Transport planning of the Dutch gas network

Finding challenging transport situations by a sufficient method

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Overview


feeder station(s) (entry points)
compressor and blending station
compressor station
blending station
export station
underground gas storage
LNG facility
nitrogen injection
LNG terminal
pipelines - Groningen gas
pipelines - high-calorific gas
pipelines - low-calorific gas
pipelines - desulphurised gas
pipelines - nitrogen
air separation facility
underground nitrogen storage
Groningen
BBL

Gas transport

- Realistic transport situation
  - Boundaries of capacity on e/e
  - Flow conservation
- Transport moment: quantity for transport load
  - Dependent of length, amount of flow, pressure, diameter of pipe, temperature
  - Length and flow
- Transport moment equations:

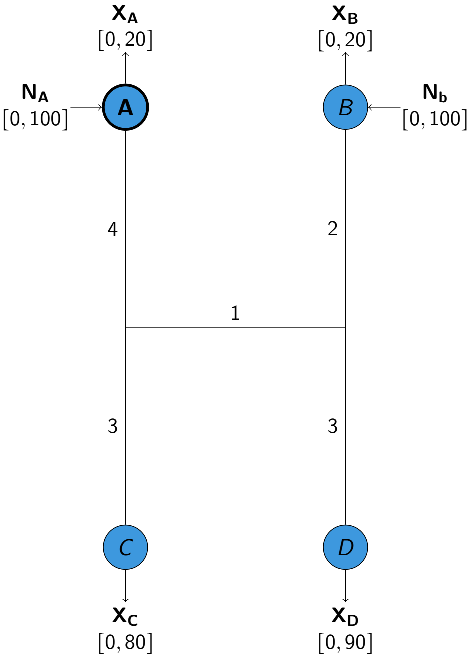
$$T = \sum_{e \in E} q(e)d(e)$$

$$T(a) = \sum_{i=1}^{I} c(X_i)d(X_i, a) - \sum_{j=1}^{J} c(N_j)d(N_j, a)$$

Stress test

- Severe transport situations
- Vector with capacities on e/e
- Sum of vector is zero
- Restricted to bounds

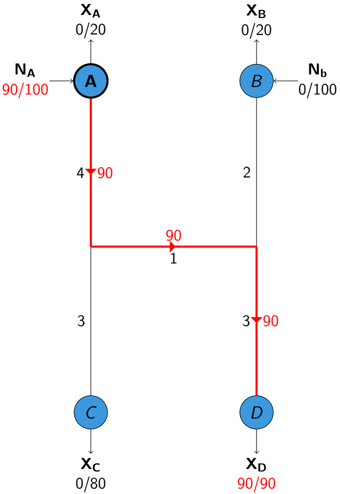
Stress test



Stress test, iteration 1

- Find entry and exit point
  - Closest entry is N_A
  - Furthest exit is X_D
- Minimum of the maximal capacity on the e/e: $\min\{100, 90\} = 90$
- Transport moment:

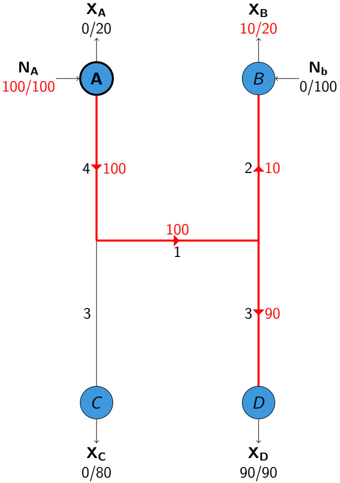
$$T(A) = 90 \cdot 8 - 90 \cdot 0 = 720$$



Stress test, iteration 2

- Find entry and exit point
  - Closest entry is N_A
  - Furthest exit is X_B
- Minimum of the maximal capacity left on the e/e: $\min\{10, 80\} = 10$
- Transport moment:

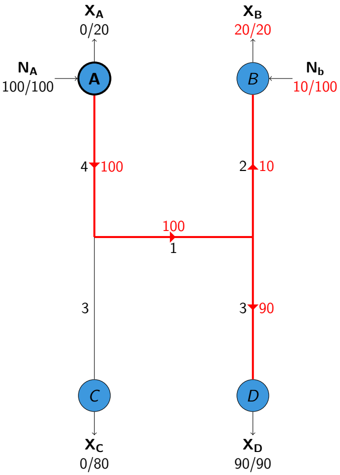
$$T(A) = 10 \cdot 7 + 90 \cdot 8 - 100 \cdot 0 = 790$$



Stress test, iteration 3

- Find entry and exit point
  - Closest entry is N_A
  - Furthest exit is X_B
- Minimum of the maximal capacity left on the e/e: $\min\{10, 80\} = 10$
- Transport moment:

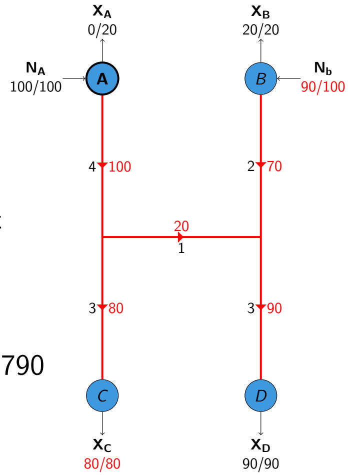
$$T(A) = 10 \cdot 7 + 90 \cdot 8 - 100 \cdot 0 = 790$$



Stress test, iteration 4

- Find entry and exit point
  - Closest entry is N_B
  - Furthest exit is X_C
- Minimum of the maximal capacity left on the e/e: $\min\{90, 80\} = 80$
- Transport moment:

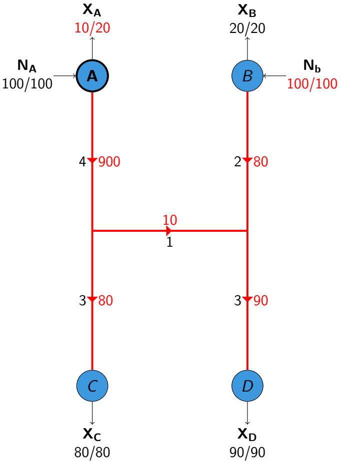
$$T(A) = 20{\cdot}7 + 90{\cdot}8 + 80{\cdot}7 - 100{\cdot}0 - 90{\cdot}7 = 790$$



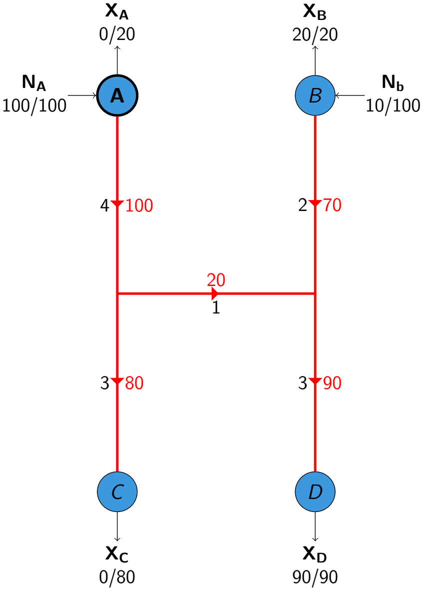
Stress test, iteration 5

- Find entry and exit point
  - Closest entry is N_B
  - Furthest exit is X_A
- Minimum of the maximal capacity left on the e/e: $\min\{10, 20\} = 10$
- Transport moment:

$$T(A) = 10 \cdot 0 + 20 \cdot 7 + 90 \cdot 8 + 80 \cdot 7 \\ - 100 \cdot 0 - 100 \cdot 7 \\ = 780$$



Stress test



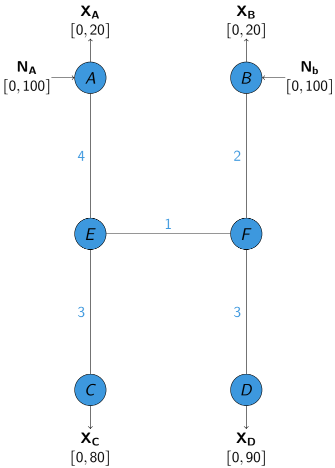
Stress test w.r.t. anchor point A:

$$\begin{matrix} N_A \\ N_B \\ X_A \\ X_B \\ X_C \\ X_D \end{matrix} \begin{pmatrix} 100 \\ 90 \\ -0 \\ -20 \\ -80 \\ -90 \end{pmatrix}$$

Distance between stress tests

- Measure difference between vectors
- $\mathcal{L}_p$, for example Euclidean distance
- Network properties
- Quadratic form distance

Quadratic form distance



$$D = \begin{array}{c} \\ N_A \\ N_B \\ X_A \\ X_B \\ X_C \\ X_D \end{array} \begin{array}{c} \begin{array}{cccccc} N_A & N_B & X_A & X_B & X_C & X_D \end{array} \\ \begin{pmatrix} 0 & 7 & 0 & 7 & 7 & 8 \\ 7 & 0 & 7 & 0 & 6 & 7 \\ 0 & 7 & 0 & 7 & 7 & 8 \\ 7 & 0 & 7 & 0 & 6 & 7 \\ 7 & 6 & 7 & 6 & 0 & 7 \\ 8 & 7 & 8 & 7 & 7 & 0 \end{pmatrix} \end{array}$$

Quadratic form distance

$$a_{ij} = 1 - \frac{d_{ij}}{d_{\max}}$$

$$QFD_A(u, v) = \sqrt{(u - v)^T A(u - v)}$$

Quadratic form distance

$$a_{ij} = 1 - \frac{d_{ij}}{d_{\max}}$$

$$D = \begin{pmatrix} 0 & 7 & 0 & 7 & 7 & 8 \\ 7 & 0 & 7 & 0 & 6 & 7 \\ 0 & 7 & 0 & 7 & 7 & 8 \\ 7 & 0 & 7 & 0 & 6 & 7 \\ 7 & 6 & 7 & 6 & 0 & 7 \\ 8 & 7 & 8 & 7 & 7 & 0 \end{pmatrix}, \qquad A = \begin{pmatrix} 1 & \frac{1}{8} & 1 & \frac{1}{8} & \frac{1}{8} & 0 \\ \frac{1}{8} & 1 & \frac{1}{8} & 1 & \frac{1}{4} & \frac{1}{8} \\ 1 & \frac{1}{8} & 1 & \frac{1}{8} & \frac{1}{8} & 0 \\ \frac{1}{8} & 1 & \frac{1}{8} & 1 & \frac{1}{4} & \frac{1}{8} \\ \frac{1}{8} & \frac{1}{4} & \frac{1}{8} & \frac{1}{4} & 1 & \frac{1}{8} \\ 0 & \frac{1}{8} & 0 & \frac{1}{8} & \frac{1}{8} & 1 \end{pmatrix}$$

Earth mover's distance

- Minimal amount of work to go from one situation to another
- Based on transportation

Earth mover's distance

$$\min \sum_{i=1}^{I} \sum_{j=1}^{J} d_{ij} f_{ij} \tag{1a}$$

subject to

$$\sum_{i=1}^{I} \sum_{j=1}^{J} f_{ij} = \min \left\{ \sum_{i=1}^{I} c(N_i), \sum_{j=1}^{J} c(X_j) \right\} \tag{1b}$$

$$\sum_{j=1}^{J} f_{ij} \leq c(N_i) \qquad \forall i \in [1, I] \tag{1c}$$

$$\sum_{i=1}^{I} f_{ij} \leq c(X_j) \qquad \forall j \in [1, J] \tag{1d}$$

$$f_{ij} \geq 0 \qquad \forall i \in [1, I],\ j \in [1, J] \tag{1e}$$

Earth mover's distance

$$EMD = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J} d_{ij} f_{ij}}{\sum_{i=1}^{I}\sum_{j=1}^{J} f_{ij}}$$

$$EMD = \sum_{i=1}^{I}\sum_{j=1}^{J} d_{ij} f_{ij}$$

$$(100, 0, 0, -100)^T \qquad (20, 0, 0, -20)^T$$

$$(0, 100, -100, 0)^T \qquad (0, 20, -20, 0)^T$$

Distance

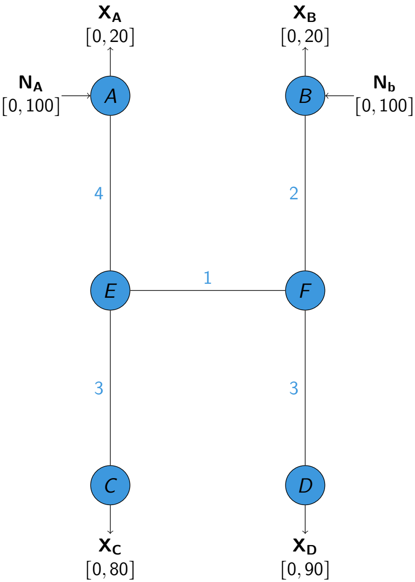
QFD:

- No big pre-calculation
- Only distance matrix and stress tests needed
- Matrix is big in practice $(I + J) \times (I + J)$

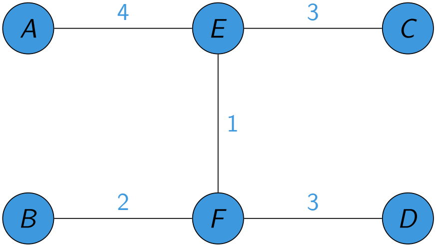
EMD:

- Based on flows
- Two matrices, but smaller $I \times J$
- Based on two different transport moments

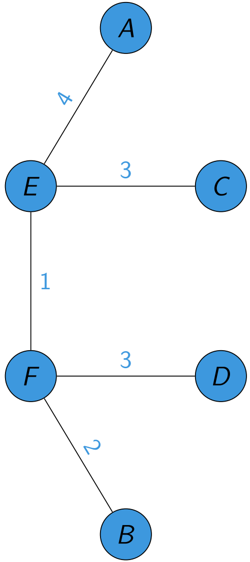
Flow representation



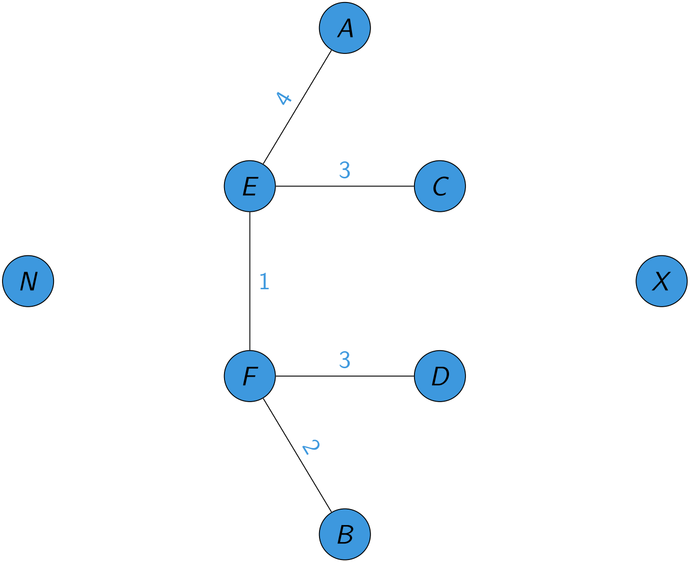
Flow representation



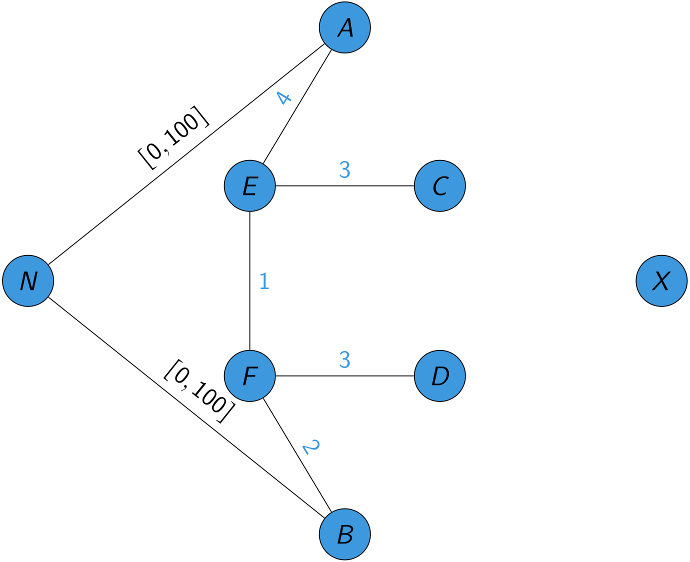
Flow representation



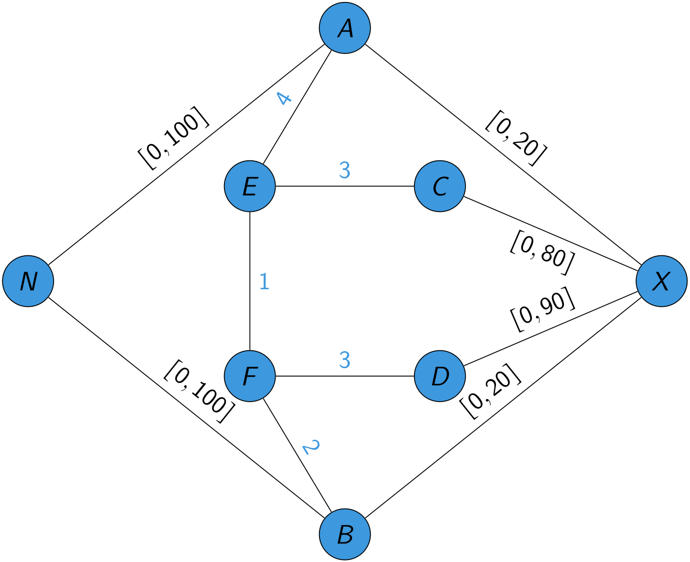
Flow representation

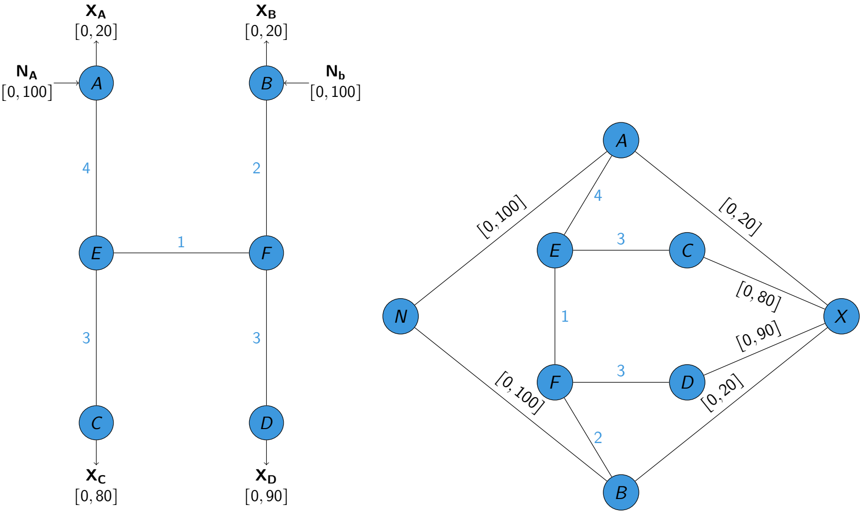


Flow representation



Flow representation




X_A
[0, 20]
X_B
[0, 20]
N_A
[0, 100]
N_b
[0, 100]
A
B
4
2
E
1
F
3
3
C
D
X_C
[0, 80]
X_D
[0, 90]
A
[0, 100]
4
[0, 20]
E
3
C
[0, 80]
N
1
X
[0, 90]
[0, 100]
F
3
D
[0, 20]
2
B

(a) (b)

Linear Programming

$$\begin{aligned} \max \quad & c^T x \\ \text{s.t.} \quad & Ax \leq b \\ & x \geq 0 \end{aligned}$$

- x optimisation variable: flow
- c cost function: distance
- A, b constraints, flow conservation, etc.

Linear Programming

- Simplex method
    - Mostly polynomial time complexity
    - Worst-case exponential time complexity
    - Simple algorithm
- Interior-point method
    - All cases polynomial time complexity
    - Based on different numerical methods

Research questions

1. Current method
   - Are all severe situations taken into account?
   - Other distances
   - Criterion on similarity in distances
2. Other methods
   - Advantages and disadvantages
   - How can the computer find the flow through the network for the earth mover's distance?
3. Network structures
   - Which complex structures should be taken into account?
   - How in each method

Research questions

4. Transformation from capacity (e/e) to flow representation
   - Advantages and disadvantages
   - Algorithms
5. Pressure
   - Addition to each method
   - Transformation to linear programming

Continuation

Answering the research questions:

1. Current method
2. Other methods
3. Network structures
4. Representation of the network
5. Pressure