A SP model and a DSS for strategic and operational gas purchase portfolio planning

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Agenda

1. The gas retail problem
2. Modelling
   1. A deterministic model
   2. A two-stage stochastic model
3. The SAPHIR System
4. Some computational experiences
5. Conclusions and outlook
Natural Gas Lines in Germany

- from the Norwegian North Sea
- from the Dutch North Sea
- from the Netherlands and the British North Sea
- from Denmark
- from Russia

natural gas lines
- existing
- planned or under construction
- natural gas import point
Abbildung 2.1: Versorgungsstufen im deutschen Erdgastransportnetz [Hellwig 2003]
German market model for gas trading

- The gas retail problem
Typically uninterruptable long term contracts guarantee to cover future demand.

Gas load for one year (starting in October)

Gas load one week in winter

Gas load one week in summer
Purchase contracts

- Yearly / monthly baseload contracts
  - Take-or-pay contracts
  - Fixed amount of gas have to be ordered at the beginning of the gas year
  - Prices refer the amount of energy, typically cheap

- Open contracts
  - Amount of energy and power level can vary in a prefixed intervall
  - Prices refer to the amount of energy AND the maximal power level
  - Typically much more expensive than baseload contracts

- Spot market
  - Gas is mainly traded in daily baseload contracts
  - Prices are fixed a day ahead
  - Prices depend largely on temperature
Cavern storages

Natural Gas Storage Facilities in Germany in 2003

Compression costs | Fixed costs | Injection costs | Extraction costs

Down times between injection and extraction mode switch.

Koberstein, König, Suhl: Gas purchase portfolio planning - The gas retail problem
The gas retail problem

- Strategic problem
  - Point of decision: before beginning of new gas year
  - Planning horizon: one gas year (12 month)
  - Strategic decisions:
    - Baseload purchase portfolio
    - Order limits for used open contracts
    - Ordered storage capacity

- Operational problem
  - Point of decision: every day with rolling planning horizon
  - Planning horizon: 3-4 days, anticipation of rest of gas year
  - Operational decisions:
    - Purchase from open contracts and spot market
    - Transportation
    - Storage injection and extraction quantities
    - Storage down-times have to be taken into account
A multiperiod network flow formulation

(First version was developed by König, Wodianka and Dada in 2004.)

Nodes: market regions, national entry points, storages

Decision Variables:
- Power purchased from purchase contracts and spot market
- Power transported on each arc
- Energy injected into and extracted from storages
- Technical variables to determine maximal power levels

Parameters
- Purchase, storage, transportation prices
- Transportation and storage capacities
- Purchase limits, etc.
A basic deterministic model

\[
\begin{align*}
\text{max} & \sum_{i \in T} \sum_{t \in T} \sum_{c \in C} E \cdot P R I C E^{SC}_{c} \cdot \Delta_{t}^{T} \cdot LOAD_{i,t} \\
& - \sum_{b \in BC} \sum_{m \in M_{b}} E \cdot P R I C E_{b,m}^{BC} \cdot \Delta_{m}^{T} \cdot p_{b,m}^{BC} \\
& - \sum_{o \in OC} \left( \sum_{t \in T_{o}^{OC}} E \cdot P R I C E^{OC}_{o,t} \cdot \Delta_{t}^{T} \cdot p_{o,t}^{OC} + E \cdot P R I C E^{OC}_{o} \cdot p_{o,t}^{OC} \right) \\
& - \sum_{(i,j) \in L} (\text{ENTRY}_{i,j} \cdot p_{\text{max}_{i,j}}^{L} + \text{EXIT}_{i,j} \cdot p_{\text{min}_{i,j}}^{L}) \\
\text{subject to} & \sum_{b \in BC} p_{b,\text{month}_{t}}^{BC} + \sum_{o \in OC} p_{o,t}^{OC} = \text{LOAD}_{i,t} \quad \forall i \in N, t \in T \\
& p_{o,t}^{OC} \leq p_{\text{max}}^{OC} \\
& p_{i,j,t}^{L} \leq p_{\text{max}}^{L} \\
& p_{i,j,t}^{L} \geq p_{\text{min}}^{L} \\
& \text{EMIN}_{b,m}^{BC} \leq \Delta_{m}^{T} \cdot p_{b,m}^{BC} \leq \text{EMAX}_{b,m}^{BC} \\
& \text{EMIN}_{o}^{OC} \leq \sum_{t \in T_{o}^{OC}} \Delta_{t}^{T} \cdot p_{o,t}^{OC} \leq \text{EMAX}_{o}^{OC} \\
& p_{b,m}^{BC} \leq p_{b,m}^{BC} \leq p_{b,m}^{BC} \\
& p_{o,t}^{OC} \leq p_{o,t}^{OC} \leq p_{o,t}^{OC}
\end{align*}
\]

\[1\] Revenues
\[2\] - purchase costs BC
\[3\] - purchase costs OC
\[4\] - transportation costs OC
\[5\]

Node balance

\[6\] \forall o \in OC, t \in T_{o}^{OC}
\[7\] \forall (i,j) \in L, t \in T
\[8\] \forall o \in OC

Determine maximal power levels

\[9\] \forall b \in BC, m \in M_{b}^{BC}
\[10\] \forall o \in OC

Power and energy limits

\[11\] \forall b \in BC, m \in M_{b}^{BC}
\[12\] \forall o \in OC, t \in T_{o}^{OC}

+ storages and spot market

Koberstein, König, Suhl: Gas purchase portfolio planning - Modelling
Sources for binary variables

- Storage fixed costs
  - Typically very few storages in the model
  - Can be handled by creating different problem instances

- Fill-level dependent injection and extraction power limits
  - Storage power limits can be approximated due to typical seasonal fill-levels

- Storage down-times
  - Have to be considered only in operational planning

Strategic problem can be handled as an LP!
A two-stage stochastic model

1st stage

Baseload portfolio
Limits for open contracts
Dimensioning of storage capacity

Realisation of gas load and spot prices

2nd stage

Gas transportation
Purchase via open contracts and spot market
Injection into and extraction from storages
SAPHIR 2.0
Rechenzentrum für Versorgungsnetze
Wehr & Partner
SAPHIR is being deployed at a large German public utility. Cost savings of 4% - 8% compared to traditional purchase strategy.
Practical case study

Test instance (from a large German public utility):

- 11 nodes, 10 arcs
- 2 monthly base load purchase contracts, 3 open purchase contracts
- 3 sales contracts
- Spot market
- 3 storages

Time aggregation:

- Hourly: 8760 time periods
- Daily: 1095 time periods
- Weekly: 159 time periods
Computational experience: deterministic model

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Solved with MOPS 9.17 Interior Point Method (without cross-over) on Intel PIV 3.2 GHz, 2GB.

Optimal objective function values:

- Hourly: 141451997.5
- Daily: 141105224.3 Error: 0.2 %
- Weekly: 136870610.0 Error: 3.2 %

Is it computationally possible to do stochastic?
**Computational experience: stochastic model**

Solve deterministic equivalent on Intel Core 2 Duo 64 bit, 8GB:

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**Computational challenges:**
- Cross-over, if basic solution is needed
- Numerical difficulties (Cplex)
- Model generation times (several hours for the above instances)
- LP preprocessing has great impact on actual model sizes

Can decomposition methods help to improve on solution times?
This is currently being studied...
Conclusion and outlook

- The gas retail problem is highly relevant for large public utilities.
- Strategic problem can be formulated as an LP and a 2-stage SLP.
- Stochastic model is solvable computationally for daily and weekly time aggregation only.

- Up to 8% of cost savings could be realized using DSS SAPHIR.
- SAPHIR has been made commercially available and will be constantly improved.

- Current and future research is focusing on:
  - Implementation of strategic model in stochastic modelling language SAMPL and SPInE (in cooperation with Prof. G. Mitra, Brunel University)
  - Incorporating risk measures CVaR, ICC into strategic problem
Thank you for your attention!