Offshore Oilfield Infrastructure Planning under Complex Fiscal Rules

Vijay Gupta
Ignacio E. Grossmann
Department of Chemical Engineering
Carnegie Mellon University
Pittsburgh PA 15213

Enterprise-Wide Optimization (EWO) Meeting, March 2012
Problem Description: Offshore Oilfield Infrastructure Planning

Goals

1. Formulate a new generic model for offshore oil and gas field infrastructure planning under complex fiscal rules (e.g. progressive PSAs with ringfencing provisions)
2. Efficient solution methods for the large scale multi-field site problems

Key realistic features in the Proposed Model

Multi-field site
Nonlinear reservoir behavior
Three components (oil, water, gas)
Facility Expansions
Facility lead times
Well Drilling Schedule
Fiscal Considerations

Investment decisions in each time $t$:
- FPSO Installation and Capacities
- Selection of FPSO-field connection
- Number of wells to drill in a field

Operation decisions in each time $t$:
- Production profile for each field

Objective:
Maximize NPV after paying taxes to the Govt.
Production Sharing Agreements (PSAs): Revenue Flow

Production

Cost Oil

Profit Oil

Royalty

Contractor’s Share

Government’s Share

Contractor’s after-tax share

Income Tax

Total Contractor’s share

Total Government’s share

Maximize

(World Bank, 2007)
Sliding Scale (Progressive) PSAs

- Royalty, Govt. production sharing rates etc. increase with income (i.e. sliding scale based on Daily Production, Cumulative production, ROR etc.)

Fiscal policies to promote long term investment and operation in host country

Widely Used (Indonesia, Nigeria, Russia, Egypt, China, India etc…)
Ringfencing Provisions

Investment and Operational costs for a specified group of fields or block can only be recovered from the Revenue generated from those fields or block.

What are the issues with Ringfencing?
1. Cost Calculations
   - Shared Facilities
2. Problem Size
   - Binary variables
     (tier for each ringfence)

Constraints

Most Generic Fiscal Terms:
Sliding Scale Production Sharing Agreements with Ringfencing Provisions
Generic Model for Oilfield Infrastructure Planning under complex fiscal rules

Objective: Maximize NPV

- Economic Constraints
- Reservoir Constraints
- FPSO-field Flow Constraints
- FPSO Capacity Constraints
- Constraints for wells
- Logic Constraints
- Variable UB Constraints

Royalty, Profit oil share Calculations (Progressive PSAs with Ringfencing)

- Cost Recovery Ceiling
  \[
  CO_{rf,t} = \min(CR_{rf,t}, f_{rf,t}^{CR} \cdot REV_{rf,t})
  \]
- Sliding Scale Profit Oil split linked to cumulative oil production

\[
\begin{align*}
\forall i, t \\
Z_{rf,i,t} & \geq \sum_{t} Z_{rf,i,t} \\
ConSh_{rf,t}^{beforetax} & = f_{rf,i}^{PO} \cdot PO_{rf,t} \\
L_{rf,t}^{oil} & \leq x_c_{rf,t} \leq U_{rf,t}^{oil}
\end{align*}
\]

Convex Hull Formulation of the Disjunction

Contractor’s Profit Oil Share

% Profit Oil Share

0% 20% 40% 60% 80% 100%

Cumulative Oil Production (MMbbls)

0 200 400 600 800 1000

Tier i
Example: 5 Oilfields, 20 years, Complex Fiscal Rules

**Given**

- 5 Fields, 3 Potential FPSO’s
- 11 Potential Connections
- 31 Potential Wells
- 20 Years Horizon
- 3 yr lead time for FPSO construction
- 1 yr lead time for FPSO expansion
- 4 Tiers for Profit Oil, Cost Ceiling
- 2 Ringfences

**Results**

<table>
<thead>
<tr>
<th>MILP Model with progressive PSA</th>
<th># of constraints</th>
<th># of continuous variables</th>
<th># of discrete variables</th>
<th>NPV ($Million)</th>
<th>Time (s)</th>
<th>Optimality gap (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No ringfencing</td>
<td>9363</td>
<td>6223</td>
<td>551</td>
<td>$2,228.94</td>
<td>1,163.70</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>With ringfencing</td>
<td>14,634</td>
<td>9,674</td>
<td>651</td>
<td>$2,149.39</td>
<td>&gt;36,000.00</td>
<td>&lt;15.42%</td>
</tr>
</tbody>
</table>

✔ Problem with ringfencing provisions becomes very expensive to solve.
### Solution Strategies

#### Reformulation Technique

Include Logic Constraints and Valid Inequalities (tightening)

\[
Z_{f,i,t} \Rightarrow \bigwedge_{t} Z_{f,i',t} \quad \forall r, i, t < i, t
\]

\[
Z_{f,i,t} \Rightarrow \bigwedge_{t} Z_{f,i',t} \quad \forall r, i, t > i, t
\]

\[
\sum_{t \leq t} (\text{Contsh}^{\text{before tax}}_{f,i,t} / \alpha_t) \leq \sum_{i' < i} (f_{f,i',t} - f_{f,i'-1}) \cdot (\text{xc}_{f,i,t} - L_{f,i'}) - f_{f,i''} \cdot \sum_{t \leq t} (\text{CO}_{f,i,t} / \alpha_t) \quad \forall r, i, t
\]

#### Decomposition Technique

Bi-level decomposition

**Upper Level:**
Aggregate Fiscal Model (1 ringfence)

**Investment Decisions**

**Lower Level:**
Detailed Fiscal Model (multiple ringfences) for the selected field-FPSO

Add cuts

Stop if \( UB-LB < \epsilon \)
Else continue

#### Approximation Technique

Include Sliding scale fiscal terms in approximate form

\[
\sum_{t \leq t} (\text{Contsh}^{\text{before tax}}_{f,i,t} / \alpha_t) \leq \sum_{i' < i} (f_{f,i',t} - f_{f,i'-1}) \cdot (\text{xc}_{f,i,t} - L_{f,i'}) - f_{f,i''} \cdot \sum_{t \leq t} (\text{CO}_{f,i,t} / \alpha_t) \quad \forall r, i, t
\]
Results: 5 Oilfield Example Revisited

**Progressive PSA no ringfencing**

<table>
<thead>
<tr>
<th>MILP Model with progressive PSA</th>
<th># of constraints</th>
<th># of continuous variables</th>
<th># of discrete variables</th>
<th>NPV (Million)</th>
<th>NPV after fixing decisions in Original MILP (Million)</th>
<th>Time (s)</th>
<th>Optimality gap (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>9,363</td>
<td>6,223</td>
<td>551</td>
<td>2,228.94</td>
<td>-</td>
<td>1,163.70</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>After Tightening</td>
<td>11,963</td>
<td>6,223</td>
<td>551</td>
<td>2,222.40</td>
<td>-</td>
<td>274.71</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>Approximate</td>
<td>8,803</td>
<td>5,903</td>
<td>471</td>
<td>2,197.63</td>
<td>2,228.94</td>
<td>81.61</td>
<td>&lt;2%</td>
</tr>
</tbody>
</table>

**Progressive PSA with ringfencing**

<table>
<thead>
<tr>
<th>MILP Model with progressive PSA</th>
<th># of constraints</th>
<th># of continuous variables</th>
<th># of discrete variables</th>
<th>NPV (Million)</th>
<th>NPV after fixing decisions in Original MILP (Million)</th>
<th>Time (s)</th>
<th>Optimality gap (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>14,634</td>
<td>9,674</td>
<td>651</td>
<td>2,149.39</td>
<td>-</td>
<td>&gt;36,000.00</td>
<td>&lt;15.42%</td>
</tr>
<tr>
<td>After Tightening</td>
<td>19,834</td>
<td>9,674</td>
<td>651</td>
<td>2,161.27</td>
<td>-</td>
<td>3,333.76</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>Approximate</td>
<td>13,514</td>
<td>9,034</td>
<td>491</td>
<td>2,148.90</td>
<td>2,142.75</td>
<td>133.66</td>
<td>&lt;2%</td>
</tr>
</tbody>
</table>

**Bi-Level Decomposition**

<table>
<thead>
<tr>
<th>Iteration</th>
<th>UB*</th>
<th>LB</th>
<th>% Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2222.40</td>
<td>2161.27</td>
<td>2.75</td>
</tr>
<tr>
<td>2</td>
<td>2039.76</td>
<td>-</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*problems solved within 2% of gap
Conclusions

- A Generic Model is proposed for Oilfield Infrastructure planning under Complex Fiscal Rules that can be used to derive the specific contracts.

- Sliding scale terms and Ringfencing provisions cause exponential increase in the computational effort.

- Solution Strategies are proposed to reduce the computational expense by orders of magnitude (a tighter formulation, bi-level decomposition, approximation scheme).

- Uncertainty in the field characteristics will be introduced as a next step.