Olympus Optimization under Geological Uncertainty

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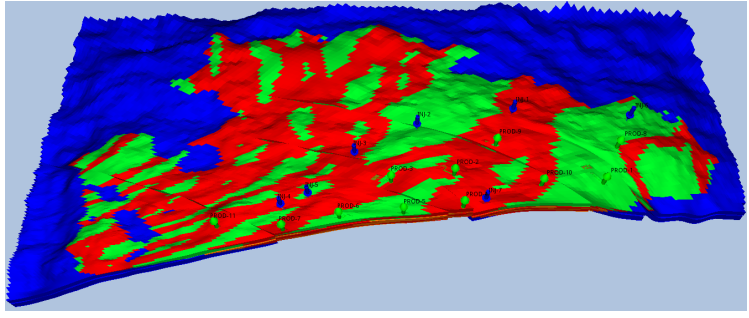
Introduction

- Task 1: Well Control Optimization
- Task 2: Field Development Optimization
- Task 3: Joint Field Development and Well Control Optimization



Objective function

- Objective function:

$$NPV = \sum_{i=1}^{N_t} \frac{R(t_i)}{(1+d)^{t_i/\tau}},$$

- Revenue term:

$$R(t_i) = Q_{op}(t_i) \cdot r_{op} - Q_{wp}(t_i) \cdot r_{wp} - Q_{wi}(t_i) \cdot r_{wi} - P(t_i) - D(t_i).$$

$P(t_i)$ - platform cost, $D(t_i)$ - drilling cost.

Ensemble based optimization (EnOpt)

- Pre-conditioned steepest ascend:

$$x_{k+1} = x_k + \eta_k C \nabla J_k$$

- Gradient approximation with geological uncertainty:

$$\nabla J_k \approx N^{-1} \sum_{i=1}^{N} [J(x_k^i, y^i) - J(x_k, y^i)][x_k^i - x_k]$$

- For more information we refer to:
  Fonseca et al. (2017), Stordal et al. (2016), Chen et al. (2009), Lorentzen et al. (2006)

Line Search Derivative-Free (LSDF) Method

- Based on evaluation of simplex points (Hooke-Jeeves):

$$J(x_k + \alpha e_j) = J(z_j), \qquad j = 1, \ldots, N_x, \qquad x_k \leftrightarrow z_{\text{best}}$$

- Method enhanced using line search:

$$x_{k+1} = x_k + \eta_k G_k$$

- A simplex gradient is computed as:

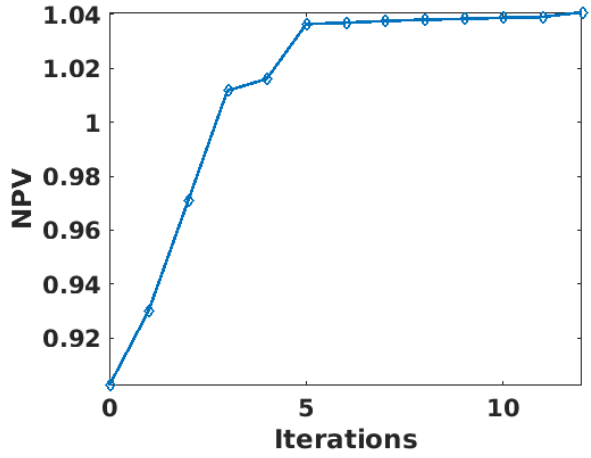
$$G_k = [z_1 - x_k, \ldots, z_{N_x} - x_k]^{-1} [J(z_1) - J(x_k), \ldots, J(z_{N_x}) - J(x_k)]^T$$

- For more information we refer to:
  Asadollahi et al. (2014)

Task 1: Well Control Optimization

- EnOpt with backtracking is applied, $N = 50, \quad \eta_k = 0.5$
- Control variables are shut-in times for producers, and pressures for injectors
- Initial mean for parameters obtained using the TNO reference case
- Ensemble generated by drawing perturbations $\sim \mathcal{N}(0, 0.01)$

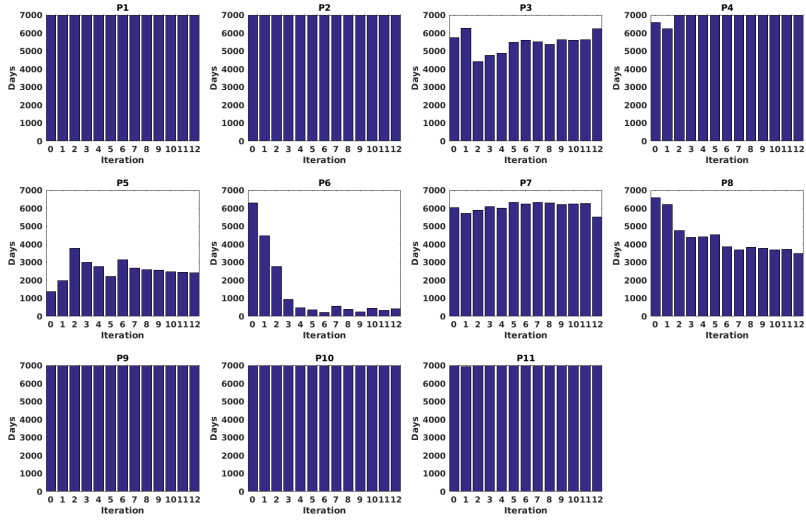
Task 1: Scaled NPV as function of iterations



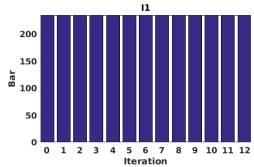
$NPV_{ref} = \$1.4875 \cdot 10^9$

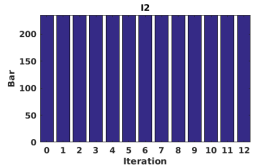
$NPV_{max} = \$1.5480 \cdot 10^9$

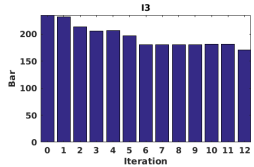
Task 1: Shut-in times as function of iterations

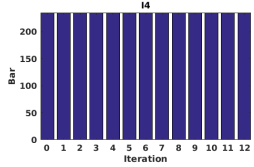


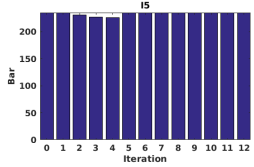
Task 1: Injection pressures as function of iterations

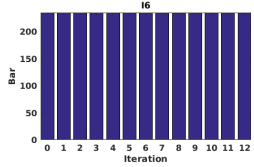


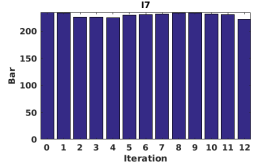


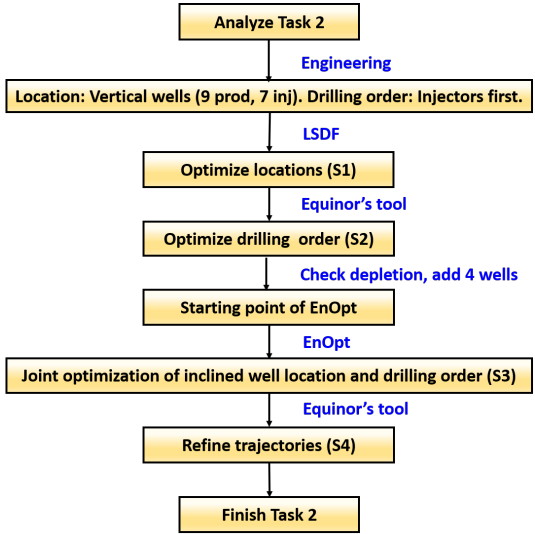




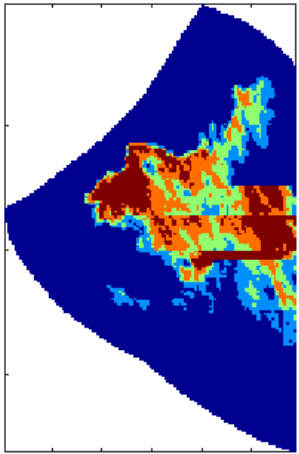




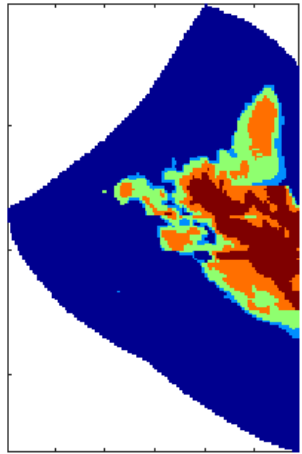



Analyze Task 2
Engineering
Location: Vertical wells (9 prod, 7 inj). Drilling order: Injectors first.
LSDF
Optimize locations (S1)
Equinor's tool
Optimize drilling order (S2)
Check depletion, add 4 wells
Starting point of EnOpt
EnOpt
Joint optimization of inclined well location and drilling order (S3)
Equinor's tool
Refine trajectories (S4)
Finish Task 2

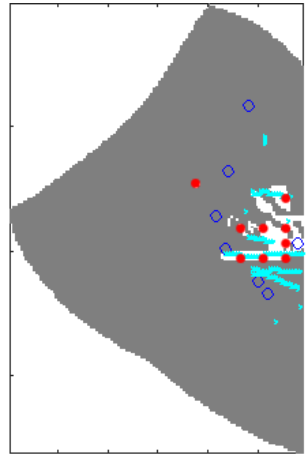
Task 2: Engineering judgment



OIP top zone

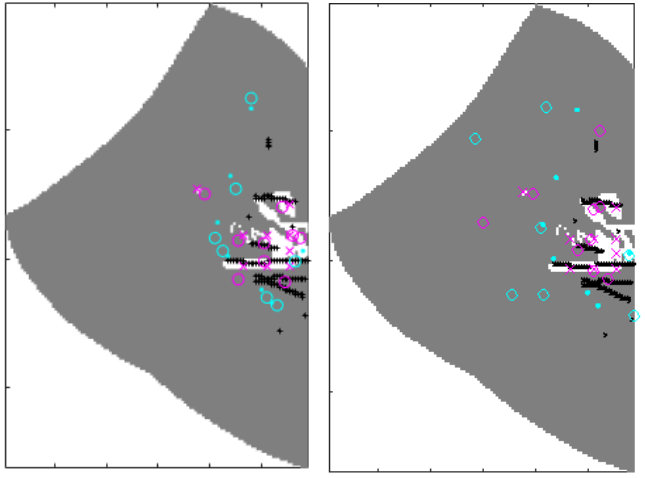


OIP bottom zone



Target map

Task 2: Vertical well optimization (S1)



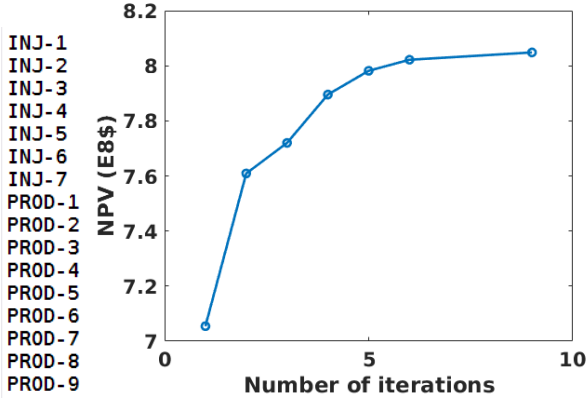
$NPV_{ref} = \$0.35 \cdot 10^9$
$NPV_{S1} = \$0.70 \cdot 10^9$

Legend:

- × : initial producers
- ○ : final producers
- × : initial injectors
- ○ : final injectors
- • : reference producers

EnOpt (left) and LSDF (right) on vertical well optimization (S1)

Task 2: Drilling order optimization (S2)

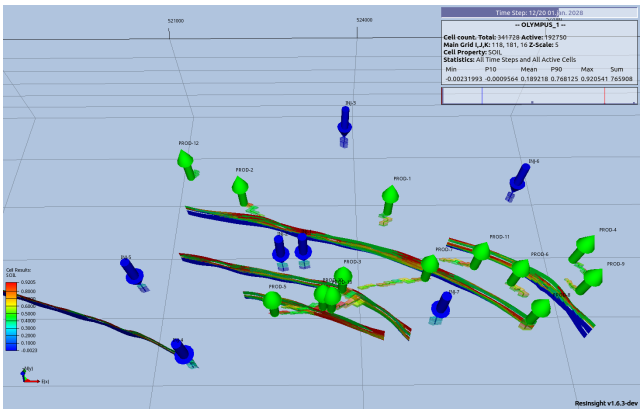


$$NPV_{ref} = \$0.35 \cdot 10^9$$
$$NPV_{S1} = \$0.70 \cdot 10^9$$
$$NPV_{S2} = \$0.81 \cdot 10^9$$

Equinor's internal tool

For more information:
Hanea et al. (2016)

Task 2: EnOpt on inclined well optimization (S3)

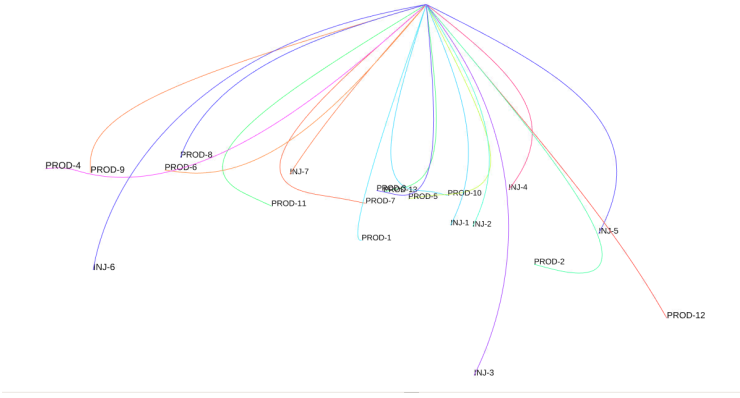


PROD-3
PROD-7
INJ-1
PROD-1
INJ-5
PROD-5
INJ-7
PROD-11
INJ-2
INJ-6
PROD-4
PROD-2
INJ-3
PROD-10
PROD-8
PROD-12
INJ-4
PROD-9
PROD-6
PROD-13

$$\begin{aligned} \mathrm{NPV}_{\mathrm{ref}} &= \$0.35 \cdot 10^9 \\ \mathrm{NPV}_{\mathrm{S1}} &= \$0.70 \cdot 10^9 \\ \mathrm{NPV}_{\mathrm{S2}} &= \$0.81 \cdot 10^9 \\ \mathrm{NPV}_{\mathrm{S3}} &= \$0.94 \cdot 10^9 \end{aligned}$$

$$u_{prod} = \begin{bmatrix} x_{hp} \\ y_{hp} \\ x_{tp} \\ y_{tp} \\ z_{tp} \end{bmatrix}, \; u_{inj} = \begin{bmatrix} x_{hi} \\ y_{hi} \\ z_{ti} \end{bmatrix}$$

Task 2: Final results (S4)



$$\begin{aligned} \mathrm{NPV}_{\mathrm{ref}} &= \$0.35 \cdot 10^9 \\ \mathrm{NPV}_{\mathrm{S1}} &= \$0.70 \cdot 10^9 \\ \mathrm{NPV}_{\mathrm{S2}} &= \$0.81 \cdot 10^9 \\ \mathrm{NPV}_{\mathrm{S3}} &= \$0.94 \cdot 10^9 \\ \mathrm{NPV}_{\mathrm{S4}} &= \$1.15 \cdot 10^9 \end{aligned}$$

Equinor's internal tool, combining EnOpt and RMS

For more information:
Hanea et al. (2017)

Task 3: Joint Optimization

- Final well trajectories from Task 2 (S4) is used
- LSDF is run using three geomodels
- Control variables are shut-in times for producers, and pressures for injectors
- Initial mean for parameters obtained using the TNO reference case
- Final $\mathrm{NPV}_{\max} = \$1.15 \cdot 10^9$

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
Initial	20.0	20.0	20.0	13.2	20.0	20.0	20.0	20.0	20.0	20.0	20.0	17.7	20.0
Optimal	20.0	20.0	9.74	11.4	20.0	20.0	14.5	13.6	15.4	20.0	20.0	11.6	13.3

Summary

	Task 1	**Task 2**	**Task 3**
NPV_{ref} (10^9 \$)	1.49	0.35	1.15
NPV_{ini} (10^9 \$)	1.34	0.35	1.01
NPV_{max} (10^9 \$)	1.55	1.147	1.153
P_{ref} (%)	4.1	230	0.52
P_{ini} (%)	16	230	14
N_{sim}	1450	1750	1209
N_{core}	25	25/3	3

Acknowledgments

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