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Year 19, Number 7 | 161st edition | December, 2024

> *"The focus is to reduce computational budget of reservoir production strategy analysis by properly calibrating and selecting optimization methods."*

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Optimization technique selection and calibration for petroleum field management

Leandro Henschel Danes

Introduction

Numerical simulations are the most used method for forecasting an oil reservoir production and field's economic returns. Scheming a field's life-cycle development and management strategies concerns numerous parameters and requires many simulations to be used on optimizations to determine the best strategies to maximize a field's utility for the global economy.

When conducting oil production optimizations, multidimensional, non-convex search spaces are usually found. These complexities can either compromise the search quality or demand excessive simulations, potentially failing to meet industry deadlines.

This text is a summary of the work of Danes et al. (2024) which presents a methodology to calibrate, develop, and select optimization algorithms for oil production strategy applications. We compared six different optimization techniques, develop improvements in new algorithms, and finally selected the optimization meta-parameters without using a prior simulation, thus obtaining efficient optimization processes.

Motivation & Goals

The computational budget reduction has great value reservoir engineering since decision-making has strict time contingencies that constrain the computational budget of each case. Time spared in each optimization stage can be used for more refined analysis, extra optimization stages, or extra loops in the decision-making process.

This work focused on comprehensively understanding the strengths and weaknesses of different optimization techniques, systematically comparing methods, developing a cost-effective methodology for testing, and calibrating and selecting optimization approaches for petroleum production applications while aiming to spare simulations.

Case Study

The study comprises optimizing the oil production for a real-world scenario: A fractured and karstified pre-salt reservoir at the Santos Basin (Brazil) with an aquifer at the bottom. The numerical model has dual-media properties and large-scale faults contributing to field connectivity and productivity. The simulated life-cycle consists of 3,091 days of observed data followed by 8,797 days of forecast.

Water-flooding was selected as the oil recovery method. The platform is very restrictive for the field with a 15,200 m3/day upper limit. A reservoir engineering study obtained a solution benchmark with 8 producers and 3 injectors with a yielded NPV (Net Present Value) of 3.89 BUSD during the life-cycle. The platform apportionment management was set to be proportional to the well's productivity index (IMEX, 2019) during this stage.

The challenge was to improve fields NPV by planning the well management variables which spanning search spaces that traditionally display multiple local-optimums.

Methodology

Reservoir's numerical simulations demands several minutes or hours to be completed, thus it would be unfeasible to select or calibrate optimization techniques with simulations, this work proposes to use modified optimization test functions to tackle this obstacle. The classical Levy and Griewank multi-dimensional test functions were inverted, normalized and translated into six functions which aimed to mimic oil production management objective functions such as the NPV. Figure 1 shows the bidimensional space of two of the developed functions.

An important step is to establish a simulation budget which was defined as 500 simulations. The test functions

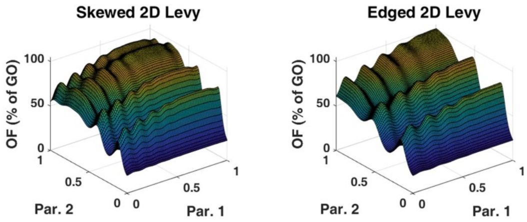

***Figure 1**: Two modified optimization functions: 2-D space.*

were used to test and calibrate different optimization techniques for a 27-D search space using this budget. Figure 2 shows meta-parameter impact for 2 of the tested techniques, with different sensibilities to hyperparameter selection. The study evaluated 6 different optimization algorithms and the overall performance was evaluated as the percentage of the yielded best solution to global optimal result.

The calibration study selected the Nelder-Mead Simplex, Archive Shrinking Latin HyperCube (ASLHC), Iterative Discrete Latin HyperCube (IDLHC) and Particle Swam Optimization (PSO) to be implemented as external engines for commercial software use. These techniques were used to conduct real-case optimizations with their respective obtained metaparameters.

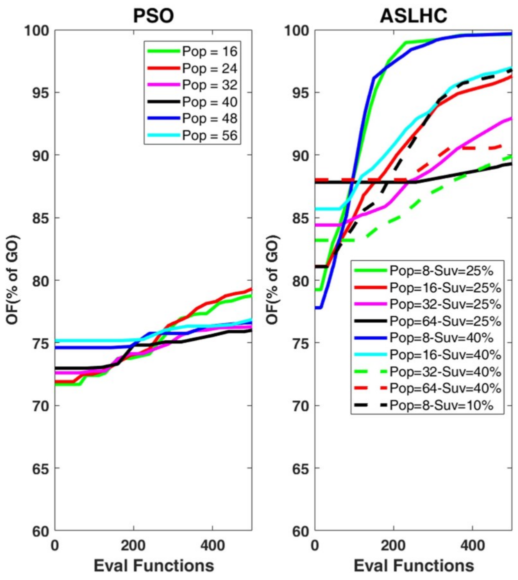

***Figure 2**: Meta-parameter impact regarding the 27-dimension Edged Levy Function, average of 6 runs.*

Results

A comprehensive set of 36 optimizations, each limited to 500 simulations, was executed to compare the performance of the four selected optimizers regarding 3 runs of two parametrizations groups: (**A**) the apportionment rate of each of the 8 producers; (**B**) a study with 27 parameters regarding the apportionments of (**A**) added of the water-cut limit of each producer and BHP of each producer and injector; (**C**) similar to (**B**), however the apportionment is on schedule with 12 different values during the life-cycle, totalizing 115 parameters. Figure 3 displays the average of the evolution of the best NPV for the 3 parametrizations.

Each optimization of parametrizations (**A**) and (**B**) improved the benchmark NPV by at least 8% and displayed a convergence behavior compatible with the established 500 simulation budget. Parametrization (**A**) yielded slightly better NPV than (**B**), due to the simplicity of the search space. Regarding (**C**), the multidimensionality

"Through decreasing the number of demanded simulations per oil production optimization, the spared computational budget can improve decision-making being used at more refined analysis, extra optimization stages, or extra loops."

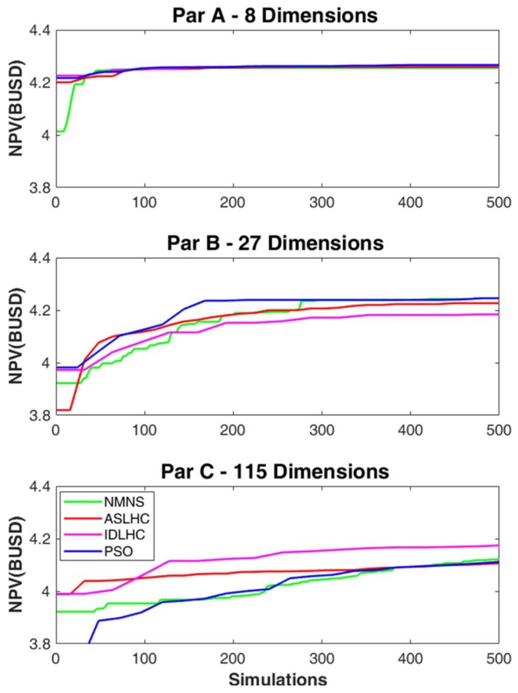

***Figure 3**: Best NPV per simulation for parametrization (2).*

case hindered the optimizations; nonetheless, every maximization still yielded an NPV over 4 BUSD. Noteworthy, the IDLHC retained a good performance at case (**C**), showing a good explorative behavior. Exploratory optimizers will maintain the potential of finding new, improved solutions better than the other techniques.

The best obtained solution, obtained by a run of IDLHC with (**A**), yielded a 4.275 BUSD NPV: A 9.9% improvement. The new solution can maintain the water cut under 5% for the initial 9 years of production and hold the liquid production at the platform limit 2 years longer.

In a nutshell, this study observed:

- All tested optimizers enhanced oil production at each of the 3 tested optimizations.
- Each optimizer contains its strengths and weaknesses.
- Optimizer meta-parameter has a noticeable impact at optimizations, but suitable test functions pose as an alternative to set these values without wasting simulations.
- Avoiding to use of excessive parameters at oil production optimization is a good practice.
- Poor apportionment potentially compromised hundreds of millions of dollars at toped platforms.

Conclusions

Using test functions to tailor optimization algorithms and their respective metaparameters for well management strategies can successfully improve and accelerate decision-making. The implemented algorithms successfully improved NPV by at least 8% at each of the 24 proposed real-case optimizations performed with less than 500 simulations. Two parametrizations with 8 and 27 parameters, respectively were used.

Therefore, we endorse IDLHC, PSO, ASHC and the Nelder–Mead simplex optimizers as suitable techniques for enhancing oil production strategies.

Figure 4 summarizes the study's recommendations regarding the exploitative and explorative behavior of the selected techniques, and provides the best selected meta-parameters according to the study. Explorative approaches gather information about the problem space more widely and keep more information in the decision spectrum to identify the most promising strategies later, thus being more conservative and requiring a larger computational budget and being suitable for larger dimensional spaces. Exploitative approaches commit to a narrower band of decisions earlier, thus converging faster to a good solution, requiring less computational power at the compromise of a larger probability to yield a suboptimal strategy.

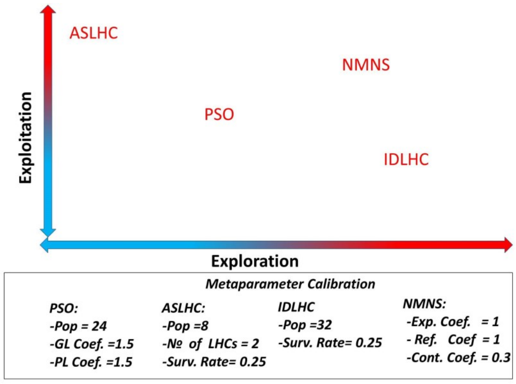

***Figure 4**: Optimization technique recommendation chart.*

Acknowledgments

The authors want to acknowledge Shell Brazil for sponsoring this work, conducted in association with the project registered under ANP number 19061-1.

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