A Route Planner for Gas Transport through the Netherlands

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I: GAS
History of Gas in the Netherlands - I

1579 – 1644: Jan van Helmont invents the concept of "gas"

(actually, he discovered CO$_2$, not methane)
History of Gas in the Netherlands - II

1959: Discovery of the huge Groningen gas field

1963: foundation of the integrated company Gasunie

► ~99.8% of Dutch buildings connected to gas
► gas ~50% of the Dutch primary energy mix
1973: Policy of small fields secures long-term gas production of ~80 BCM/year

Export of ~40 BCM/year to large parts of Western Europe (D, B, LUX, F, CH, I)
Dutch Gas Transport Network (July 1st, 2005)

- ~11000 km high pressure pipelines
- gas transported ~100 BCM/year
- exit capacity ~300 GW
- 8 compressor stations with ~ 800 MW of installed power
- 5 different gas quality bands
- third-party storage

- centralized planning

(for comparison: Eemscentrale ~2.4 GW)
History of Gas in the Netherlands - IV

European integration

Liberalization of the gas market:
► entry-exit system
► capacity booking and nomination (~ "check-in")

2005 – 2009: unbundling of the gas industry:
► gas trading company
► gas transport company
► gas consulting & services
Vision of Gasunie as the Gas Roundabout of Northwest Europe
Vision of Gas as the Backbone of a Renewable Energy Infrastructure

► Use the flexibility of gas-fired power as back-up for wind and solar power

► Make natural gas, itself, renewable: certification and injection of green gas
Challenges of Gas Transport

- Entry-exit system driven by market parties
- Shorter lead times down to 1 – 2 hours ahead
- Structural changes in direction of gas supply
- Higher volatility due to intermittency of renewable power

- Concerns about security of supply
- Increased regulatory pressure on cost

Challenges of gas transport: "provide safe and reliable gas transport against minimal cost, environmentally friendly"
II: OPERATIONS RESEARCH

(ref: T. van der Hoeven, Math in Gas and the Art of Linearization)
Route Planner for Gas Transport

► Run autonomously in the background
► Find a feasible gas transport plan 24 hours ahead at all times
► Optimize the operational cost of gas transport
  ► compressor fuel
  ► nitrogen for blending
  ► flexibility
  based on nominations by market parties and own predictions of gas demand
Background: Gas Transport Simulator (GUS - Gasunie simulator)

- State estimation of the gas transport network
- Interpolation of field measurements
- Quality and consistency checks on field measurements
- Checking the feasibility of gas transport plans

Optimization with the simulator:

- Trial-and-error
- Rules-of-thumb
- Full integration of the simulator with an optimizer is not feasible
Operations Research Challenges

- ~100 entry points, ~1000 exit points, thousands of pipeline segments
- Nonlinear relation between pressure drop and flow, depending on gas quality
- Nonlinear compressor performance curves, depending on gas quality
- Compressible line pack
- Interchangeability between gas blending and compression
- Loops in the network

"more like a weather model than a typical supply chain optimization problem"
Operations Research Strategy - I

1. Starting with the simulation model, reduce the number of variables by creating pseudo pipelines, pseudo compressors, pseudo entry points, pseudo exit points, etc.

Routine for automatic network reduction on the basis of valve positions
"Econometric approach to physical modelling": Tune the pressure drop equations and the compressor performance curves to actual field data

- Routine for automatic (re-)calibration of model parameters on the basis of realizations
  - Pseudo-pipelines 24 hours
  - Pseudo-compressors 1 year
Operations Research Strategy - III

3 Convert the problem into a linear program (LP)
   ► Linearize the pressure drop equations in the current point
   ► Linearize the compressor performance curves in the current point
Operations Research Strategy – IV

4 Actually, use sequential linear programming (SLP)

5 Use more than one model
   ► Initially, do the calculations without pressure
   ► Then include the pressure variables, but keep the quality constant
   ► Finally, use the full model

6 Gradually increase model stiffness

7 Introduce flow stabilizers
Result I: Security of Supply

😊Find a feasible, day-ahead gas transport plan at all times, based on nominations by market parties and predictions for gas demand in the public market

► Currently: robust within pressure margins
► In the future: robust against alternative scenarios
Result II: Minimal Cost

Dispatchers configure certain set points and ranges prior to optimization

► The route planner runs in the background, autonomously producing "optimal" gas transport plans

► After optimization, plans are fed into the simulator for manual fine tuning

😊 Determine day-ahead, cost-optimal gas transport plans, based on nominations by market parties and predictions for gas demand in the public market
Result III: new intuition for gas transport in the new world

- Dispatchers are living in a "pressure" world, not a "flow" world

- Ageing human assets

  - Develop awareness of the operational cost of gas transport

  - Develop intuition and new rules-of-thumb

  - Train new operators
Key findings and new insights

► Different order of preference of compressors
► Flexible use of blending stations
► Extensive use of the flexibility offered by contractual means and line pack
► The main instabilities are caused by the blending stations
► Inaccuracies resulting from automatic network reduction are exploited, and lead to unrealistic plans
► The optimizer outsmarts the dispatcher time and again, but does not explain how
Result IV: Energy Management of Electric Compressors

- The advent of electric compression creates opportunities for trade-off between line pack in the gas network and imbalance of the electric grid through the spot market for power production ramp-up/ramp-down

- Current trials with an integrated energy management system for fuel gas and electricity show promising results
III: DEMONSTRATION
Concluding remarks I: GAS

► The route planner has run without problems for more than one year
► The route planner is capable of finding optimal day-ahead plans in a highly complex gas transport network
► The resulting plans must be read as providing directions and not details
► The route planner is a powerful tool for developing insight in the changing gas transport landscape
Concluding remarks II: OR

► Since most algorithms are loops around linear programs, why not design your own loop around linear programs?
► Very good results with an econometric approach to physical modeling
► "anything goes": use all the tricks you know
► Spend 50 % of your time on the relationship with the client, 40 % on the problem formulation, and 10 % on modeling and optimization
Thank you for your attention

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