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Influence of Well Control Management in Oil Field Development Phase

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"Although simultaneous optimization of the design (G1) and well control (G2) variables includes the entire solution space, it requires greater computational effort and may provide similar or even lower economic returns than hierarchical optimization."

Introduction

In order to reduce oil field development economic risks it is important to optimize two main groups of variables (GASPAR *et al.*, 2016): the design (G1) and control variables (G2). The G1 and G2 can be optimized hierarchically, as two subproblems, or simultaneously.

Simultaneous optimization includes all search space but can be computationally expensive, especially if uncertainties are considered. Hierarchical optimization is one way to reduce this computational effort, although it may yield suboptimal economic results because this process does not cover all solution space.

Regarding the economic return and the number of simulations required, it is important to verify if it is necessary to optimize G1 and G2 simultaneous or if it can be conducted hierarchically because sometimes simultaneous approach leads to similar or even lower outcome (e.g., algorithm is trapped in a local maximum point) requiring a much higher computational cost (Humphries *et al.*, 2013).

In this edition of UNISIM ON-LINE, we describe the relevance of G2 optimization under geological uncertainties during the development phase of the field for different situations (Santos, 2017) so that we divided this work in parts. In Part I, we investigate whether G2 optimization may change the selection of G1 variables previously optimized and whether the hierarchical process can be performed. In Part II, we analyze G2 influence on the economic return in two different cases from Part I. In Part IIa, we verify G2 impacts on the economic return for a restricted platform. In IIb, besides the platform restriction, we also consider lower oil sales price and higher water production costs. The goal of Part II is to identify which situations need a more thorough evaluation of G2.

Methodology

The methodology consists of performing five procedures described below for G2 optimization based on well reactive, proactive and mixed control to maximize Expected Monetary Value (EMV) of the project.

- Procedure P1 is a BHP proactive control along the time for problematic producer wells selected by one of the following conditions: (P1a) the lowest average time of water breakthrough in the representative models (RM); (P1b) well with the lowest average shut-in time by water cut (WCUT) in the RM; and (P1c) well with the highest average cumulative water production in the RM.
- P2 is based on a short-term reactive control to reallocate producers rate prioritizing those with lower WCUT. It is done by INGUIDE function from IMEX.
- P3 is a long-term proactive control to redistribute rates among producers and injectors wells through IMEX GUIDE function.
- In P4, we perform a long-term reactive control to determine the optimum time for closing wells.
- P5 combines the two procedures that provided the best EMV, that is; to apply P4 to the best result obtained with P3.

We use the designed exploration and controlled evolution (DECE) from CMOST to optimize procedures P1, P3 and P4. The five aforementioned procedures are applied to Part I of this work. For Part II we only use P5.

Application

We performed G2 optimization under uncertainties to the simulation model, named UNISIM-I-D, which represents Namorado field located in Brazil. UNISIM-I-D is a three-dimensional model constituted by 81×58×20 cells of 100×100×8m each and 36,739 active cells. The field's life cycle is 10,957 days including 1,491 days of four vertical wells production data. This field is subject to waterflood to maintain reservoir pressures over the bubble point pressure.

Nine representative models (RM) of the UNISIM-I-D selected by Schiozer *et al.* (2015) to represent the geological and technical uncertainties are used in Part I, IIa and IIb. For Part I and IIa, we consider economic uncertainties through three scenarios. In Part IIb, we adopt a more pessimistic economic scenario, which considers lower sales prices and higher water production costs.

In Part I, we use two previously optimized strategies for G1with G2 controlled in a simplified way that provided the best EMV in Schiozer *et al.* (2015), called E2-G1 and E9-G1. Part IIa and IIb use G1 strategy, which achieved the best EMV after G2 optimization in the previous step, reducing the platform capacity by half. The strategy for Part IIa is called E9'-G1. In Part IIb, the original strategy is named E9'-G1M due to the different economic scenario used in this case.

Results

The following topics show the results explanation for Part I, IIa and IIb. After G2 optimization, the strategies are named Ex-Py, where "x" identifies the strategy (2, 9 or 9') and "y" correspond to G2 optimization procedure.

Part I

E2-P1 and E9-P1

Although we have achieved the secondary goal of P1 – delay the water breakthrough (P1a), postpone the well shut-in time (P1b), and decrease the water production (P1c) for the modified wells – this procedure did not produce good results since the EMV declined in all tests (P1a, P1b and P1c).

It must be highlighted that DECE was not efficient for BHP proactive control over time, since the algorithm got trapped in a local maximum point. As the procedure P1 did not increase original strategies EMV, it should not be applied neither for E2-G1 nor E9-G1.

E2-P2 and E9-P2

Procedure P2 consists of applying INGUIDE control rule to prioritize production in wells with higher WCUT. This control works only when the platform reaches a specific production parameter, such as liquid (QL) and water production (QW) rates. The aforementioned situation happens shortly and for few models both for E2-G1 and E9-G1, as a result, EMV percentage increase was negligible using E2-P2 and E9-P2 strategies, but this procedure increased NPV in all models that INGUIDE was activated.

E2-P3 and E9-P3

Similarly to INGUIDE, GUIDE operates only when platforms constrain QL or QW or water injection rate (QWINJ) as injectors are also controlled in P3. Again, EMV increase was minimal compared to the original strategies and NPV rises for all RM where GUIDE performs. The GUIDE control rule provides better EMV results in comparison to INGUIDE and may be promising for a more restricted platform.

E2-P4 and E9-P4

Applying P4 to define the optimum producers and injectors shut-in time, EMV improved 11.12 (0.63%) and 37.20 (2.12%) millions dollars (USD) in relation to E2-G1 and E9-G1, respectively. Figure 1 shows the economic risk curve from the NPV differences between the P4 and the original strategies. As we observe, this procedure yield a greater NPV for all RM and the improvement depends on the scenario (RM) that best represents the field. In addition, EMV gains resulting from G2 optimizations rely on G1 strategy. For instance, G2 control was slightly more important to E9-G1 than to E2-G1 strategy.

E2-P5 and E9-P5

The goal of this procedure is to improve EMV and to verify how it was underestimated without G2 control. P5 provided the best EMV among all procedures. It was shown that EMV from E2-G1 and E9-G1 were undervalued about 11.25 (0.64%) and 37.70 (2.15%) millions USD, respectively. Moreover, E9-G1 became the best G1 option after G2 optimization, since its EMV overcame 0.57% (10.21 million USD) E2-P5. However, this percentage gain is included in the evaluation of uncertainties error, suggesting that G1 were well optimized in previous work and that G2 controlled automatically by the simulator is enough to define G1 strategy for Part I.

The low percentage increase of EMV also indicates a poor correlation between G1 and G2 for Part I, allowing conduct G1 and G2 optimization hierarchically for this situation.

We also demonstrate that G2 optimization must be carri-

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"G1 and G2 simultaneous optimization is not justified in waterflood projects to a non-restricted platform where G1 was previously optimized.
This statement cannot be generalized to other cases."

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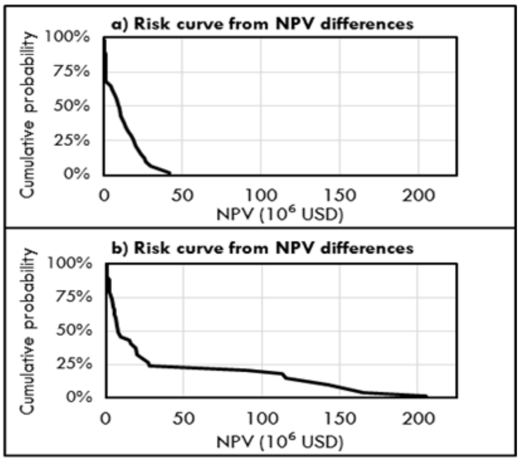

***Figure 1:** Risk curve from NPV diferences between: (a) E2-P4 and E2-G1, and (b) E9-P4 and E9-G1.*

ed out at least during field's management phase because increments on EMV are added without costs, and considerable gains can be achieved (207 million USD or 7.67% according to the scenario) depending on the model that best represent the oil field.

It should be noted that although P5 provided the highest increase in EMV, the percentage difference between the EMV obtained with P5 and P4 was insignificant. Therefore, in cases similar to those of Part I, we should employ just P4, since less computational effort is required.

Part IIa (E9'-P5)

We performed procedure P5 to Part II, which consists of determining the optimum wells shut-in time (P4) for the best GUIDE configuration (P3). In Part II, GUIDE works for most of the models and for longer periods. As a result, strategy E9'-P3 increases EMV in 48.8 million USD (3.35%) for Part IIa, indicating GUIDE effectiveness to a restricted platform and when G1 are not previously optimized. Subsequently, we apply procedure P5, which provided 110 million USD (7.54%) gain in the EMV. NPV increased for all models resulting from Np improvement and Wp reduction (Figure 2). For some models, we achieved a substantial NPV gain, greater than 275 million USD or 23.33% for different RM. EMV increases on Part IIa point out that G2 can somehow mitigate a set of G1 variables considered suboptimum. Moreover, the greater EMV percentage improvement for Part IIa when compared with Part I shows more flexibility to control G2 variables when platform operates under restriction.

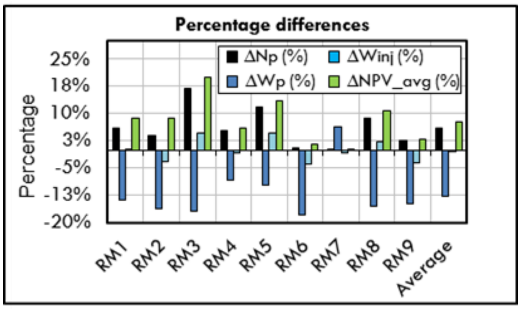

***Figure 2:** Percentage variation of Np, Wp, Winj and of NPV average between E9'-P3 and E9'-G1.*

Part IIb (E9'-P5M)

Appling E9'-P3M for Part IIb, EMV improves in 33.61 million USD (17.50%) in relation to E9'-G1M and, after applying E9'-P5M, EMV increases over 64 million USD (33.52%). Furthermore, NPV became positive for an unviable economic scenario (Figure 3). Part IIb showed that G2 may be fundamental to reduce risks and to the decision-making process.

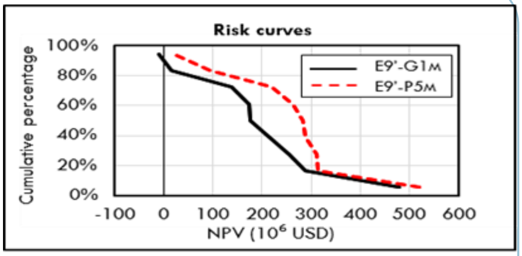

***Figure 3:** Comparison between E9'-P5M and E9'-G1M economic risk curves.*

Conclusion

Although optimizing control variables (G2) for Part I modify the project variables (G1) strategy selection, the percentage gain is small compared to the uncertainties evaluation error showing no great dependence between G1 and G2 for Part I. We can conclude that G1 and G2 may be optimized hierarchically because this process allows us to reduce computational effort. Due to the small percentage increase after G2 optimization in relation to E2-G1 and E9-G1, we assert that G1 was well optimized in a previous work and the automatic simulator well control rule is a reasonable analysis to select production strategy during oil field development phase for Part I.

From Part IIa, we conclude that G2 optimization enables to reduce economic losses from a less effective G1 configuration. The greater EMV gains for Part IIa compared with Part I indicates that platform operating under its limits give us more flexibility to control G2.

In Part IIb, we got a significant improvement in EMV (34%), besides that we convert an unviable economic scenario into a profitable one, highlighting the need to consider economic uncertainties as well as geological ones.

Our results also suggest that G1 and G2 relation depends on the case studied; for instance, a simultaneous approach may be mandatory, even requiring a higher computational effort, for a restricted platform under a more pessimistic economic scenario (as in Part IIb).

All studied cases show the importance of optimizing G2 at least during the management phase in order to increase the EMV without additional cost.

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