Solving Operational and Tactical Problems in the LNG Value Chain

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Talk Outline

- Introduction to the LNG business
- Decision support tools
  - MIP-based
  - Heuristics
  - Combined
- Results and summary
What is LNG?

- LNG is natural gas (primarily methane) that is ‘cleaned’ and cooled down to about \(-163 \, ^\circ C\) \((-261 \, ^\circ F)\) to a liquid state
- By transforming natural gas to LNG the volume is reduced by a factor of 600
Project history

- SINTEF and GDF Suez started cooperation on decision support tools for the LNG value chain in 2005
- Statoil joined the activity in 2007
- Long term project with a strong research focus
- Close cooperation between researchers and planning personnel in the companies
The LNG value chain

- Exploration & Production
- Liquefaction
- Transportation
- Sales
- Regasification
Liquefaction terminal
LNG transportation
Regasification terminal
### The need for decision support

<table>
<thead>
<tr>
<th></th>
<th>Long-term (2-6 years)</th>
<th>ADP (next year)</th>
<th>Operations (3 mths)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Study mode (days)</strong></td>
<td>Business development</td>
<td>Preparation of ADP submission</td>
<td>Deal scanning without urgency for remainder of year</td>
</tr>
<tr>
<td><strong>Negotiation mode (hours)</strong></td>
<td></td>
<td>Scheduling meetings during breaks or evenings</td>
<td>Deal negotiation with counterparty or urgent rescheduling</td>
</tr>
<tr>
<td><strong>Meeting mode (15 mins)</strong></td>
<td></td>
<td>Bottleneck to be solved</td>
<td></td>
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ADP = Annual Delivery Program

(Stremersch et al., 2008)
Conceptual model

Liquefaction terminal → LNG carrier → Regasification terminal → Hub

Purchase contract(s) → Sale contract(s) → NG contract(s)
LNG supply chain schedules

A LNG supply chain schedule consist of three components specified for the whole period under study:

1. Liquefaction terminal production schedules
   - LNG production rates

2. Shipping schedules
   - Where, when and how much each vessel load or unload and on which contracts

3. Regasification terminal send-out schedules
   - Daily volumes from the terminal on each sale contract, market or pipeline
Solving as a mixed integer problem

- Profit maximizing
- Flow-centric approach
- Daily time granularity
- Constraints
  - Flow conservation
  - Routing
  - Vessel inventory, boil-off and fuel
  - Inventories and onshore facilities
  - Contract limitations
  - Maintenance
  - Port visits, loading and unloading

\[
\gamma_{iwt} = \sum_{w \in \mathcal{W}^P} \gamma_{iwt} + \sum_{w \in \mathcal{W}^F} \eta_{iwt} \quad \text{for all } i \in \mathcal{N}^P, w \in \mathcal{W}^P, t \in \mathcal{T} \tag{A.1}
\]

\[
\sum_{w \in \mathcal{W}^F} \lambda_{iwt} + \sum_{w \in \mathcal{W}^P} \gamma_{iwt} = \pi_{iwt} + \sum_{w \in \mathcal{W}^\text{SI} \cup \mathcal{W}^\text{SL}} \omega_{iwt} \quad \text{for all } i \in \mathcal{N}^C, w \in \mathcal{W}^P, t \in \mathcal{T} \tag{A.2}
\]

\[
\sum_{w \in \mathcal{W}^P} Q_w (1 - F^C_{iwt}) \psi_{iwt} = \sum_{h \in \mathcal{H}} x_{iht} \quad \text{for all } i \in \mathcal{N}^C, t \in \mathcal{T} \tag{A.3}
\]

\[
\sum_{w \in \mathcal{W}^P} \sum_{v \in \mathcal{V} \cap \mathcal{W}^P} Q_w (1 - F^B_{iwt}) \lambda_{iwt} + \sum_{w \in \mathcal{W}^P} Q_w (1 - F^W_{iwt}) \psi_{iwt} = \sum_{h \in \mathcal{H}} x_{iht} \quad \text{for all } i \in \mathcal{N}^B, t \in \mathcal{T} \tag{A.4}
\]

\[
\sum_{i \in \mathcal{N}^C \cup \mathcal{N}^B} x_{iht} = \sum_{w \in \mathcal{W}^P \cup \mathcal{W}^F} \psi_{iwt} + \omega_{iht} \quad \text{for all } h \in \mathcal{H}, t \in \mathcal{T} \tag{A.5}
\]
Illustrative Example

\[ V_{p,t} = V_{p,t-1} - z_{p,t}^{\text{out}} + z_{p,t}^{\text{in}} \]

\[ 0 \cdot V_{p,t} \cdot C_p \]

\[ z_{p,t}^{\text{out}} = q_{p,c_1,t} + q_{p,c_2,t} \]

\[ L_{v,t} = L_{v,t-1} + \sum_{p \in P} l_{p,v,t} \]

\[ 0 \cdot L_{v,t} \cdot C_v \]

\[ z_{p,t}^{\text{out}} = l_{p,v,t} \]
Illustrative Example (cont.)

\[ x_{p,v,t} = u_{p,v,t} + w_{v,t-1} - w_{v,t} \]

\[ u_{p,v,t} = \sum_{r \in P} y_{r,p,v,t-T_{r,p}} \]

\[ x_{p,v,t} = \sum_{p \in P} y_{p,q,v,t+1} \]

\[ l_{p,v,c,t} \cdot x_{p,v,t} M \]
Solving using heuristics

- Routing-centric approach
- Based on a framework for general maritime inventory routing problems
- Omitting market details
Solution strategy

- Heuristic construction and optimization
- Violate constraints by doing too little → penalize
  - Stockout/overflow
  - Contract limit not met
  - Too few visits in time period
- Reduce penalty by adding shipments
- Be greedy
- Try to resolve conflicts using delays
Construction: select penalty to fix

- Stockout/overflow
- Contract limit
- Too few visits in time period
Construction: shipment generation

- Choose
  - Contract
  - Counterpart inventory
  - Counterpart contract
  - Vessel
  - Insertion points
# MIP vs Heuristics

<table>
<thead>
<tr>
<th></th>
<th>Pros</th>
<th>Cons</th>
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<tbody>
<tr>
<td><strong>MIP</strong></td>
<td>• Rich in details</td>
<td>• Slow</td>
</tr>
<tr>
<td></td>
<td>• Volume flexibility</td>
<td>• Problems handling large problems</td>
</tr>
<tr>
<td></td>
<td>• Market modeling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Bounds</td>
<td></td>
</tr>
<tr>
<td><strong>Heuristics</strong></td>
<td>• Fast</td>
<td>• Only full vessel loads</td>
</tr>
<tr>
<td></td>
<td>• Can handle large problems</td>
<td>• Few market details</td>
</tr>
<tr>
<td></td>
<td>• Finding feasible solutions</td>
<td>• Greedy</td>
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Combined approach

• Use heuristics to generate a diversified set of feasible solutions
• Use routing part of solution to fix routing decisions in MIP
• Variations
  – +/- days
  – Subset of vessels
  – Liquefaction visits only
Example

- Test case constructed from a real world setting
- Medium sized problem, 180 days horizon
  - 8 vessels
  - 4 liquefaction terminals
  - 3 regasification terminals
Vessel schedule/inventory
Port schedule/inventory
Results
Summary

- Decision support tools for the LNG value chain developed in close cooperation with the industry
- The appropriate tool depends on problem characteristics and the study settings
  - Mixed integer problem
  - Heuristics
  - Combined method
Further information


Thanks for your attention!