Production optimization in oil & gas systems

TTK 16 - Optimization in energy and oil & Gas systems

Lecture 4

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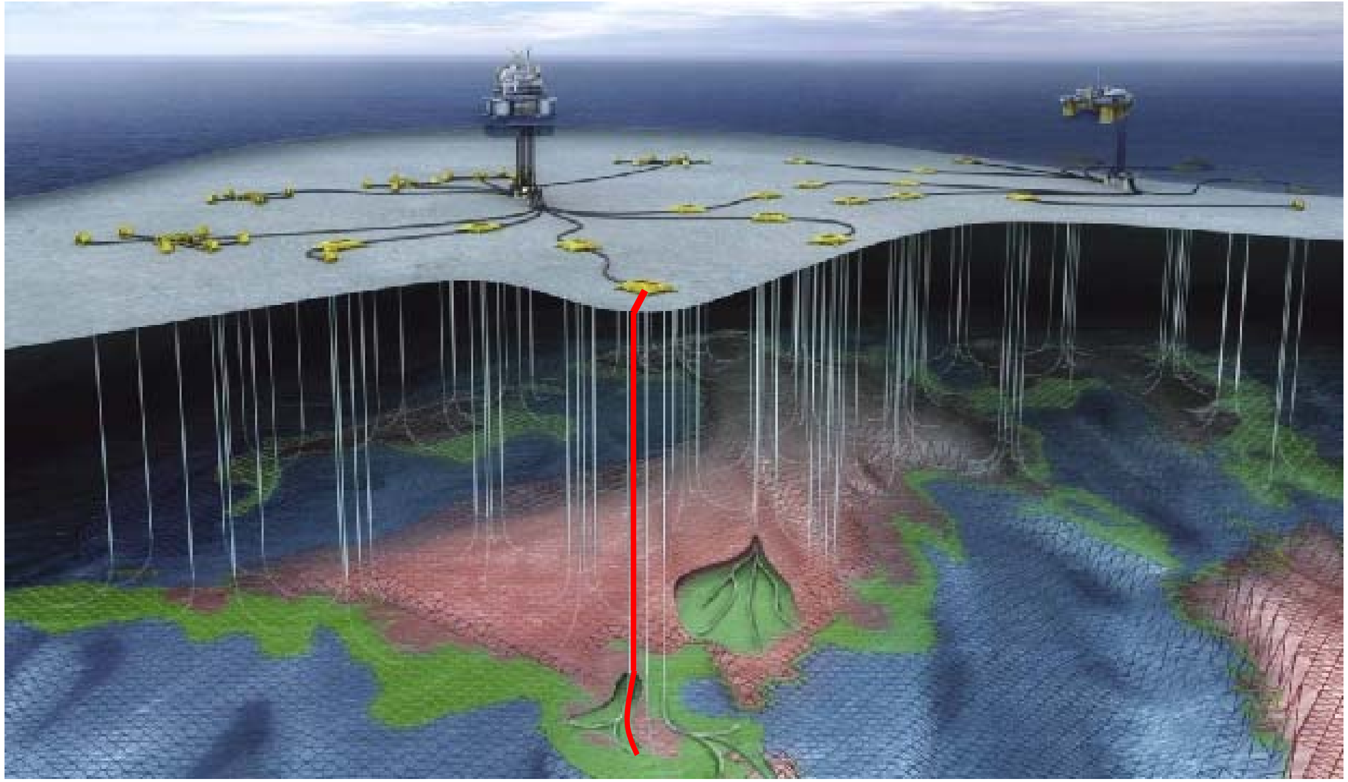
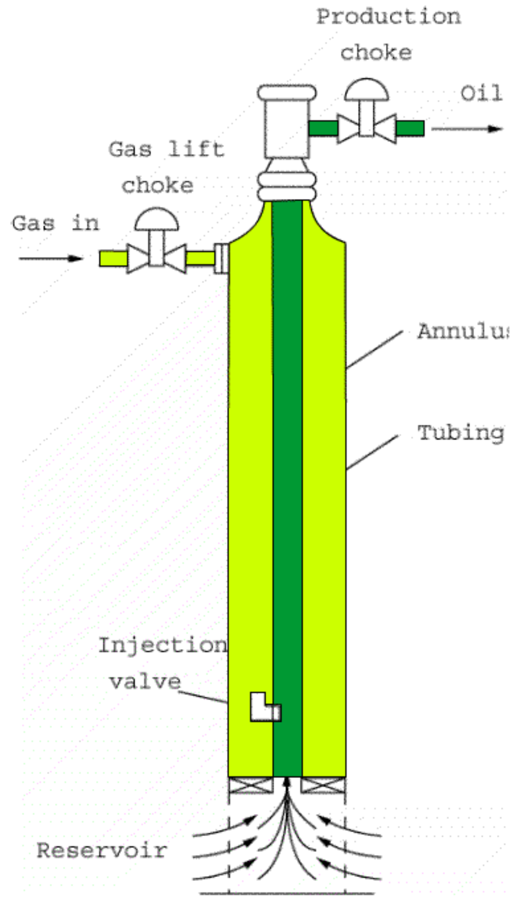
Outline

1. Production optimization
   - system overview – components from well to inlet separator
   - problem description
   - simple example using Excel
   - Workflow issues
2. General description
   - structure using a directed graph formulation
   - formulating the optimization problem
   - two strategies for simulation based optimization
     - embedding the simulator in the optimization loop
     - surrogate models
3. MILP formulation
   - piecewise linearization
4. Results

System overview 1: Wellheads, manifolds, pipelines and FPSO

System overview 2: Wells





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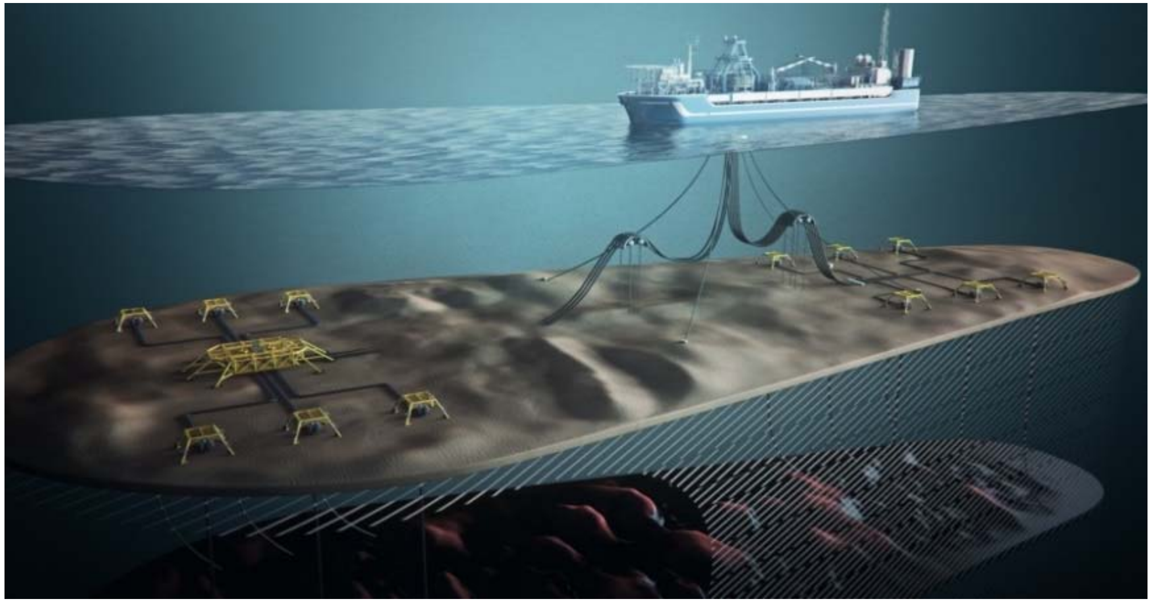
Problem description: Maximize daily revenues while honoring all important constraints



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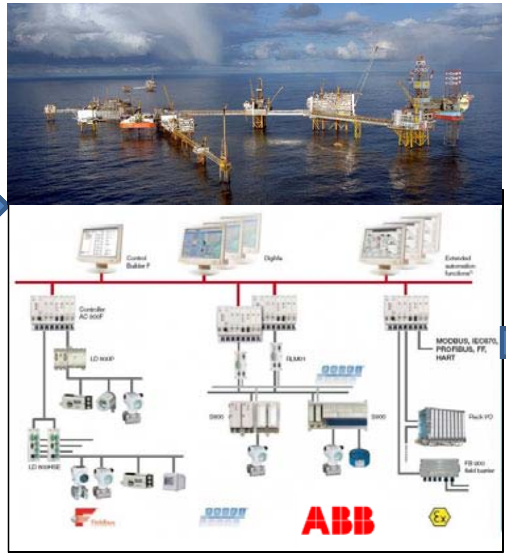
Daily production optimization - workflow

Implement decisions



Realtime data stream

Objectives
Safety and capacity constraints

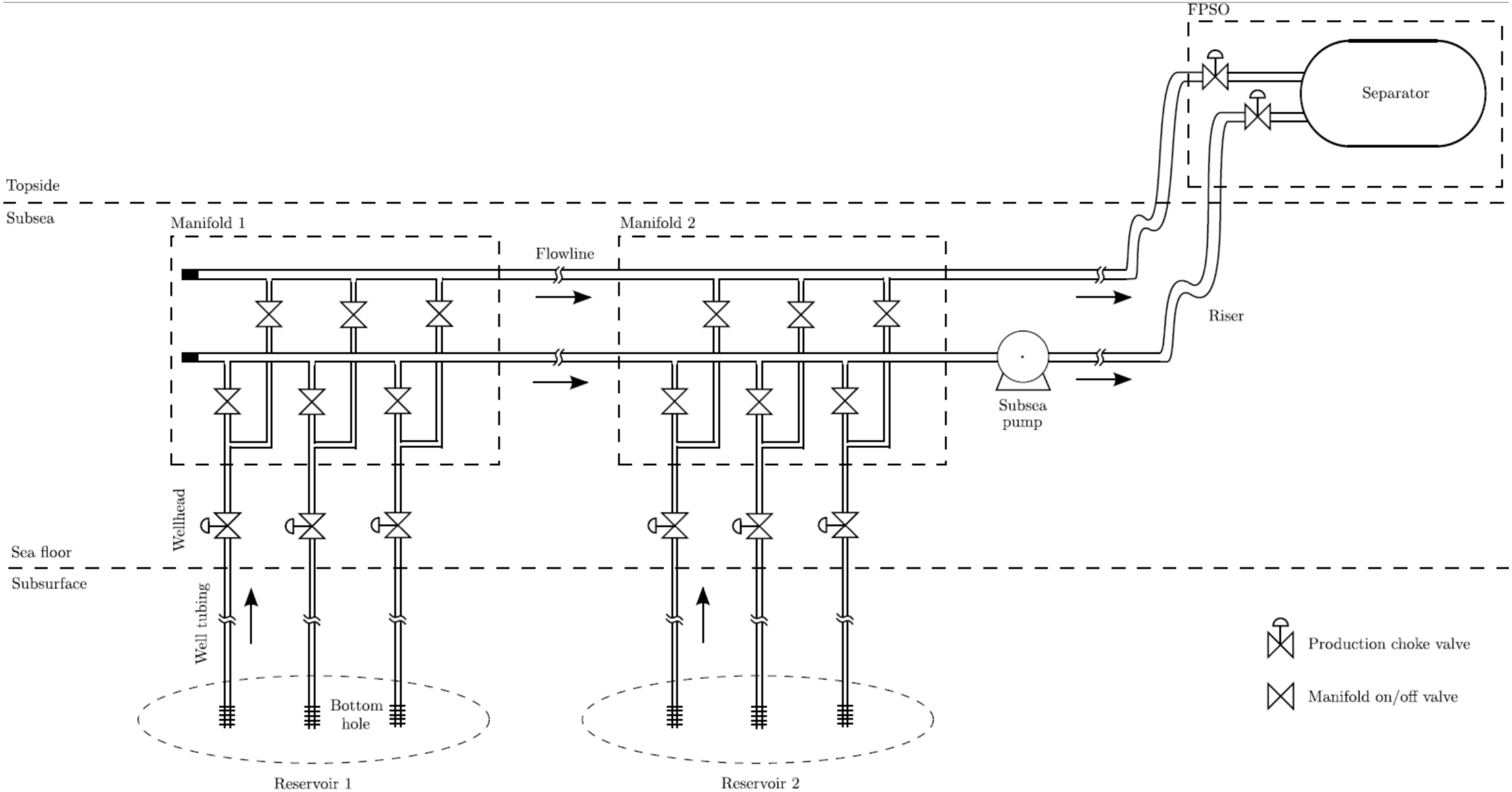
Mathematical Optimization
with Models and Realtime data

Recommendations

Decision variables

- choke settings
- artificial lift settings
- separator pressure
- routing of well streams
- …

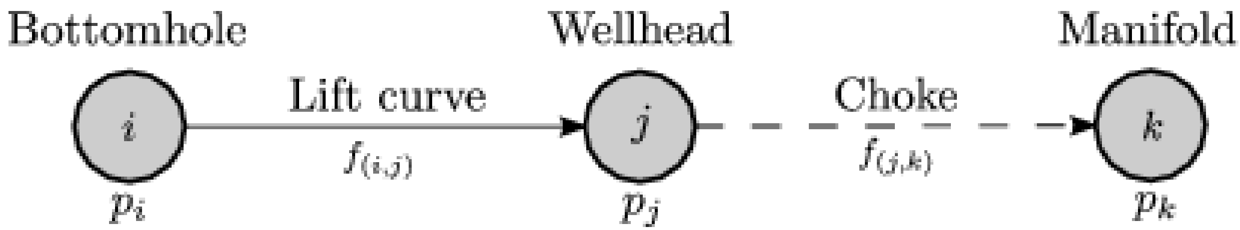
Network structure



Graph formulation for defining topology

- Graph $G = (\mathbf{N}, \mathbf{E})$
- Nodes $\mathbf{N}$
- Edges $\mathbf{E}$
- Discrete edges $\mathbf{E}^d \subseteq \mathbf{E}$

- A node $i \in \mathbf{N}$
- An edge $(i, j) \in \mathbf{E}$



A well model with three nodes and two edges

Interpretation

- Edges represent pipes, valves (chokes), and equipment (e.g. pumps)
  - Related variables: differential pressure, rates
  - For discrete edges: binary variables for turning the edge on/off (open/close valves, turn pumps on/off, etc.)
- Nodes represent joints in the network
  - Related variables: pressure
- Set of fluid components (phases)
  - Example: water, oil, gas

Formula

- Can handle a wide range of topologies
- Any number of fluid components
- Mass, momentum, and energy conservation
- Flexible
  - Operational constraints
  - Artificial lift
- Convex properties
- Routing handled explicitly with integer variables

$$\underset{\mathbf{y},\mathbf{q},\mathbf{p},\boldsymbol{\Delta}\mathbf{p}}{\text{maximize}} \quad z = \sum_{e \in \mathbf{E}^{\text{snk}}} q_{e,\text{oil}} \tag{1}$$

subject to

$$\sum_{e \in \mathbf{E}_i^{\text{in}}} q_{e,r} - \sum_{e \in \mathbf{E}_i^{\text{out}}} q_{e,r} = 0, \qquad \forall r \in \mathbf{R}, i \in \mathbf{N}^{\text{int}} \tag{2}$$

$$\zeta_{i,r}(\mathbf{q}_e, p_i) = 0, \qquad \forall r \in \mathbf{R}, i \in \mathbf{N}^{\text{src}} \tag{3}$$

$$p_i = \text{const.}, \qquad \forall i \in \mathbf{N}^{\text{snk}} \tag{4}$$

$$\Delta p_e = f_e(\mathbf{q}_e, p_i), \qquad \forall e \in \mathbf{E} \setminus \mathbf{E}^{\text{d}} \tag{5}$$

$$\Delta p_e = p_i - p_j, \qquad \forall e \in \mathbf{E} \setminus \mathbf{E}^{\text{d}} \tag{6}$$

$$\begin{aligned} -M_e(1 - y_e) &\le p_i - p_j - \Delta p_e, \\ M_e(1 - y_e) &\ge p_i - p_j - \Delta p_e, \end{aligned} \qquad \forall e \in \mathbf{E}^{\text{d}} \tag{7}$$

$$\sum_{e \in \mathbf{E}_i^{\text{out}}} y_e \le 1, \qquad \forall i \in \mathbf{N}^{\text{d}} \tag{8}$$

$$y_e q_{e,r}^L \le q_{e,r} \le y_e q_{e,r}^U, \qquad \forall r \in \mathbf{R}, e \in \mathbf{E}^{\text{d}} \tag{9}$$

$$q_{e,r}^L \le q_{e,r} \le q_{e,r}^U, \qquad \forall r \in \mathbf{R}, e \in \mathbf{E} \setminus \mathbf{E}^{\text{d}} \tag{10}$$

$$p_i^L \le p_i \le p_i^U, \qquad \forall i \in \mathbf{N} \tag{11}$$

$$y_e \in \{0, 1\}, \qquad \forall e \in \mathbf{E}^{\text{d}} \tag{12}$$

$$\sum_{e \in \mathbf{E}^{\text{snk}}} q_{e,\text{gas}} \le C_{\text{gas}}, \tag{13}$$

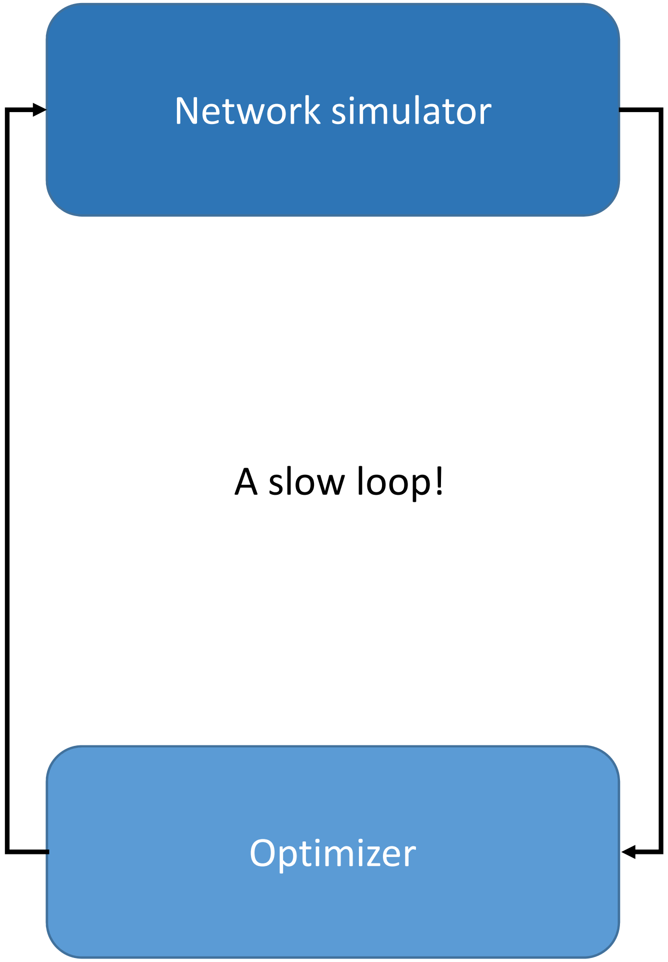
$$\sum_{e \in \mathbf{E}^{\text{snk}}} q_{e,\text{wat}} \le C_{\text{wat}}. \tag{14}$$

Black-box optimization

1. No gradient information
2. Difficult to handle discrete variables, e.g. routing
3. The simulator may return with 'error message'

Available software for DPO

- GAP (Petex)
  - Chokes and gas lift - Routing changes are readily available
- MaxPro (FMC)
  - Chokes and gas lift - Exhaustive routing search



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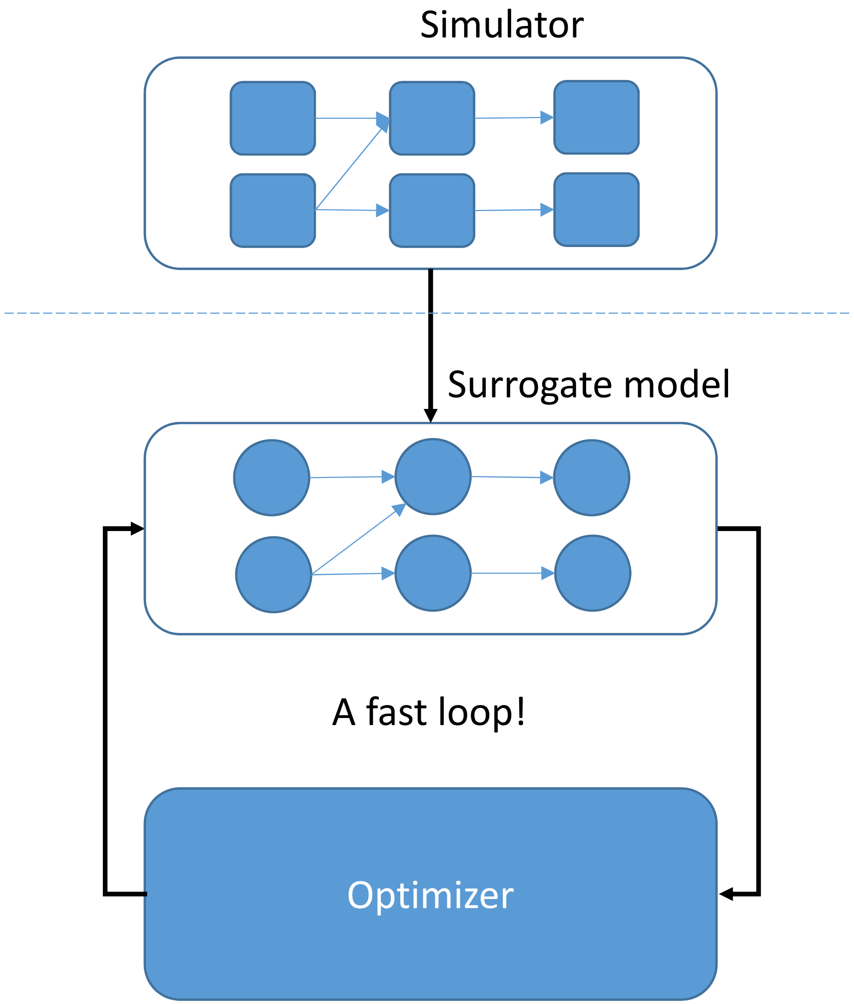
Surrogate model approach

1. Build a surrogate model for each component with desired accuracy
2. Replace simulator components (retain topology)
3. Solve optimization problem
   - No communication with simulators during optimization
4. Verify solution in simulator
5. (Optional) Use solution as starting point for a local search with gray-box or black-box method



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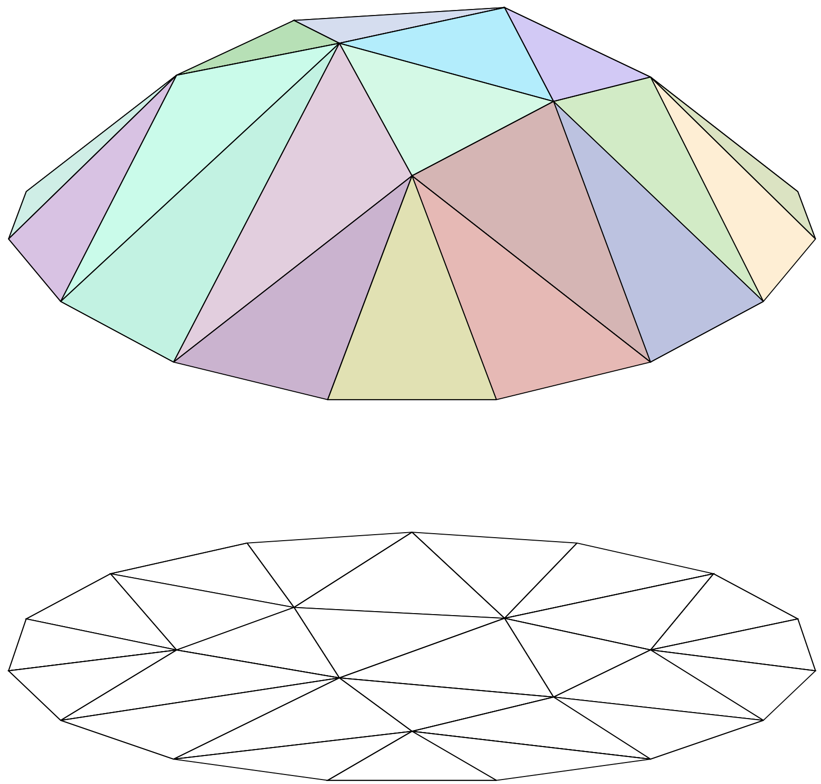
Piecewise linear surrogate models

- Widely used and several formulations exist
- MILP formulations
  - Triangulate domain
  - Select linear model for each polytope using binary variables
  - Many available models: disaggregated convex combination model, convex combination model, multiple choice model, incremental model, and logarithmic models
- Branching-based formulations
  - SOS2 model



Subsea production system

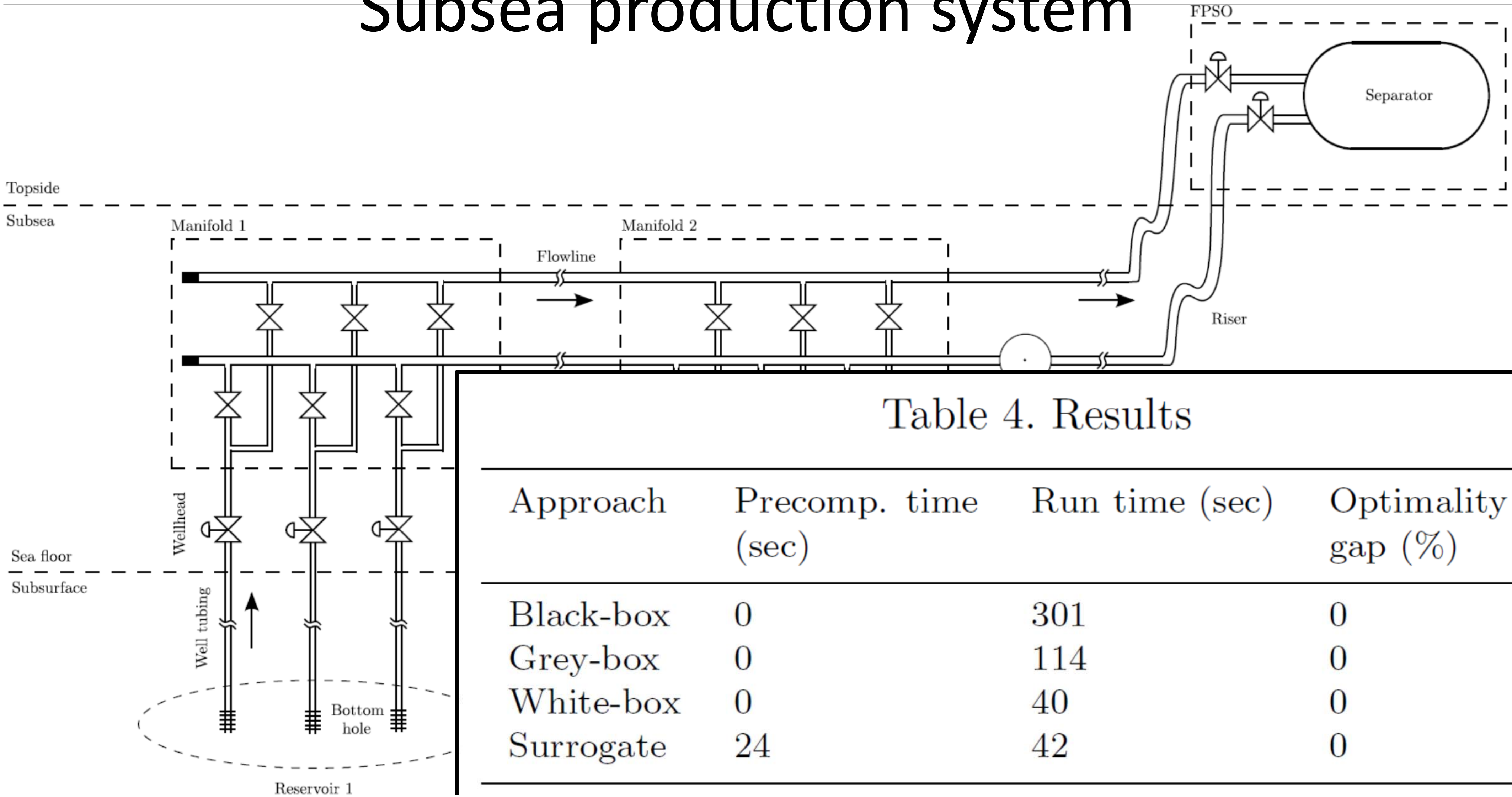


Table 4. Results

Approach	Precomp. time (sec)	Run time (sec)	Optimality gap (%)
Black-box	0	301	0
Grey-box	0	114	0
White-box	0	40	0
Surrogate	24	42	0

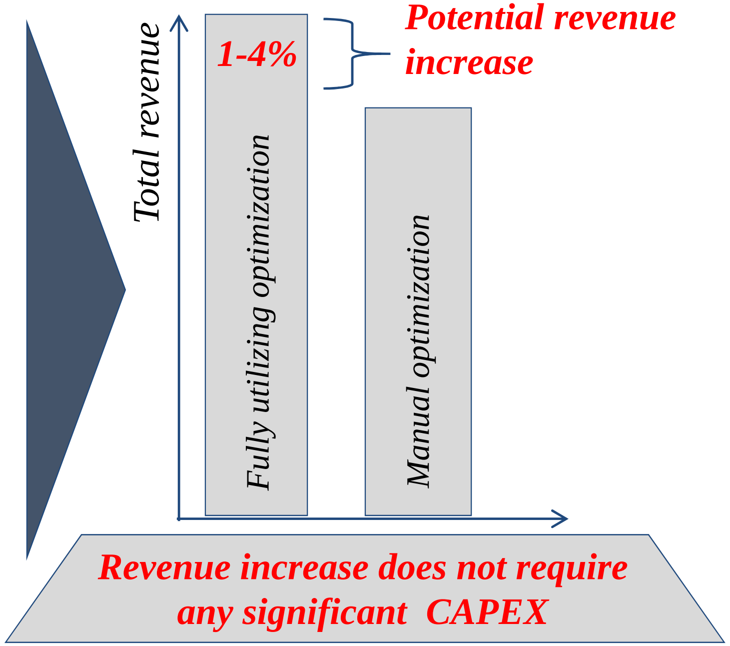
Incentives for Daily production optimization

Backdrop

- Complex and varying bottleneck structure – in particular in mature assets

Reasons for DPO revenue increase

- Production teams obtain more precise advice, thus they make better operational decisions
- Faster response to abnormal situations
- Consistency in operations between teams



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