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

Truls Flatberg, Marte Fodstad, Oddvar Kloster, Arnt-Gunnar Lium, Vibeke Nørstebø, Frode Rømo, Kristin Tolstad Uggen and Adrian Werner

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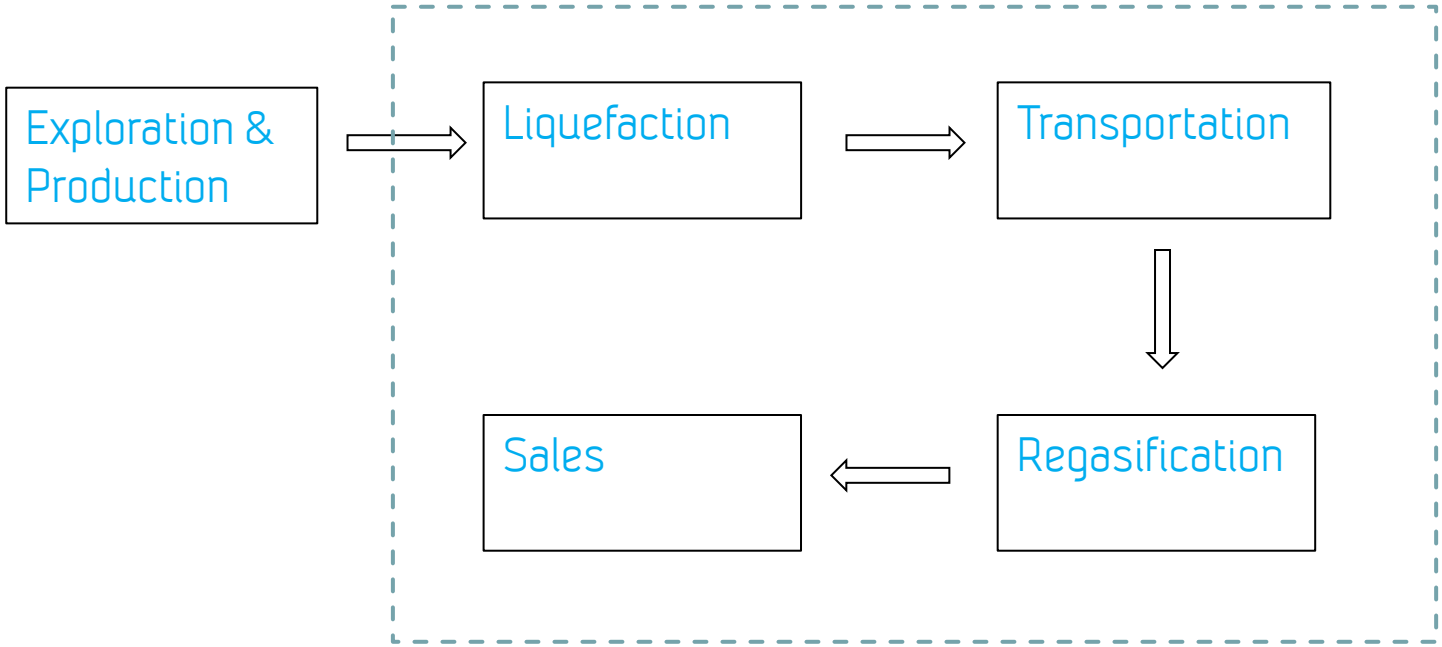
# Talk Outline

- 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



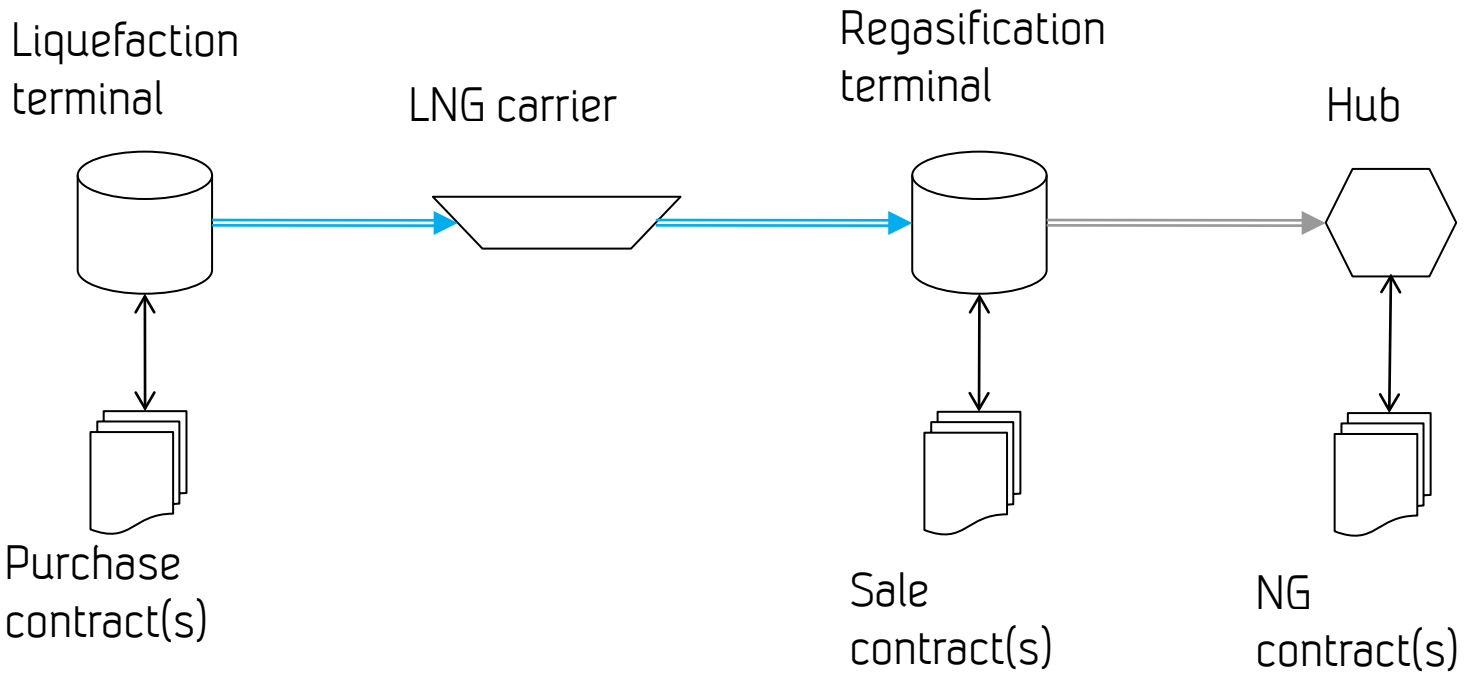
# The need for decision support

| | Long-term (2-6 years) | ADP (next year) | Operations (3 mths) |
|---|---|---|---|
| **Study mode (days)** | Business development | Preparation of ADP submission | Deal scanning without urgency for remainder of year |
| **Negotiation mode (hours)** | | Scheduling meetings during breaks or evenings | Deal negotiation with counterparty or urgent rescheduling |
| **Meeting mode (15 mins)** | | Bottleneck to be solved | |

(Stremersch et al., 2008)

ADP = Annual Delivery Program

# Conceptual model



# 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

$$\gamma_{wt} = \sum_{u \in \mathcal{W}^{\mathrm{SF}}} \sigma_{wut} + \sum_{v \in \mathcal{V}} \eta_{ivwt} \quad \text{for all } i \in \mathcal{N}^{\mathrm{P}},\ w \in \mathcal{W}^{\mathrm{P}},\ t \in \mathcal{T} \tag{A.1}$$

$$\sum_{v \in \mathcal{V}} \lambda_{ivwt} + \sum_{u \in \mathcal{W}^{\mathrm{P}}} \gamma_{ut} = \pi_{iwt} + \sum_{u \in \mathcal{W}^{\mathrm{SE}} \cup \mathcal{W}^{\mathrm{SI}}} \sigma_{wut} \quad \text{for all } i \in \mathcal{N}^{\mathrm{C}},\ w \in \mathcal{W}^{\mathrm{P}},\ t \in \mathcal{T} \tag{A.2}$$

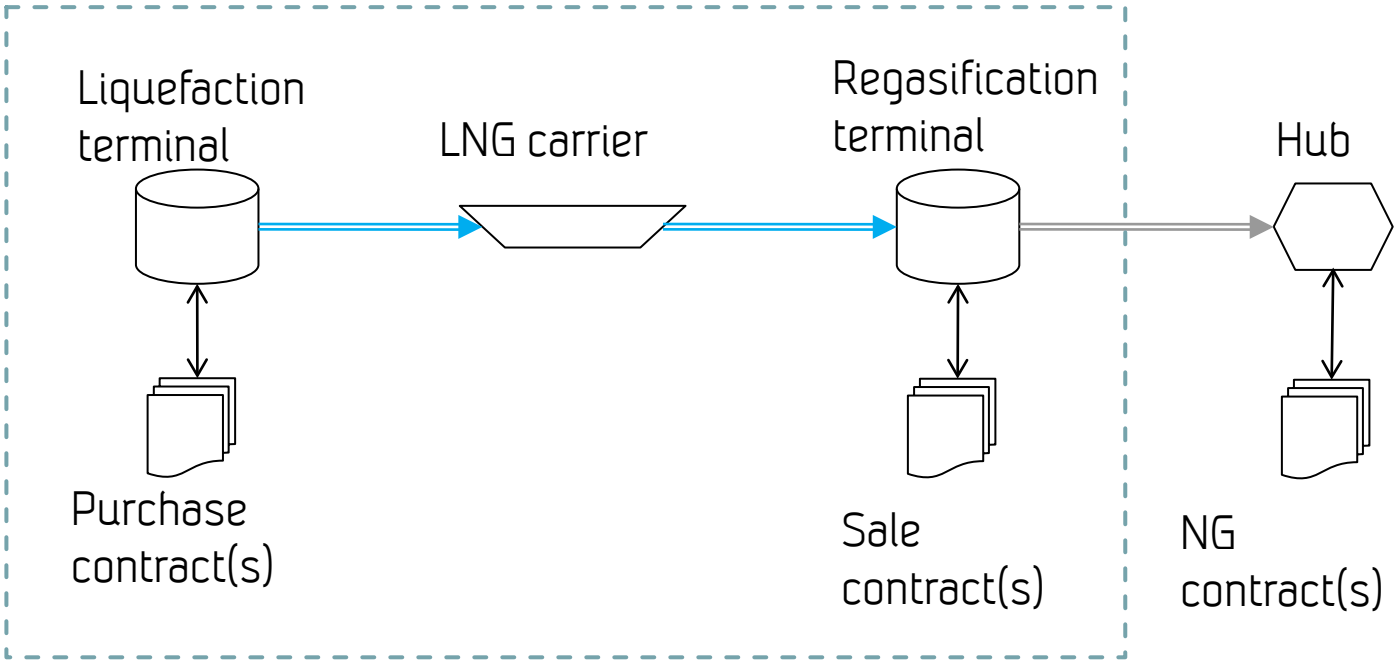
$$\sum_{w \in \mathcal{W}^{\mathrm{P}}} Q_w (1 - F^{\mathrm{C}}_{it}) \phi_{iwt} = \sum_{h \in \mathcal{H}} \chi_{iht} \quad \text{for all } i \in \mathcal{N}^{\mathrm{C}},\ t \in \mathcal{T} \tag{A.3}$$

$$\sum_{v \in \mathcal{V}} \sum_{w \in \mathcal{W}^{\mathrm{P}}} Q_w (1 - F^{\mathrm{BV}}_{ivt}) \lambda_{ivwt} + \sum_{w \in \mathcal{W}^{\mathrm{P}}} Q_w (1 - F^{\mathrm{BW}}_{iwt}) \gamma_{wt} = \sum_{h \in \mathcal{H}} \chi_{iht} \quad \text{for all } i \in \mathcal{N}^{\mathrm{B}},\ t \in \mathcal{T} \tag{A.4}$$

$$\sum_{i \in \mathcal{N}^{\mathrm{C}} \cup \mathcal{N}^{\mathrm{B}}} \chi_{iht} = \sum_{w \in \mathcal{W}^{\text{natural gas}}} \psi_{wt} + \omega_{ht} \quad \text{for all } h \in \mathcal{H},\ t \in \mathcal{T} \tag{A.5}$$

# 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

| | Pros | Cons |
|---|---|---|
| **MIP** | • Rich in details<br>• Volume flexibility<br>• Market modeling<br>• Bounds | • Slow<br>• Problems handling large problems |
| **Heuristics** | • Fast<br>• Can handle large problems<br>• Finding feasible solutions | • Only full vessel loads<br>• Few market details<br>• Greedy |

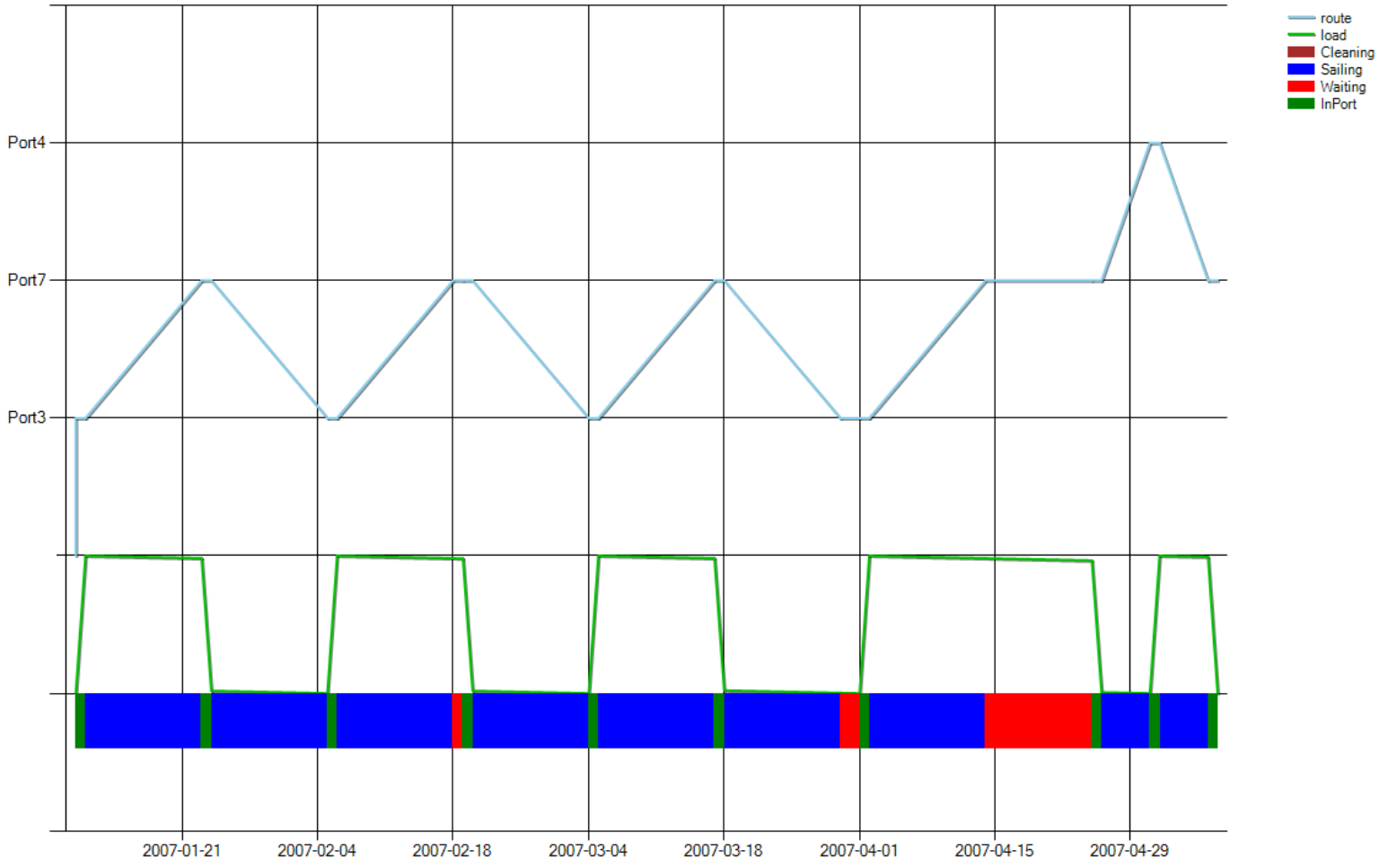
# Combined approach

- 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

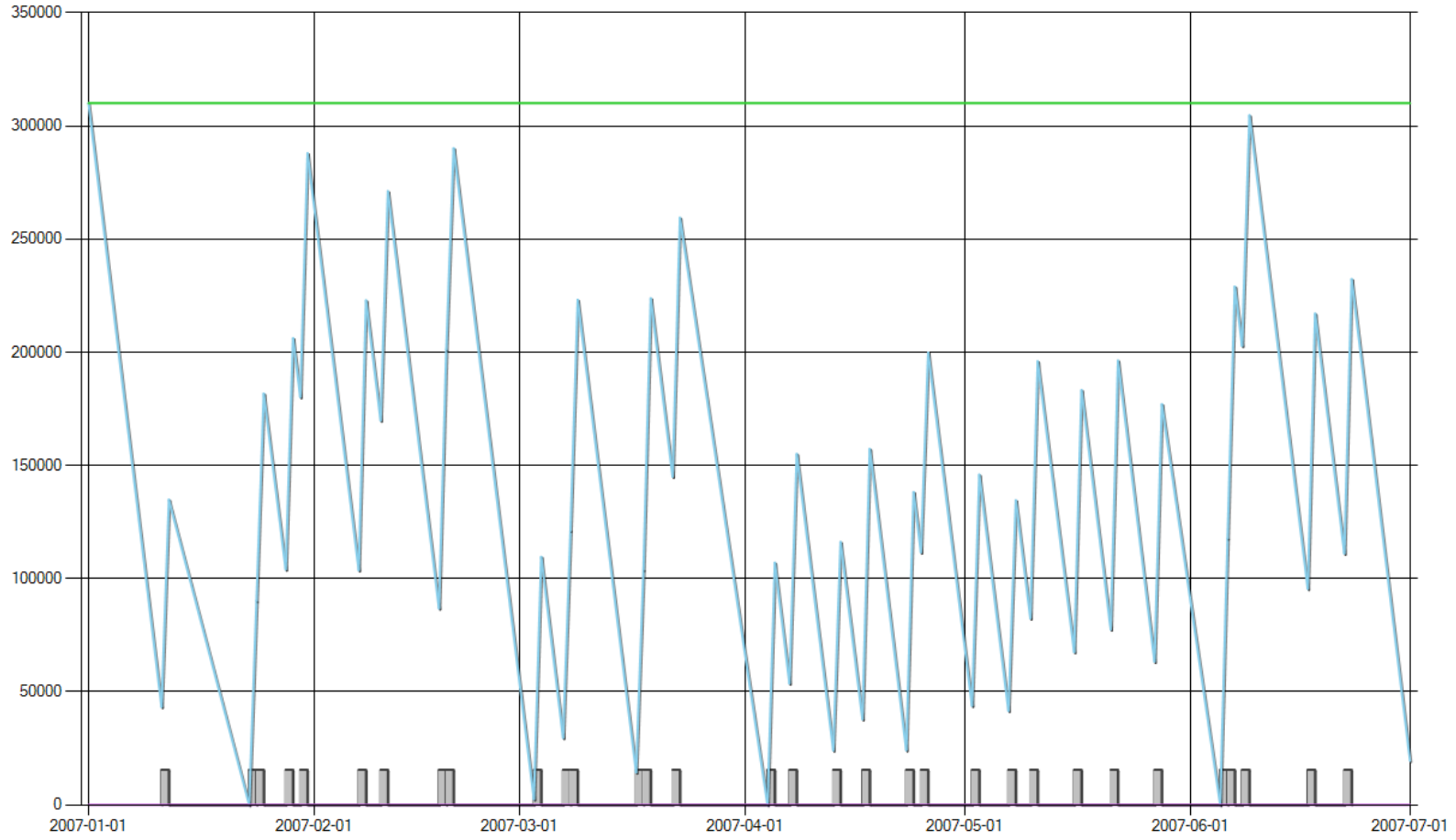
# Example

- Test case constructed from a real world setting
- Medium sized problem, 180 days horizon
  - 8 vessels
  - 4 liquefaction terminals
  - 3 regasification terminals

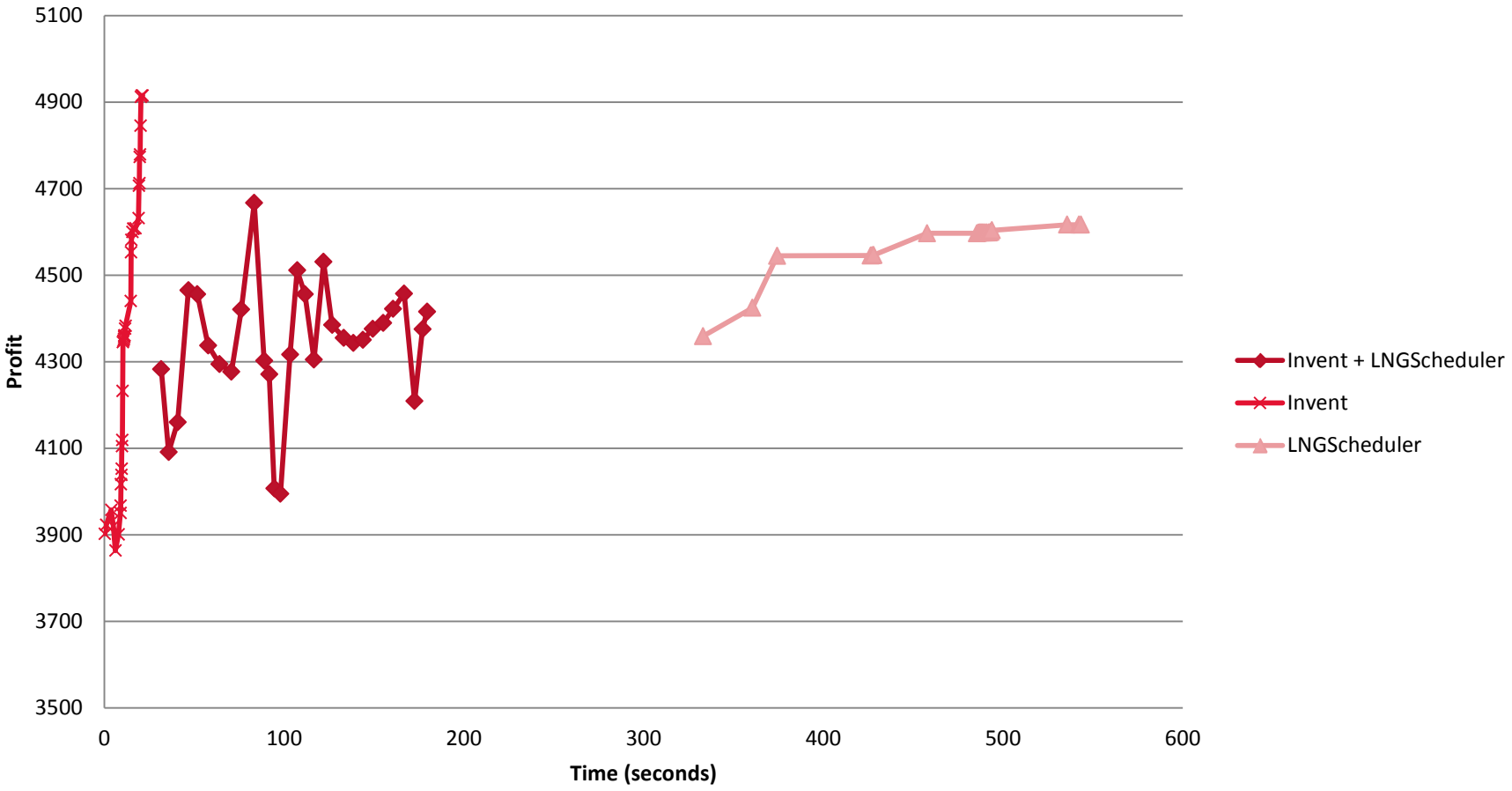
# Vessel schedule/inventory



# Port schedule/inventory



# Results


5100
4900
4700
4500
4300
4100
3900
3700
3500
Profit
0
100
200
300
400
500
600
Time (seconds)
Invent + LNGScheduler
Invent
LNGScheduler

# 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


- G. Stremersch , J. Michalek and S. Hecq, *Decision Support Software Tools for LNG Supply Chain Management*, Gastech 2008.
- M. Fodstad, K.T. Uggen, F. Rømo, A.-G. Lium, G. Stremersch and S. Hecq, *LNGScheduler: a rich model for coordinating vessel routing, inventories and trade in the liquefied natural gas supply chain*, The Journal of Energy Markets (2010).
- M. Christiansen , K. Fagerholt, T. Flatberg, Ø. Haugen, O. Kloster and E.H. Lund, *Maritime inventory routing with multiple products: A case study from the cement industry*, European Journal of Operational Research (2010)


Thanks for your attention!