Selection of Severe Transport Situations in the High-Pressure Gas Network of GTS

Introduction of a Similarity Measure based on Optimal Flow Patterns

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TU Delft

gasunie transport services

Gasunie Transport Services

- Gas Transmission System Operator of the Netherlands
- Regulated part of the holding Gasunie
- Ensure safety of supply of natural gas
- No control on entry and exit capacities

Gasunie Transport Services

Complex network

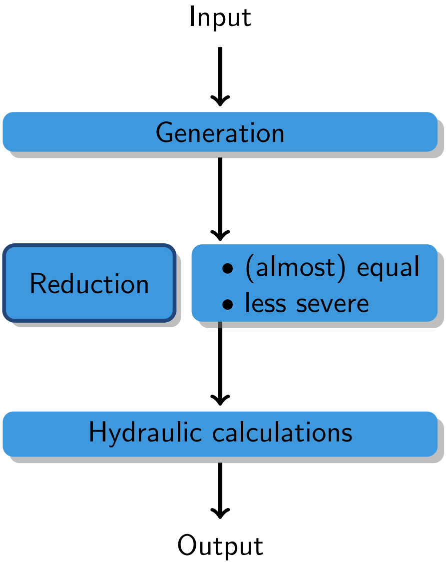
- Entry and exit points (end points)
- Pipelines: length, diameter
- Loops
- Storages
- Compressor and blending stations

Goal of the research

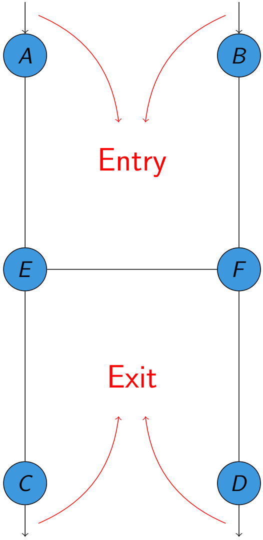
- Extremely many gas transportation situations possible
- Computations are time consuming
- Stress tests: severe and realistic transport scenarios
- Still a large set of scenarios

Find a small representative set of stress tests

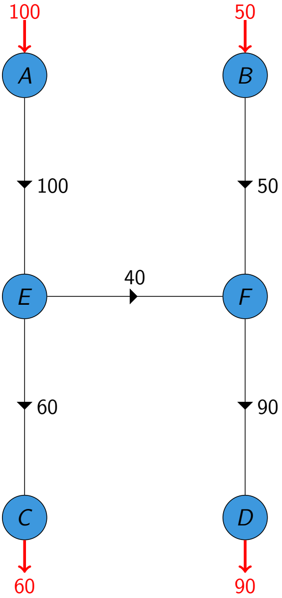
Process of checking scenarios



Example: H-network



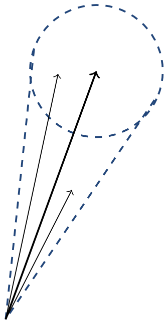
End point representation



$$\begin{matrix} A \\ B \\ C \\ D \end{matrix} \quad \begin{pmatrix} 100 \\ 50 \\ -60 \\ -90 \end{pmatrix}$$

End point representation

- Generation of stress tests
    - Taking all directions into account
    - Many scenarios
- Reduction
    - Equal
    - Similar
    - Less severe
- Find distance function



Example: One Pipeline Network

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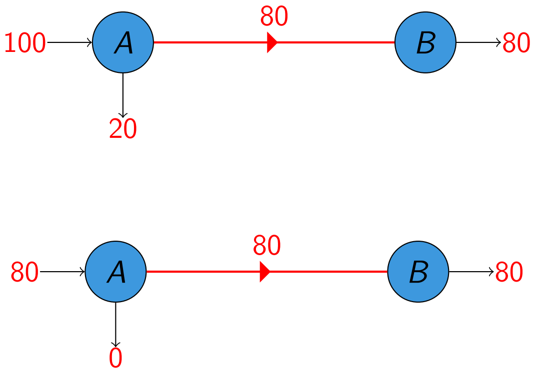


$$x = \begin{pmatrix} 100 \\ -20 \\ -80 \end{pmatrix}$$

$$y = \begin{pmatrix} 80 \\ 0 \\ -80 \end{pmatrix}$$

x, y: same transport load

Example: One Pipeline Network

$$x - y = (20, -20, 0)^T$$

$$\begin{aligned}\mathcal{L}_1(x-y) &= \sum_i |x_i - y_i| \\ &= 20 + 20 \\ &= 40 \neq 0\end{aligned}$$

$$\begin{aligned}\mathcal{L}_2(x-y) &= \sqrt{\sum_i (x_i - y_i)^2} \\ &= \sqrt{400 + 400} \\ &= 20\sqrt{2} \neq 0\end{aligned}$$

Quadratic Form Distance

$$QFD_{\mathbf{A}}(x, y) = \sqrt{(x-y)^T \ \mathbf{A}(x-y)}$$
$$\text{with } a_{ij} = 1 - d_{ij}/d_{\max}$$

$$\begin{aligned} x, y &: \text{vector of capacities} \\ d_{ij} &: \text{transport distance from } i \text{ to } j \\ d_{\max} &: \max_{ij} d_{ij} \end{aligned}$$

Example: one Pipeline Network

$$\mathbf{A} = \begin{pmatrix} 1 & 1 & 0 \\ 1 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad x - y = \begin{pmatrix} 20 \\ -20 \\ 0 \end{pmatrix}$$

$$QFD_{\mathbf{A}}(x, y) = \sqrt{\begin{pmatrix} 20 & -20 & 0 \end{pmatrix} \begin{pmatrix} 1 & 1 & 0 \\ 1 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 20 \\ -20 \\ 0 \end{pmatrix}}$$
$$= 0$$

Quadratic Form Distance

- Works for complex networks
- High-pressure network: 400×400 matrix
- $QFD_{\mathbf{A}}$ is not a metric distance function

$$QFD_{\mathbf{A}}(x, y) = \sqrt{(x - y)^T \; \mathbf{A}(x - y)}$$

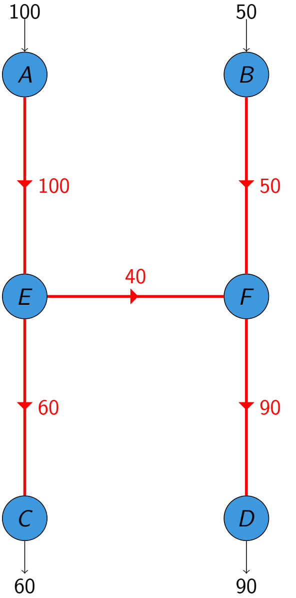
Transport moment

Transport moment (T): linear measure of transport load

$$T = \text{flow} \times \text{transport distance}$$

$$Q \cdot \Delta p \sim Q \cdot L$$

Flow representation



End point:

$$\begin{matrix} A \\ B \\ C \\ D \end{matrix} \quad \begin{pmatrix} 100 \\ 50 \\ -60 \\ -90 \end{pmatrix}$$

Flow:

$$\begin{matrix} AE \\ BF \\ EC \\ FD \\ EF \end{matrix} \quad \begin{pmatrix} 100 \\ 50 \\ 60 \\ 90 \\ 40 \end{pmatrix}$$

Weighted norm

$$\mathcal{L}_1^L(x,y) = \sum_i L_i |x_i - y_i| \qquad \text{(Weighted } \mathcal{L}_1\text{-norm)}$$

$$\mathcal{L}_2^L(x,y) = \sqrt{\sum_i L_i^2 (x_i - y_i)^2} \qquad \text{(Weighted } \mathcal{L}_2\text{-norm)}$$

x_i, y_i : flow through pipeline i of scenario x, y

L_i : length of pipeline i

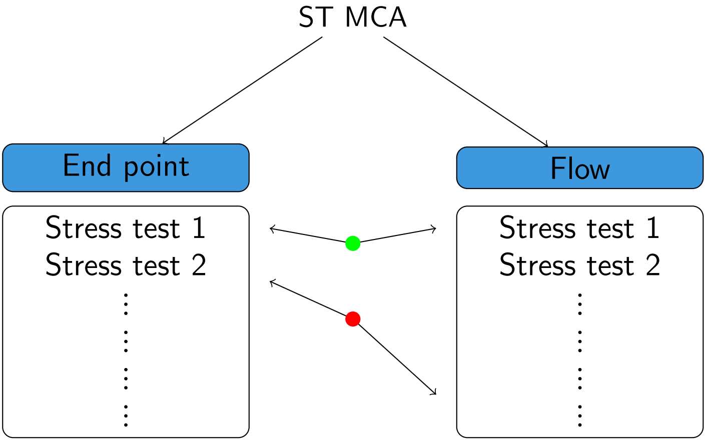
- $\mathcal{L}_1^L$: close to transport moment

Comparison of representations

Representation	End point	Flow
Pre-calculations	Less	More
Close to network physics	Less	More
Simple distance function	Less	More
Metric distance function	No	Yes
Adaptable distance function	Difficult	Easily

Possible adaption: weighted $\mathcal{L}$-norm: $L \rightarrow L/D^5$

Analysis of clustering



Analysis and Result

Analysis

- Measure leads to clustering of stress tests
- Compare clustering of both representations

Result

The more complex the network, the more difference in clustering in both representations

Conclusions

- Representation of transport scenarios in physical terms is possible:

flow representation

- Simple distance function, with physical transport properties
- Clustering similar for small, different for complex networks
- From experiments unclear which clustering is the best

Recommendations

- Hydraulic calculations for comparison (simple network)
- Analyse the effect of loops
- Add more network information
  - Analyse L/D^5 instead of L
  - Addition of pressure drop
- Direct generation of flow pattern

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Distance functions for stress tests

$$QFD_{\mathbf{A}}(x,y) = \sqrt{(x-y)^T \ \mathbf{A}(x-y)} \qquad \text{(Quadratic Form Distance)}$$
$$\text{with } a_{ij} = 1 - d_{ij}/d_{\max}$$

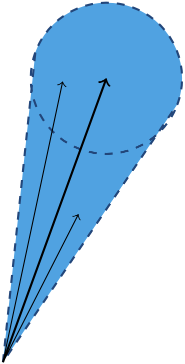
$$\mathcal{L}_1^L(x,y) = \sum_i L_i |x_i - y_i| \qquad \text{(Weighted } \mathcal{L}_1\text{-norm)}$$
$$\mathcal{L}_2^L(x,y) = \sqrt{\sum_i L_i^2 (x_i - y_i)^2} \qquad \text{(Weighted } \mathcal{L}_2\text{-norm)}$$

Pressure Drop Equation

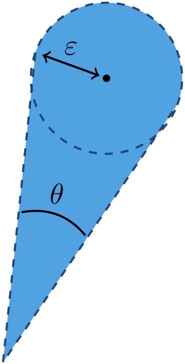
$$p_{in}^2 - p_{out}^2 = k \cdot \frac{L}{D^5} \cdot Q \cdot |Q|$$

- p_{in}: pressure at begin of pipeline
- p_{out}: pressure at end of pipeline
- k: constant
- L: pipeline length
- D: pipeline diameter
- Q: flow through pipeline

Cone of Clustering



Clustered scenarios



Definition cone

Transport moment

End point representation

$$T(\tau) = \sum_j c(X_j) d(\tau, X_j) - \sum_i c(N_i) d(\tau, N_i)$$

Flow representation

$$T = \sum_i L_i Q_i$$

QFD in flow representation

$$
\begin{aligned}
QFD(x) &= \sqrt{x^T \begin{pmatrix} w_1^2 & & \\ & \ddots & \\ & & w_n^2 \end{pmatrix} x} \\
&= \sqrt{\sum_i (w_i x_i)^2} \\
&= \mathcal{L}_2^w(x)
\end{aligned}
$$