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Optimization of casing string placement in the presence of geological uncertainty in oil wells: Offshore oilfield case studies

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ABSTRACT

Designs of petroleum wells involve many activities and technical areas. These areas cover various engineering aspects and can be solved with contributions from applied mathematics. This paper presents a new casing point optimization methodology. A novel mathematical formulation and procedure for optimization of casing string placement including geological uncertainty is developed. Determination of optimal casing point locations is a challenging task because many engineering and geologic variables affecting each other and are often uncertain and nonlinear. In this paper, the casing string placement problem was formulated as the optimization function under uncertainty. The geological uncertainty is modeled with considering different scenarios of geology. The Lingo software was used as the optimization tool. In order to find the optimum decisions for different risk attitudes, a utility framework that enables the assessment of the uncertainty of the casing string placement decisions is used. A large case study was undertaken to demonstrate the value of considering uncertainty in drilling decision-making. Numerical simulation was carried out with this selected case study to find optimum points under different risk attitudes in each section of drilling for different wells. Finally we show the application of that methodology has better performance to cost savings at least of 2.4–15.2% in the important drilling management.

1. Introduction

Cost efficiency is a strong driver in the petroleum industry. From this perspective drilling optimization is therefore of interest. Optimal placement of the casing points provides a significant potential for cost savings. Determining optimal locations of casing point for wells in oil and gas reservoirs have a potentially high economic impact. Finding these optima depends on a complex combination of geological, petrophysical, flow regimes, and economical parameters. Uncertainty exists at every step of the modeling, from the measurement and processing of raw data (seismics, well logs, geology, etc.). However, the decisions about the development plan are made in the presence of many sources of uncertainty (da Cruz, 2000; Ballin et al., 1993). Geological uncertainty about the reservoir geometry and petrophysical properties, is one of the uncertainties that could influence the CPS (casing point selection) problem decisions significantly. This research introduces a so called Full approach to incorporate the geological uncertainty in the selection of the best casing point scenario among a set of predefined scenarios.

1.1. Literature review

The drilling problems we consider have many feasible but not optimal solutions, which would all lead to a suboptimal plan. The existence of and the need to avoid these local optima led us to apply stochastic optimization techniques. One of the most significant stochastic optimization techniques will be presented in this paper. In the petroleum industry, the need to consider uncertainty in decision-making was identified already in the 1930's. Probability theory, decision trees, Monte Carlo simulation and economic models were introduced for decision analysis in exploration and in field development, for cases where the uncertainty was characterized by probability distributions of the parameters involved.

Decision analysis tools to quantify and manage risk have been utilized across a wide range of industries (Chacko, 1993). Specifically the utility framework provides an established framework that enables the quantification and management of uncertainty

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Nomenclature

B_{ijkl}	drilling cost per foot for bit type j in rotary speed $k$and bit weight l in section i of well
CPS	Casing Point Selection
CF_t	Revenue of well with trajectory i during the considered period
C_{ijk}	Casing cost per foot for casing grade j with weight coupling k in section i of well
D_{KOP}	True vertical depth of kick off point
D_1	First Length Segments for Build
D_3	Length Segments for Drop
D_5	Second Length Segments for Build
D_2	First Length Segments for Hold
D_4	Second Length Segments for Hold
INC	net cash inflow during the period
i	Discount rate
π_i	Utility value
$L_i^{Drilling}$	Length of drilling in section i
L_i^{Casing}	Length of casing in section i
MD	Measured depth
M_i	Upper Bound of Casing Depth in i Section
RPM	Revolution per minutes, the velocity of rotation of the bit
WOB	Weight on bit, the total weight applied on the bit to drill
RPM_i^{Min}	Lower Bound of rotary speed in section i
RPM_i^{Max}	Upper Bound of rotary speed in section i
RPM_k	Rotary speed in k state of drilling operation in section $i$of well
R_1	Radius of first build segment
R_2	Radius of hold segment
R_3	Radius of second build segment
$S.\ F_{ijk}^{Tensile}$	Tensile safety factor for casing grade j with weight coupling k in section i of well
$S.\ F_{ijk}^{Collapse}$	Collapse safety factor for casing grade $j$with weight coupling k in section i of well
$S.\ F_{ijk}^{Burst}$	Burst safety factor for casing grade j with weight coupling k in section i of well
$S.\ F_i^{Minumum\ Tensile}$	Minimum safety factor for tension in section i in well
$S.\ F_i^{Minumum\ Burst}$	Minimum safety factor for burst in section i in well
$S.\ F_i^{Minumum\ Collaps}$	Minimum safety factor for collapse in section i in well
TC	total cost
W_i	Bit weight in i state of drilling operation in section $i$of well
W_i^{Min}	Lower Bound of weight on bit in section i
W_i^{Max}	Upper Bound of weight on bit in section i
X_{ijkl}	1 if we select rotary speed in k state and bit weight in l state for bite type j in section i of well, otherwise is 0
Y_{ij}	1 if we select casing type j in section i with coupling type k
Z	Total Cost
ϕ_1, ϕ_2, ϕ_3	First, second, and third hold angles, deg
θ_1	Azimuth angle at kick off point, deg
θ_2	Azimuth angle at end of first build portion, deg
θ_3	Azimuth angle at end of first hold section, deg
θ_4	Azimuth angle at end of second build or drop portion, deg
θ_5	Azimuth angle at end of second hold section, deg
θ_6	Azimuth angle at end of third build portion, deg

(DeGroot, 1970). The utility framework is intuitive and very useful since it honors the fact that every decision maker who is given options with probabilistic outcomes, will act according to their own risk attitudes which may be very different. The utility theory provides the framework and the tools to quantify the rather abstract notion of risk attitude and helps in making decisions in the presence of uncertainty (Holloway, 1979). There have been several applications of decision analysis tools in the petroleum industry as well (Simpson et al., 2000; Thankur, 1995; Jonkman et al., 2000; Erdogan et al., 2001; Sarich, 2001). These applications of decision analysis tools were mostly used during exploration and initial development stages of reservoirs (Jonkman et al., 2000). Application of the decision theory framework coupled with full field-scale numerical simulation has not been common mainly due to computational issues and the lack of involvement of petroleum engineering and management. The problem was also formulated as the optimization of a random function. The GA is known to be able to cope with random functions and there have been applications to problems in industries other than petroleum engineering (Goldberg, 1989).

2. Problem statement

Reference is made to Aadnoy (1999) for description and functions of casing strings. In order to reach the reservoir or the target, a number of casing strings are usually required. The purpose of each string is to seal off the formations above to allow the next hole section to be drilled. After the casing is installed it is cemented to provide pressure integrity. A short description of each casing type follows.

- Conductor Pipe: this is the first casing string to be run, and consequently has the largest diameter. It is generally set approximately 50–100 m below the ground level or sea bed. Its function is to seal off unconsolidated formations at shallow depth.
- Surface Casing: the surface casing is run after the conductor and is generally set 200–800 m below the ground level or the seabed. The main functions of the surface casing are to seal off any fresh water sands, and support the wellhead and BOP equipment.
- Intermediate Casing: the intermediate casing is set to seal off or protect some problem area, and provide safety for further drilling.
- Production Casing: this serves to isolate the hydrocarbons during production. It is the protective housing for the pumps and other production equipment.
- Liner String: a liner is a short tubular at the bottom of a casing. The liner is not tied back to the wellhead.
- Production Tubing: this is the transport conduit for the hydrocarbons from the reservoir.

The size and setting depth of these casing strings depends almost entirely on the geological and pore pressure conditions in the particular location in which the well is being drilled (Aadnoy, 1991). Some typical casing string configurations used throughout the world are shown in Fig. 1.

In early exploration phases, the geological settings of the domain under study are poorly known. From just one or very few