ft × 328.08ft respectively. Fluid properties are oil and water density of $54.37lb_m/ft^3$ and $62.43lb_m/ft^3$ respectively at surface condition. Formation volume factor, compressibility and viscosity of water are 1.015rb/stb, $3.24\times10^{-6}psi^{-1}$ and 0.41cp respectively, while rock compressibility is 4×10^{-5}/bar at 300bar. The PVT of the dead oil is given in Figure **3** and the corresponding relative permeability for both productive zones is given in Figure **4**. Initialization of the model is given as 2755psia at 5905.5ft and 6235.6 at 3045.8psia, while initial water saturation for zone-1 and zone-2 are 0.33 and 0.30 respectively. The well (parent and secondary wellbores) starts from the centre of the reservoir at the top and is fully perforated at the entire length of contact with the grid blocks.

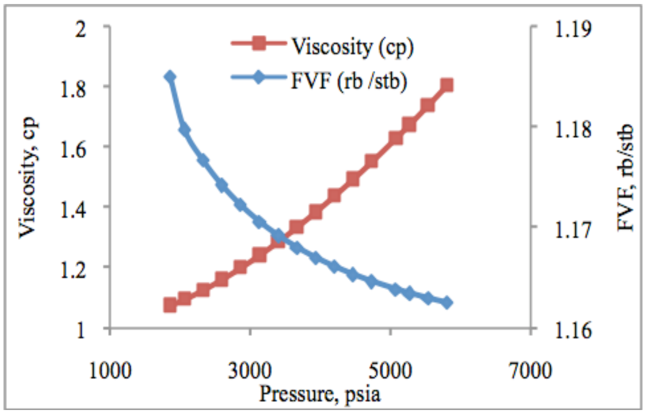


Figure 3: Formation volume factor and viscosity of oil.

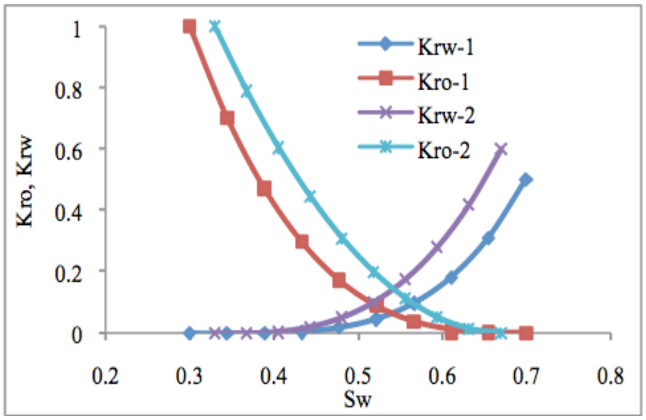


Figure 4: Relative permeability of zone 1 and zone 2.

In trying to evaluate the time to do a sidetrack /recompletion job, a proxy model which can be used to determine the profitability of alternative reservoir parameters was obtained. The four scenarios earlier discussed were used for analysis and the corresponding proxy equations derived. In order to validate these proxies (i.e. NPV equation of the four scenarios), they were applied to a hypothetical Niger Delta reservoir data. Sensitivity analysis on time of sidetrack was used to verify the equation and select the time having the maximum NPV as the proposed time to do the sidetrack job. A relationship was established between the PROXY NPV and time of sidetrack (all other factors constant) for the scenarios.

The reservoir simulations and their corresponding SIMULATION NPV and PROXY NPV of each decision scenario is discussed below.

Production from Zone-2 was scheduled to last for 10 years. After the application of ED method on the uncertain parameters, the 57 experimental runs with NPV calculated from simulation were used to build a proxy model. This model/equation contains all the seven uncertainties stated. For each scenario, the SIMULATION NPV and PROXY NPV values of other experimental runs that are not part of the 57 experimental runs used for the proxy model are used to validate the model.

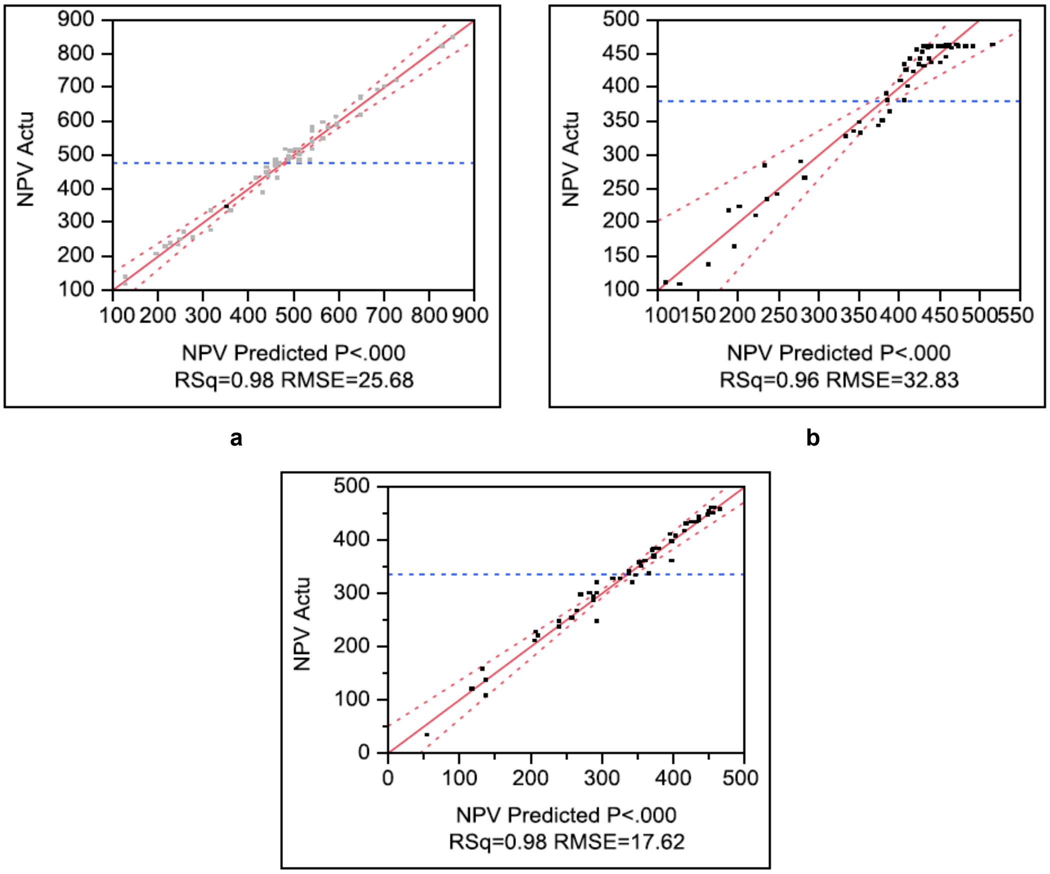
3.1. Proxy Model

Case 1: Assuming there are no chances of failure of neither one nor both of the horizons/zones after the recompletion/sidetrack job, then production will continue from Zone-2 when successful recompletion/sidetrack brings forth hydrocarbon from Zone-1 at the assumed time to recompletion/sidetrack as generated from the experimental run.

Equation 1 presented below is the proxy model obtained for case 1.

$$NPV_1 \text{ (million US\$)} = 478.68 + 159.02 * ((H2 - 97.5) / 80.5) + -65.54 * ((t - 5) / 5) + 65.14 * ((H1 - 27.5) / 22.5) + 24.62 * ((P1 - 0.2765) / 0.0765) + 55.104 * ((P2 - 0.2555) / 0.0325) + 14.32 * ((K1 - 550) / 450) + ((H2 - 97.5) / 80.5) * (((H2 - 97.5) / 80.5) * -73.85) + ((H2 - 97.5) / 80.5) * (((t - 5) / 5) * -32.71) + ((t - 5) / 5) * (((t - 5) / 5) * 77.75) + ((H2 - 97.5) / 80.5) * (((H1 - 27.5) / 22.5) * -28.501) + ((t - 5) / 5) * (((H1 - 27.5) / 22.5) * -53.283) + ((H1 - 27.5) / 22.5) * (((H1 - 27.5) / 22.5) * -25.04) + ((H2 - 97.5) / 80.5) * (((P1 - 0.2765) / 0.0765) * -56.10) + ((t - 5) / 5) * (((P1 - 0.2765) / 0.0765) * -59.19) + ((H1 - 27.5) / 22.5) * (((P1 - 0.2765) / 0.0765) * 28.82) + ((P1 - 0.2765) / 0.0765) * (((P1 - 0.2765) / 0.0765) * 21.28) + ((H2 - 97.5) / 80.5) * (((H2 - 97.5) / 80.5) * (((t - 5) / 5) * -78.93)) + ((H2 - 97.5) /80.5) * (((H2 - 97.5) / 80.5) * (((P1 - 0.2765) / 0.0765) * 37.62)) + ((H2 - 97.5) / 80.5) * (((t - 5) / 5) * (((P1 - 0.2765) / 0.0765) *51.74)) + ((H2 - 97.5) / 80.5) * (((H2 - 97.5) / 80.5) * (((P2 - 0.2555) / 0.0325) * -40.28)) + ((t - 5) / 5) * (((t - 5) / 5) * (((P2 - 0.2555) / 0.0325) * -28.98))$$

The R-Sq, P-value and root mean square error (RMSE) in Figure **5a** are all measures of the error



a b

c

Figure 5: a: NPV simulation data vs NPV proxy model - CASE 1. **b:** NPV simulation data vs NPV proxy model - CASE 2. **c:** NPV simulation data vs NPV proxy model - CASE 3.

variance. The plot shows a linear relationship. R-Squared value is the measure of how well the observed outcomes (actual SIMULATION NPV in this case) are replicated by the proxy model PROXY. R-squared value of 1 is a perfect fit. Since this plot has R-Sq of 0.98, this implies that the error margin between the NPV calculated by proxy model and actual method of calculating NPV is very small. One can say that the error involved in using the proxy to determine NPV of a project for CASE 1 is negligible.

P-value is a measure of the significance level of a parameter. Values of P< 0.05 indicate that results are statistically significant. Given that P<0.001 for this proxy equation, it is therefore considered significant. Root Mean Square Error (RMSE), measures the standard deviation from actual value. It is a measure of unexplainable random variation around the mean.

Case-2: See Equation 2 below, the proxy model obtained for case 2 based on the simulated production profile from the generated experimental data.

NPV_2 (million US$) = 430.234 + 19.92 * ((P2 - 0.2555) / 0.0325) + 16.37 * ((P1 - 0.2765) / 0.0765) + 126.85 * ((h2 - 97.5) / 80.5) +19.10 * ((h1 - 27.5) / 22.5) + 33.36* ((t - 5) / 5) +10.37 * ((K2 - 550) / 450) + -5.18 * ((K1 - 550) / 450) + ((((P2 - 0.2555) / 0.0325) * (P1 - 0.2765)) / 0.0765) * -11.74 + ((((P2 –0.2555) / 0.0325) * (h2 - 97.5)) / 80.5) * -4.45 + ((((P1 - 0.2765) /0.0765) * (h2 - 97.5)) / 80.5) * -28.77 + ((((P2 - 0.2555) / 0.0325) * (h1 -27.5)) / 22.5) * -10.42 + ((((P1 - 0.2765) / 0.0765) * (h1 - 27.5)) / 22.5) * 11.87 + ((((h2 - 97.5) / 80.5) * (h1 - 27.5)) / 22.5) * -25.95 + ((((P2 - 0.2555) / 0.0325) * (t - 5)) / 5) * -6.72 + ((((P1 - 0.2765) /0.0765) * (t - 5)) / 5) * -17.61 + ((((h2 - 97.5) / 80.5) * (t - 5))/ 5) * -9.95 + ((((h1 - 27.5) / 22.5) * (t - 5)) / 5) *2.82 + ((((P2 - 0.2555) / 0.0325) * (K2 - 550)) / 450) * -0.38+ ((((P1 - 0.2765) / 0.0765) * (K2 - 550)) / 450) * -1.23 + ((((h2 - 97.5) / 80.5) * (K2 - 550)) / 450) * -19.65 + ((((h1 - 27.5) / 22.5) * (K2 - 550)) / 450) * 12.139 + ((((t - 5) / 5) * (K2 - 550)) / 450) * 1.15 + ((((P2 - 0.2555) / 0.0325) * (K1 - 550)) / 450) * -0.096 + ((((P1 - 0.2765) / 0.0765) * (K1 - 550)) / 450) * 1.897 + ((((h2 - 97.5) / 80.5) * (K1 - 550)) / 450) * 1.56 + ((((h1 - 27.5) / 22.5)* (K1 - 550)) / 450) * 2.14 + ((((t - 5) / 5) * (K1 - 550)) / 450) *9.42 + ((((K2 - 550) / 450) * (K1 - 550)) / 450) * -3.151+ ((((P2 - 0.2555) / 0.0325) * (P2 - 0.2555)) / 0.0325) * -9.11+ ((((P1 -0.2765) / 0.0765) * (P1 - 0.2765)) / 0.0765) * 3.96 + ((((h2 - 97.5) / 80.5) * (h2 - 97.5)) / 80.5) * -85.59 + ((((h1 - 27.5) / 22.5) * (h1 - 27.5)) / 22.5) * -16.33 + ((((t - 5) / 5) * (t - 5)) / 5) * -7.709+ ((((K2 - 550) / 450) * (K2 - 550)) / 450) * -10.52 + ((((K1 - 550) / 450) * (K1 - 550)) / 450) * 9.33

The R-Sq of the proxy model for Case 2 is less than that of Case 1 as indicated in Figure **5b**. However the P-value is significant.

Case-3: Below, Equation 3 is the proxy model obtained for case 3. The RSq (see Figure **5c**) for this case is similar with that of Case-1 with the same predictive capability.

NPV_3 (million US$) = 361.79 + 85.64 * ((h2 - 97.5) / 80.5) + 97.30 * ((t - 5) / 5) + 53.39 * ((h1 - 27.5) / 22.5) + 12.29 * ((P1 -0.2765) / 0.0765) + 18.397* ((K1 - 550) / 450) + 15.35* ((P2 -0.2555) / 0.0325) + ((h2 - 97.5) / 80.5) * (((h2 - 97.5) / 80.5) * -45.17) + ((h2 - 97.5) / 80.5) * (((t - 5) / 5) * 32.52) + ((h2 - 97.5) / 80.5) * (((h1 - 27.5) / 22.5) * -23.757125) + ((t - 5) / 5) * (((h1 - 27.5) / 22.5) * -54.16) + ((h1 - 27.5) / 22.5) * (((h1 - 27.5) /22.5) * -20.124) + ((h2 - 97.5) /80.5) * (((P1 - 0.2765) / 0.0765) *-36.57) + ((t - 5) / 5) * (((P1 - 0.2765) / 0.0765) * -35.16) + ((h1 - 27.5) / 22.5) * (((P1 - 0.2765) / 0.0765) * 17.27) + ((P1 - 0.2765) /0.0765) * (((P1 - 0.2765) / 0.0765) * 12.053) + ((h2 - 97.5) / 80.5)* (((K1 - 550) / 450) * 19.1795) + ((t - 5) / 5) * (((K1 - 550) / 450) * -21.00) + ((h2 - 97.5) / 80.5) * (((h2 - 97.5) / 80.5) * (((t - 5) / 5) * -79.55)) + ((t - 5) / 5) * (((h1 - 27.5) / 22.5) * (((h1 - 27.5) /22.5) * 36.79)) + ((h2 - 97.5) / 80.5) * (((h2 - 97.5) / 80.5) * (((P1 - 0.2765) / 0.0765) * 30.42)) + ((h2 - 97.5) / 80.5) * (((t - 5) / 5) * (((P1 - 0.2765) / 0.0765) * 27.72))

Case-4: Below, Equation 4 is the proxy model obtained for case 4.

NPV_4 (million US$) = 296.20 + 228.97* ((t - 5) / 5) + 37.97 * ((h2 - 97.5) / 80.5) +0.014 * ((K2 - 550) / 450) + -0.039 * ((h1 - 27.5) /22.5) + -0.0149 * ((P1 - 0.2765) / 0.0765) + 0.645 * ((P2 - 0.2555) / 0.0325) + ((((t - 5) / 5) * (t - 5)) / 5) * -73.04+ ((((t - 5) / 5) * (h2 - 97.5)) / 80.5) * 59.88 + ((((h2 - 97.5) / 80.5) *(h2 - 97.5)) / 80.5) * -52.97 + ((((t - 5) / 5) * (K2 - 550)) / 450)* 2.70+((((h2 - 97.5) / 80.5) * (K2 - 550)) / 450) * -21.57 +((((K2 - 550) / 450) * (K2 - 550)) / 450) * -7.31+ ((((t - 5) / 5) * (h1 - 27.5)) / 22.5) * 1.49+ ((((h2 - 97.5) / 80.5) * (h1 - 27.5)) / 22.5) * -21.20 + ((((K2 - 550) / 450) * (h1 - 27.5)) / 22.5) * 12.59 + ((((h1 - 27.5) / 22.5) * (h1 - 27.5)) / 22.5) * -6.83 + ((((t - 5) / 5) * (P1 - 0.2765)) / 0.0765) * 9.63+ ((((h2 - 97.5) / 80.5) * (P1 - 0.2765)) / 0.0765) * -7.61 + ((((P1 - 0.2765) / 0.0765) * (P1 -0.2765)) / 0.0765) * -0.40 + ((((h2 - 97.5) / 80.5) * (P2 - 0.2555)) / 0.0325) * -3.97 + ((((P2 - 0.2555) / 0.0325) * (P2 - 0.2555)) / 0.0325) *7.28 + ((((K1 - 550) / 450) * (K1 - 550)) / 450) * 7.69+((((((t - 5) / 5) * (t - 5)) / 5) * (h2 - 97.5)) / 80.5) * 21.79+ ((((((t - 5) / 5) * (h2 - 97.5)) /

80.5) * (h2 - 97.5)) / 80.5) * -53.78+ ((((((t - 5) / 5) * (t - 5)) / 5) * (K2 - 550)) / 450) * 2.72 + ((((((h2 - 97.5) / 80.5) * (h2 - 97.5)) / 80.5) * (K2 - 550)) / 450) * 21.55 + ((((((h2 - 97.5) / 80.5) * (K2 - 550)) / 450) * (K2 - 550)) / 450) *29.11 + ((((((t - 5) / 5) * (t - 5)) / 5) * (h1 - 27.5)) / 22.5) *1.48 + ((((((h2 - 97.5) / 80.5) * (h2 - 97.5)) / 80.5) * (h1 - 27.5))/ 22.5) * 21.24 + ((((((h2 - 97.5) / 80.5) * (K2 - 550)) / 450) * (h1 -27.5)) / 22.5) * -12.59 + ((((((t - 5) / 5) * (t - 5)) / 5) * (P1 - 0.2765)) / 0.0765) * 9.53 + ((((((t - 5) / 5) * (h2 - 97.5)) / 80.5) * (P1 -0.2765)) / 0.0765) * -7.73 + ((((((h2 - 97.5) / 80.5) * (h2 - 97.5)) / 80.5) * (P2 - 0.2555)) / 0.0325) * 3.33

Table 5: Summary of Fit for PROXY MODEL for Case 4

Response NPV	
Summary of Fit	
RSquare	0.999952
RSquare Adj	0.999883
Root Mean Square Error	1.59501
Mean of Response	239.9741
Observations (or Sum Wgts)	57

The proxy model for this case has the highest correlation to the real scenario of experimental runs used to set up the model as indicated in Table **5**.

3.2. Proxy Model Validation

To validate the proxy models, a test case with both reservoirs (Zone-1 and Zone-2) typical of a Niger delta field were used. The assumption is, operation begins 1/1/2001 and ends 1/1/2011. The typical well drilling and completion costs, variable operating costs per well, fixed operating cost etc. are the same as stated earlier in Tables **3** and **4**. While the reservoir data to validate the proxy model is as presented in Table **6**.

Production simulation based on the experimental runs of the data in Table **7** was conducted for sidetrack at time t= 0 to t=9years after production from Zone-1 in the black oil simulator.

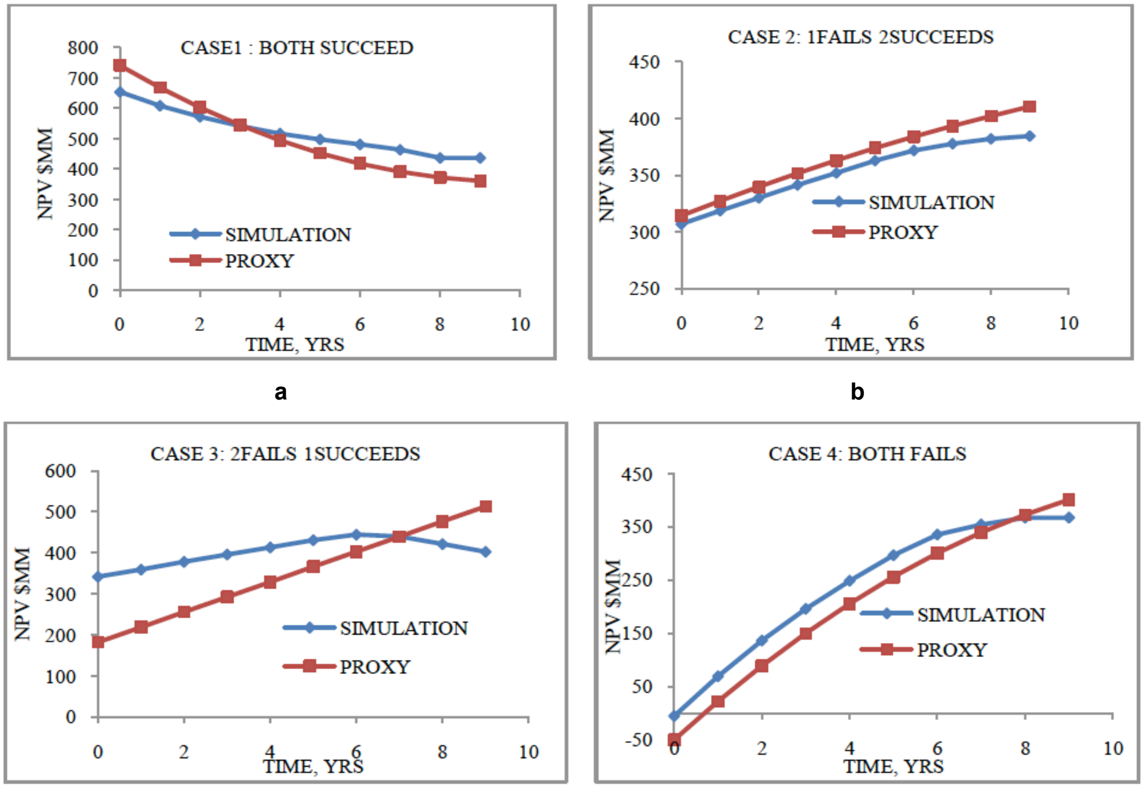
Simply put, all the reservoir properties are kept constant and sensitivity analysis are carried out to determine the effect of sidetrack time on production rate which in turn affects NPV. Evaluations for success or failure of one or both horizons are made based on the four scenarios previously stated. Application of the proxy models (Equations 1 to 4) generated were used to evaluate the profitability of the test case should any of the four situations happen. The result obtained is shown in Figures **6a** to **6d** for all the scenarios. These Figures show plots of proxy-model-NPV and simulation-NPV.

Table 6: Hypothetical Reservoir Data to Validate PROXY Models

Layer	Top of sand (ft)	Net thickness h (ft)	Porosity	NTG	Sw	Permeability (K, mD)
Zone-1	9243	83	0.263	0.89	0.140	800
Zone-2	9971	106	0.234	0.84	0.459	500

Table 7: Experimental Runs (Varying time while Reservoir Properties are kept Constant)

T, yrs	P2 (p.u)	P1 (p.u)	h2 (ft)	h1 (ft)	K2(mD)	K1(mD)
0	0.234	0.265	106	83	500	800
1	0.234	0.265	106	83	500	800
2	0.234	0.265	106	83	500	800
3	0.234	0.265	106	83	500	800
4	0.234	0.265	106	83	500	800
5	0.234	0.265	106	83	500	800
6	0.234	0.265	106	83	500	800
7	0.234	0.265	106	83	500	800
8	0.234	0.265	106	83	500	800
9	0.234	0.265	106	83	500	800



a b

c d

Figure 6: a: Graph of NPV $MM vs. Time, yrs for Case-1. **b:** Graph of NPV $MM vs. Time, yrs for CASE 2. **c:** Graph of NPV $MM vs. Time, yrs for CASE 3. **d:** Graph of NPV $MM vs. Time, yrs for CASE 4.

For three of the four scenarios, it would be observed that the proxy model is a quadratic function of time provided all other reservoir properties remain the same. Proxy for Case-3 on the other hand is a linear function of time.

Case-1: If both horizons will keep producing after sidetrack/recompletion job; it implies both wells, that is the primary and secondary wellbore can be used to capture hydrocarbon which in turn yields higher oil production. In such a case, Figure **6a** clearly depicts, that the earlier a sidetrack job is done the higher the NPV.

Case-2: If only Zone-2 will keep producing after sidetrack/recompletion job; it implies that only the main/parent/primary wellbore will be used to capture hydrocarbon and sidetrack operation may impair production from primary wellbore. In such a case, the Figure **6b** illustrates that higher NPV would be obtained by attempting the sidetrack job in later life of the field.

Case-3: If only Zone-1 (higher horizon) will keep producing after sidetrack/recompletion job; it implies that only sidetrack well or secondary wellbore will be used to capture hydrocarbon and sidetrack operation causes a complete shutdown of production from primary wellbore. In such a case, the Figure **6c** illustrates that higher NPV would be obtained by attempting the sidetrack job in later life of the field.

Case-4: If both zones stop producing after sidetrack/recompletion job; it implies both wells cannot be used to recover hydrocarbon any more which in turn gives no production. It is therefore, cost effective to recover producible hydrocarbons with primary wellbore before attempting the sidetrack job. For such a case, the graph below clearly depicts that sidetracking at the later life of the field gives higher NPV.

It cannot be said for sure which of the scenario one would encounter, therefore one cannot rely on doing a sidetrack in the early life of the field based on the results of Case-1 or at the later life of the field based on the results of Case-2 and Case-4. Due to the uncertainties associated with doing a sidetrack/recompletion job, one cannot ascertain when it will be most profitable to do the sidetrack job. Therefore, an expected mean of the four cases must be carried out to determine on a plot of NPV against time (Figures **7** and **8** shows the NPV of all cases and EMV from the numerical simulation data and proxy model), the peak NPV. The corresponding time to this NPV is the optimum time to do the sidetrack/recompletion. Figure **9** shows just the EMV of NPV of all the cases put together based on probability of success/failure of each case. It is quite glaring that peak EMV or risked NPV for obtaining the optimal sidetrack time is not feasible from the results of the proxy model used in validating the study. This is due to the poor correlation of Case-3 as shown in Figure **8** and partly as seen for the full experimental results presented in Figure **5b** for Case-2.

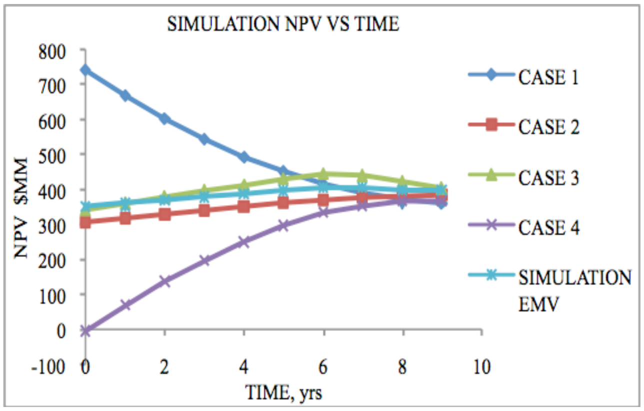


Figure 7: Graph of SIMULATION NPV $MM vs. Time, yrs.

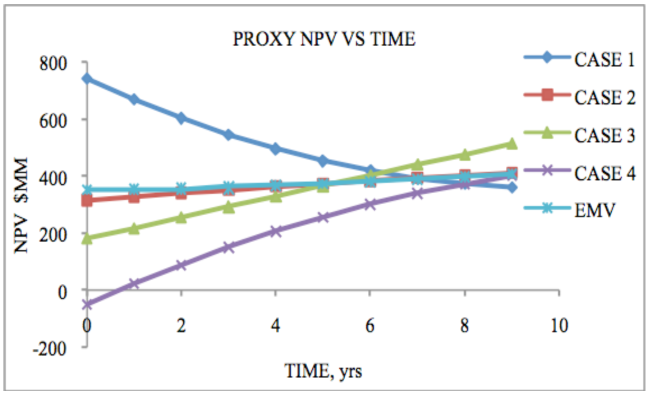


Figure 8: Graph of PROXY NPV $MM vs. Time, yrs.

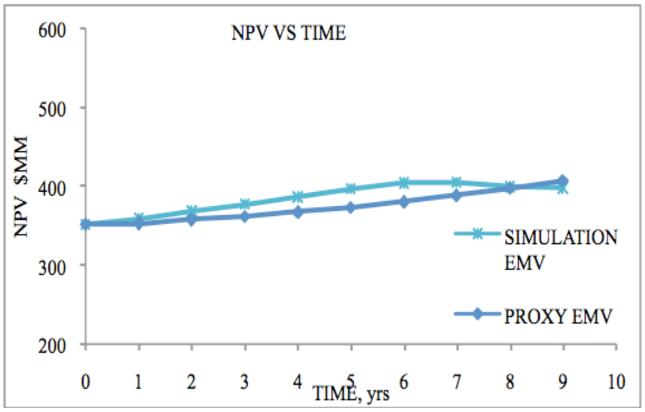


Figure 9: Graph of NPV $MM vs. Time, yrs.

The seemingly poor depiction of the NPV by simulation from the proxy model for Case-3 may be highly connected to the experimental runs used for validation of the proxy models. Values of initial water saturation for both zones as used for validation is different from that of the 57 experimental runs used to develop the proxy model. On Table **6**, the initial water saturation of 0.140 and 0.459 for Zone-1 and Zone-2 respectively were used for the validation while 0.33 and 0.30 stated at the onset of this section on results and discussion was applied to the simulation model that generated the 57 experimental runs. This may mean more movable oil for Zone-1. Hence, it has a higher influence on Case-3 than any other case as used for the simulation model that generated the production profile for the validation database.

4. CONCLUSION

The proxy model creates a means of computing net present value (NPV) of the different case scenarios that are likely to occur. This incorporates reservoir rock uncertainty and time to sidetrack or recomplete. Ultimately the decision to sidetrack or recomplete is a collective approach of the combination of the independent cases by the consideration of the probability of success by the expected monetary value of which must be optimized for a realistic optimal sidetrack time. Evaluation of this time by the proxy model requires further improvement as three out of the four individual case scenarios were quite reasonable. These results suggest a full factorial design and/or increase in the number of levels of the experimental design to adequately capture the inflexion point of the EMV curve and the NPV of each case scenario.

REFERENCES

[1] Lerche I, Noeth S. Economics of Petroleum Production. A Compendium, Volume 1: Profit and Risk. 1st ed. Multi-Science Publishing Co: Brentwood, Essex 2004.

[2] Lerche I, Mudford B. Risk Evaluation for Recompletion and Sidetrack Developments in Oil Fields, SPE Paper 71418. SPE Annual Technical Conference and Exhibition. New Orleans 2001. http://dx.doi.org/10.2118/71418-MS

[3] Orodu OD, Tang Z, Anawe PAL. Sidetrack and Recompletion Risk Evaluation – Waterflooded Reservoir. Journal of Petroleum Science and Engineering 2011; 78 (3-4): 705-718. http://dx.doi.org/10.1016/j.petrol.2011.08.015

[4] Orodu OD, Tang Z. Risk Evaluation Production-Injection Recompletion and Sidetrack, Energy Exploration and Exploitation 2011; 29 (3): 235-250. http://dx.doi.org/10.1260/0144-5987.29.3.235

[5] Onyeukwu C, Peacock A, Oshorode C, Onwuchekwa C, Adekoya O. Application of Experimental Design to unravel sub-surface complexity in Gravity assisted Water Injection Project in the Niger Delta. SPE 163006. SPE Annual Technical Conference and Exhibition, Abuja, Nigeria 2012.

[6] Spokes J, Ovuede E, Nahara G, Haga, O. Application of Experimental Design in Selecting a Development Plan for the Agbami Field. OTC 16994. Offshore Technology Conference held in Houston, Texas, U.S.A 2004.

[7] Okenyi K, Omeke J. Well Performance Optimization Using Experimental Design Approach. SPE 162973. SPE Annual Technical Conference and Exhibition. Abuja, Nigeria 2012.

[8] Venkataraman R. Application of Experimental Design to Quantify Uncertainty in Production Profiles. SPE 59422. SPE Annual Technical Conference and Exhibition. held in Yokohama, Japan 2000.

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