Coordinating Vessel Routing, Inventories and Trade in the LNG-Supply Chain

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Talk Outline

- Introduction to the LNG business
- Decision support tools
  - MIP-based
  - Heuristics
  - (Combined)
- Results and summary
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, partially funded by the Research Council of Norway
- Close cooperation between researchers and planning personnel in the companies
The LNG value chain

- Exploration & Production
- Liquefaction
- Transportation
- Sales
- Regasification
The need for decision support

<table>
<thead>
<tr>
<th>Study mode (days)</th>
<th>Long-term (2-6 years)</th>
<th>ADP (next year)</th>
<th>Operations (3 mths)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Business development</td>
<td>Preparation of ADP submission</td>
<td>Deal scanning without urgency for remainder of year</td>
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<tr>
<td>Negotiation mode (hours)</td>
<td></td>
<td>Scheduling meetings during breaks or evenings</td>
<td>Deal negotiation with counterparty or urgent rescheduling</td>
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<tr>
<td>Meeting mode (15 mins)</td>
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<td>Bottleneck to be solved</td>
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(Stremersch et al., 2008)

ADP = Annual Delivery Program
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

\[
\gamma_{wt} = \sum_{u \in W^F} y_{uw} + \sum_{v \in V} \eta_{vuw} \quad \text{for all } i \in \mathcal{N}, w \in \mathcal{W}, t \in \mathcal{T} \quad (A.1)
\]

\[
\sum_{v \in V} \lambda_{vw} + \sum_{u \in \mathcal{W}_F} \gamma_{wt} = \pi_{wt} + \sum_{u \in \mathcal{W}_T \cup \mathcal{W}_D} \sigma_{uw} \quad \text{for all } i \in \mathcal{N}_C, w \in \mathcal{W}, t \in \mathcal{T} \quad (A.2)
\]

\[
\sum_{w \in \mathcal{W}_P} Q_w (1 - F_{vuw}^C) \psi_{wt} = \sum_{h \in \mathcal{H}} \chi_{ith} \quad \text{for all } i \in \mathcal{N}_C, t \in \mathcal{T} \quad (A.3)
\]

\[
\sum_{v \in V} \sum_{w \in \mathcal{W}_P} Q_w (1 - F_{vuw}^{BY}) \lambda_{vuw} + \sum_{w \in \mathcal{W}_D} Q_w (1 - F_{iwt}^{BW}) \psi_{wt} = \sum_{h \in \mathcal{H}} \chi_{ith} \quad \text{for all } i \in \mathcal{N}_B, t \in \mathcal{T} \quad (A.4)
\]

\[
\sum_{j \in \mathcal{N}_C \cup \mathcal{N}_B} \chi_{ith} = \sum_{u \in \mathcal{W}_T \cup \mathcal{W}_D} \psi_{wt} + \omega_{ht} \quad \text{for all } h \in \mathcal{H}, t \in \mathcal{T} \quad (A.5)
\]
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
## MIP vs Heuristics

<table>
<thead>
<tr>
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<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

![Graph showing profit over time for different systems: Invent + LNGScheduler, Invent, and LNGScheduler.](image-url)
Summary and future challenges

• 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

• Future challenges
  – Handling an uncertain future – robustness and flexibility
  – New technology: floating terminals, vessel-to-vessel transfer
  – New business: storage terminals, arctic operations
Further information


Thanks for your attention!