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A Route Planner for Gas Transport Through The Netherlands

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ABSTRACT

In this paper we present the first results of the development of an on-line model-based decision support tool, also known as the “route planner for gas transport”. The route planner is an on-line tool that advises dispatchers on how to minimise operational costs while maintaining security of supply. The tool consists of a model of the Dutch gas transport network that can be loaded with actual network status and forecasts for upcoming 24 hours. The output is the cost optimal use of compression, nitrogen ballasting and supply flexibility for network balancing i.e. the most cost effective route gas can take through the Gasunie network to meet end-user demand.

The non-linear dynamics in the network model are handled via a successive approximation approach. Starting with an initial seed, based on the actual network state in combination with the last accepted dispatching plan, a linear transport model is solved iteratively until sufficient convergence is achieved.

Important milestone of the route planner development has been the demonstration of “apparent intelligence”, an essential feature of any decision support tool. By presenting the route planner with dilemma’s that could occur in practice and rating the proposed solution with experts, we established that the route planner displays “common sense”. Moreover, the first results indicate that a cost reduction of 5 to 10 % is feasible.

MOTIVATION

With the unbundling of the integrated company Gasunie in 2005 in the trading company GasTerra and the transport company Gasunie, the day-to-day gas dispatching process has become considerably more complex. The network is now open to a much larger number of shippers and gas brought in to the network can be traded on the TTF spot market. In the mean time indigenous supply flexibility has decreased, new pipelines, LNG terminals, storages come on-line and energy prices have doubled. The challenge for the transport company Gasunie is to reduce costs for compression, gas quality conversion and gas supply flexibility in this new market environment in order to maintain profit margins.

Gasunie Engineering & Technology is investigating the use of an on-line model-based decision support tool for gas dispatching, also known as the "route planner for gas transport". The task of the route planner is to provide real time information on the most cost effective manner to operate the gas transport network in the upcoming 24 hours. The name “route planner” was chosen for two reasons: a) the purpose of the tool is to find optimal routes for gas through the transport network and b) to provide a useful metaphor for establishing the desired functionalities of the tool.

DUTCH GAS TRANSPORT NETWORK

The route planner has to operate in the environment of the Gasunie gas transport system. The key technical features are [1,2]:

- 3750 miles [6000 km] of high pressure transport pipeline and 3750 miles of medium pressure regional distribution pipeline, summing up a total of 7500 miles [12.000 km].
- 3390 BCF [96 BCM] gas transported annually.
- 15 compressor stations, 35 blending stations, (4 including Nitrogen), 43 production entries, 16 border points and 1180 delivery points.

Key economic figures Gasunie:

- 1.3 billion euro annual revenue, 435 million euro profit after taxes.

- Annual use of 6.7 BCF [190 MCM] gas and 150 GWh electricity.

What sets the Gasunie system apart from most other transport systems is the wide range of gas qualities that need to be dealt with. We distinguish the gas qualities: H^+ from Norway, H, H^- and L from the small Dutch fields and G from the large Groningen field. Calorific values range from 44 MJ/m^3 (H^+) to 35 MJ/m^3 (G) and blending stations allow for downward quality conversion (i.e. H to L, L to G, etc). H-gas is used for indigenous power generation and industrial processes and is exported to the UK, Belgium and Italy (via German network). L-gas with a wide quality band is supplied to the Belgium and German residential/commercial markets and G-gas with a narrow quality band is used for the Dutch residential/commercial market.

Both L-and G exits show large seasonal demand swings and can be very unpredictable, especially during flank periods of the heating season. This combined the interconnection of the various gas quality networks via blending stations creates a dynamic interplay that dispatchers and the route planner must deal with.

SCOPE

END-USER CRITERIA

The main challenge of the route planner project is to develop and test prototypes that have the best chance of meeting the end-user requirements and expectations [3]. From previous projects and experiences and through discussions the following general criteria were identified towards successful implementation:

1) Completeness: the route planner should take into account all sources of daily operational costs in order to determine the overall cost optimal plan. Moreover the plan should span a period of typically 24 hours. Furthermore it should find a solution to all situations that could arise in practice.

2) Accuracy: the route planner must handle the network dynamics with such accuracy that predictions are considered trustworthy by the end-user.

3) Robustness: the route planner must be able to mitigate the intrinsic uncertainties in gas entry and exit prognoses in order to assure that security of supply is not compromised.

4) User-friendliness: The route planner should provide the end-user with enough insight and means for interaction to establish a working relationship. The route planner should find a solution within several seconds.

5) Compatibility: The route planner should be implemented in such a way that it can be maintained for a prolonged period of time.

During the first development stages the focus has been mainly on the completeness and accuracy criteria, in addition to the user-friendliness arising from the "apparent intelligence" of the tool. However the route planner prototypes have been designed in such a manner that eventually all criteria can be met.

ECONOMICS

The goal of the route planner tool is to eventually create real economic value for the end-user on a day-to-day basis. It can do so by:

- Minimizing daily operational costs for compressor fuel, nitrogen ballasting and use of entries for network balancing.
- Assisting dispatchers in avoiding network operation outside of contractual limits.
- Quantizing the up to now unclear costs of specific contractual arrangements with shippers and neighboring transmission system operators.
- Streamlining the daily planning processes and allowing dispatchers to focus more on their core activities.

The main target set for the route planner is to shave at least 5% of the total operational costs. This value is derived from previous experiences with decision support tools and is considered to be not unrealistic by the Gasunie experts. Given these savings, the total costs for the implementation of the route planner tool will be earned back in ~1 year. The other economic benefits can then be considered as a bonus.

Modelling approach

The route planner has many aspects that will be addressed during the development stage. Most important are:

- Reducing a complex network to a simplified version containing all essential features.
- Designing and testing the optimiser engine.
- Creating a user friendly interface.
- Managing the large information streams.

In this paper we will focus mainly on the optimiser engine as it is considered the most innovative and critical part of the tool.

OPTIMIZER ENGINE DESIGN

In order to have the full creative freedom during the early stages of development we chose to work with the AIMMS rapid prototyping platform for optimizers using a CPLEX solver [4]. Simplified models of the gas transport network were constructed in a similar manner to those in our simulation tools MCA and GUS [5,6]. Figure 1 illustrates the manner in which the simplified networks are constructed, in this case a blending station:

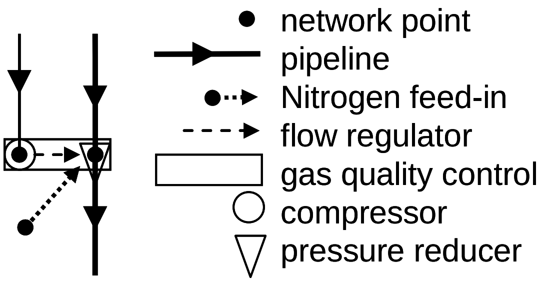

Figure 1 - example of the network blocks used in the route planner (blending station).

Network points connect pipelines and may contain a gas entry or an exit, compression, pressure reduction or may be part of a blending station. By assigning multiple properties to a single network points the total number of network points can be limited, hence minimizing data streams and calculation time. Flow through the (generalized) pipelines is allowed to be bi-directional and the intrinsic gas buffer of the pipelines (line-pack) is included in the flow balance.

VARIABLES AND PARAMETERS

The main variables to be determined by the solver engine are:

- Pressure per node.
- Compression and pressure reduction per station.
- Transport per pipeline, including line pack.
- Entry and exit flows.
- Gas blending and nitrogen flows.

The main input parameters are:

- Pipeline volume and flow-pressure drop characteristics.
- Desired/nominated entry and exit flows.
- Compressor station efficiency and range.
- Blending stations quality bandwidths and Nitrogen availability.
- Nitrogen and fuel prices.
- Fines for exceeding contractual limits.
- Gas quality of entries.
- State of the network at T=0.

Main constraints are:

- Minimum and maximum pressure per node.

Objective:

- Minimize total cost.

The gas quality in the network is managed in a special manner. A “preprocessor” runs a (LP) algorithm once to find an initial gas transport route and calculates the gas quality throughout the network. The preprocessor then calculates the allowable range for the blending flow, reruns the LP algorithm and refines the blending flow boundaries, etc.. With this iterative control loop the solver algorithm can focus solely on routing flows within the preset boundaries, guaranteeing that the optimal solution will be within gas quality specifications.

ROUTE PLANNING

After loading network model, the route planner is asked to supply the requested exit flows at a minimum pressure and for a minimum of total costs. The flow can be delivered via pipeline transport, line-pack, blending stations and entry points. The associated pressure gradients can be created from entry supply pressure, compressor stations and pressure reducers. The main cost functions are fuel for driving compressors, nitrogen feed-in at blending stations and penalties for using entry points for network balancing purposes only. The main sources of flexibility for the route planner are the operational bandwidths of the blending stations and using the line pack within the network.

NON-LINEARITIES

The route planner would have been presented with a typical linear logistical problem, if it were not for unavoidable non-linearity’s associated with gas transport. The main sources of non-linearity are:

- the non-linear relation between flow pressure drop across pipelines: $P_{in}^2 - P_{out}^2 = \lambda_* Q^2$, where P_i are the entry and exit pressures, Q the flow and λ a characteristic pipeline constant,
- dependence of compression efficiency η_{comp} (and hence fuel costs) on flow and compression ratio,
- Control of the gas quality via blending stations.

The method used to address the non-linearity was expressing the equations in terms of *variables* Q, P and *parameters* Q_{mean}, P_{mean}. In this manner the non-linear problem is translated into a LP problem developed around a set of Q_{mean}, P_{mean}’s and iterated by a preprocessor in N steps until sufficient convergence is established , i.e. $Q \sim Q_{mean}$, $P \sim P_{mean}$. The typical strong points of this successive approximation approach are:

- Solving N times a LP problem still takes only little calculation time.
- Smoothed but non-linear empirical data can be included in finding cost optimal routes. Figure 2 illustrates this in case of compression efficiency of one particular station.

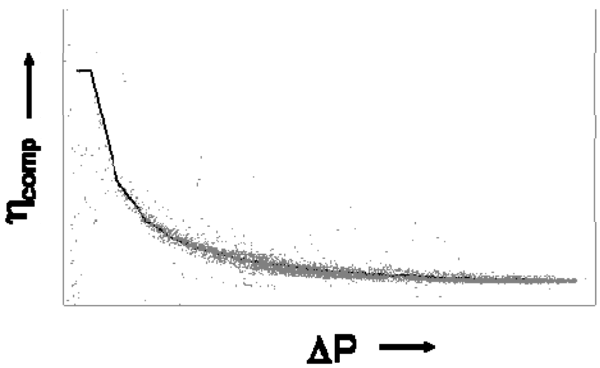

Figure 2 - measured performance data of a compressor station (points) and relation included in the route planner (solid line).

The typical weak points of the successive approximation approach are however:

- An initial state or "seed" of P_{mean}, Q_{mean} is required and the solutions may depend on the initial starting point. Moreover no guarantee can be given anymore that solutions represent true global optima.
- Networks with loops can flip-flop between solutions and fail to properly converge.

The first issue is of minor importance to a decision support tool since the application runs real time and the state of the network at T=0 is given and will be incorporated in the final solution. Therefore no need for estimating the initial values or seed from blank. Actually the main task of the route planner will be to update the previous plan, the rolling horizon approach. As discussed by Sekirnjak [7], it is even not desirable to move away from an initial state too quickly and considering the uncertainty of for example load forecasting, in practice the true optimum is of lesser significance.

The convergence issue is a more serious one. It is currently addressed by analyzing the magnitude of $\Delta Q = Q - Q_{mean}$ in order to spot possible oscillations. Depending on the type and magnitude of the oscillation the case is re-run with dedicated additional constraints or changes in settings in order to address the specific issue. This is however still very much work in progress.

EMBEDDING IN END-USER ENVIRONMENT

The route planner was designed with a click-on approach for optimal flexibility and minimal interference with the daily operations in mind. Figure 3 illustrates the envisaged process: the route planner receives all required information concerning network configuration, flow and gas quality forecasts, etc. from the main simulator. With this data a case is constructed and presented to optimizer. The solution is then either inspected automatically or if necessary by the end-user. When a plan is accepted it can be uploaded into the simulator for verification, closing the total loop.

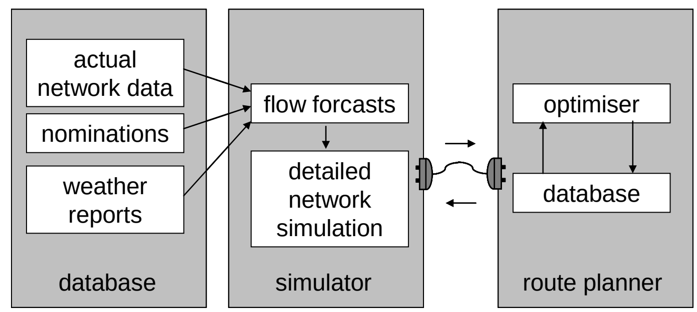

Figure 3 - a click-on approach to the route planner in to the main Gasunie database and simulator.

RESULTS

To test the proof-of-principle of the route planner only a section of the total network was modeled (figure 4) in order to not get lost in complexity in the early stages of development. The southern part of the Gasunie network was selected since it has most of the key features of the total network and is effectively an island within the total network. An additional (virtual) compressor stations was added upstream to the Ravenstein station in order to investigate the handling of the interplay between compressor stations.

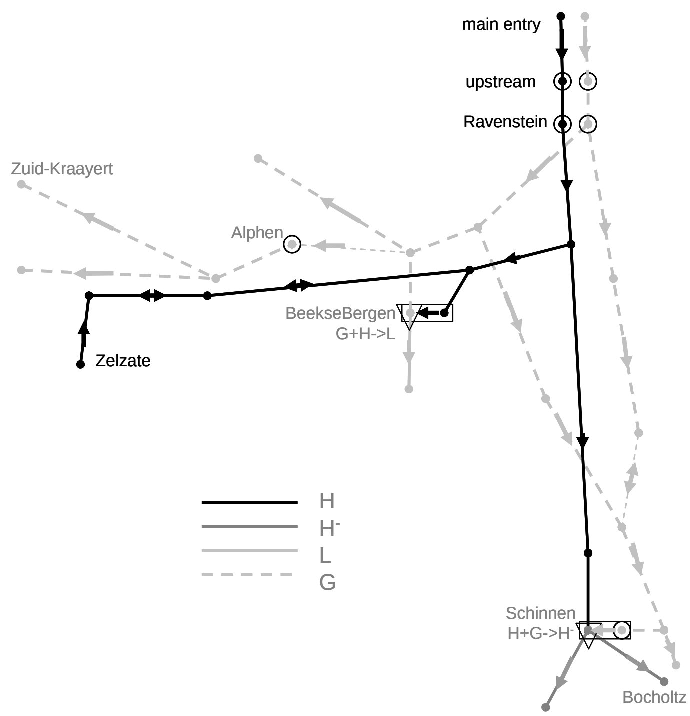

Figure 4 - route planner model in the gas transport network in the south of the Netherlands for the H^+, H^-, L and G gas quality.

The types of choices the dispatchers and hence also the route planner will need to make for cost optimization are:

- Network balancing with entries versus strategically planning the use of the intrinsic network buffer.
- Balancing the use of compression power between the stations upstream (H & G), Ravenstein (H &G), Alphen (G), Schinnen (G).
- Degree of blending at the Beeksebergen and Schinnen stations.

The route planner must mitigate the loop in the G network and the minimum pressure constraints on each exit point and the required pressure difference for the blending stations to operate.

NORMAL OPERATION

By replaying historic cases we could compare the route planner performance to the actual realization. During normal operations in winter, we observed that:

- The choices made by the route planner during normal operations resemble closely those made by dispatchers (illustrated by figure 5). The main cause of differences is not model inaccuracy but to slightly different use of compression and gas blending stations.
- With sufficient supply flexibility the route planner will focus on minimizing the total amount of work required to deliver the exit flows. This is achieved by a) exactly meeting the exit pressure constraints including a sufficient margin as specified by the end user and b) operating the blending stations at high levels in order to best distribute the load across the network and minimizing the overall pressure drop.
- The route planner was able to save up to 10% in compression fuel use in the higher flow winter cases.

However the latter value should be taken as the upper level since the route planner did not yet take the uncertainties in flow predictions into account, something dispatchers will do. Important is however that there appears to be a cost saving potential through careful overall work minimization alone and the initial 5% cost shaving target is still realistic. Moreover, the aim is expand the route planner with a risk analysis tool for optimizing operational safety.

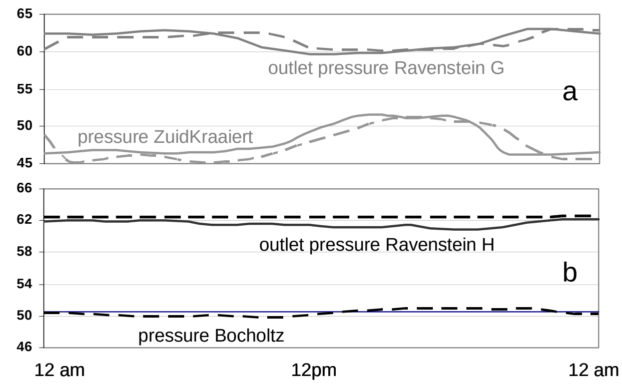

Figure 5 - Example of route planner outlet pressure propositions and predictions with actual realization (solid line route planner, dashed line actual realization).

APPARENT INTELLIGENCE

In order for the route planner to become a true decision support tool, a strong focus must also be placed on its ability to “think like a dispatcher”. A decision support tool that appears to perceive a different reality to an end-user will not gain the benefit of the doubt by the latter. This “apparent intelligence of the route planner” was tested by confronting the route planner during normal operation with an additional dilemma and observing the proposed escape route. The effort of the route planner was rated by an expert panel.

Dilemma 1: small compression restriction
It is no longer possible, but only just, to supply the requested pressures in the g-gas system with the preferred compressor station.
Solution: the route planner relieved the G-gas network through the blending stations rather then switching on a second compressor station and operating both stations in a less efficient range. This was indeed considered by the experts as the “best way out”.

Dilemma 2: large compression restriction
It is no longer possible, now by a wide margin, to supply the requested pressures in the g-gas system with the preferred compressor station.
Solution: the route planner proposed to switch over completely to a compressor station that can supply the required pressures. Again the option of operating two stations in partial load is avoided. This was also considered as the expected and desired solution.

Dilemma 3: preparation for exit point fluctuation.
A large demand peak is expected on a main exit but there is not enough entry capacity available to meet this demand.
Solution: The route planner proposes to slowly accumulate a network buffer in the hours before the exit spike. The slow accumulation is to avoid the penalties for using G and H entries out of their boundaries. During the exit peak the blending stations are used to transfer the G-gas line-pack to relieve the troubled section of the H-gas network. This was considered an "elaborate but elegant" solution.

These tests indicate that the route planner can find the most sensible routes out of trouble in addition to finding merely cost optimal. One potential issue may be that for much larger networks the proposed "escape routes" may become even too complex for any human to understand.

FUTURE WORK

With the results obtained so far enough confidence has been build to take on the entire network, around four times as large as the network displayed in figure 4. The main issues that need to be addressed are:

- Creating the reduced network models on which the actual network configurations can be mapped.
- Mitigating the increasing tendencies to flip-flop due to the introduction of various network loops.

In addition to the expansion of the network also the user-friendly GUI's and management of the large data streams will be addressed.

As this work progresses various spin-offs are expected. A strong candidate is the cost reduction by optimizing the operational safety margins. Furthermore the tool will be investigated for off-line purposes such as tackling complex planning issues and dispatcher training purposes.

SUMMARY

We have presented the results obtained with the route planner for gas transport, a prototype decision support tool for gas dispatching. The aim of the tool is to assist the Gasunie dispatchers during daily operations in reducing the costs for compression, nitrogen ballasting and use of supply flexibility for network balancing. First results indicate that a cost reduction of 5 to 10 % is feasible.

An important design choice has been to use a successive approximation approach towards addressing non-linearities. Since a decision support tool must start with actual network state at T=0 and can use the previous plan for an update (rolling horizon), a "seed" is available to linearize the model and solve iteratively until sufficient convergence is achieved.

A milestone in the development so far has been the demonstration of an "apparent intelligence" by the tool. By posing dilemma's to the decision support tool and observing the subsequent chosen solutions were considered as "clever and sensible" by experts, a major step has been taken towards end-user acceptance.

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Author biographies

Dr. Jan Willem Turkstra is a researcher and project manager at Gasunie Engineering&Technology (GET), the R&D department of N.V. Nedderlandse Gasunie. He received his PhD. degree in 2001 for his work on interactions of highly charged ions with laser cooled Sodium atoms. At GET he developed a simulation environment for the analysis and optimization of complex domestic heating and cooling appliances such as solar combination boilers and micro-CHP. Currently he is involved in the development of intelligent energy grids and innovative methods for the optimization of the national gas transport system.

Bert Kiewiet has a background in chemical engineering, specializing in process design methodologies. He is currently a project leader in the design of novel methods for technical capacity planning and optimisation of the gas infrastructure at

Gas Transport Services - The Netherlands. Furthermore he is involved in the long term gas infrastructure development projects, applying advanced simulation and optimization tools to design network expansions. Earlier research and consultancy projects focussed on the model based optimisation and scheduling of large scale energy intensive processes.

Dr. Frits Bliek is a consultant and project/programme manager at Gasunie Engineering & Technology (GET), the R&D department of N.V. Nederlandse Gasunie. His key qualifications are 15 years of research and consultancy experience in technical, process and strategic aspects of the energy market. With a strong expertise in energy distribution & grid balancing, market liberazation, business process modelling & automation, change management. Currently he is working on intelligent energy grids and economic optimization of the Dutch national gas transport system of Gasunie.

FIGURES

Figure 1 – example of the network blocks used in the route planner (blending station).

Figure 2 – measured performance data of a compressor station (points) and relation included in the route planner (solid line).

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