Optimal Control of Gas and Water Networks

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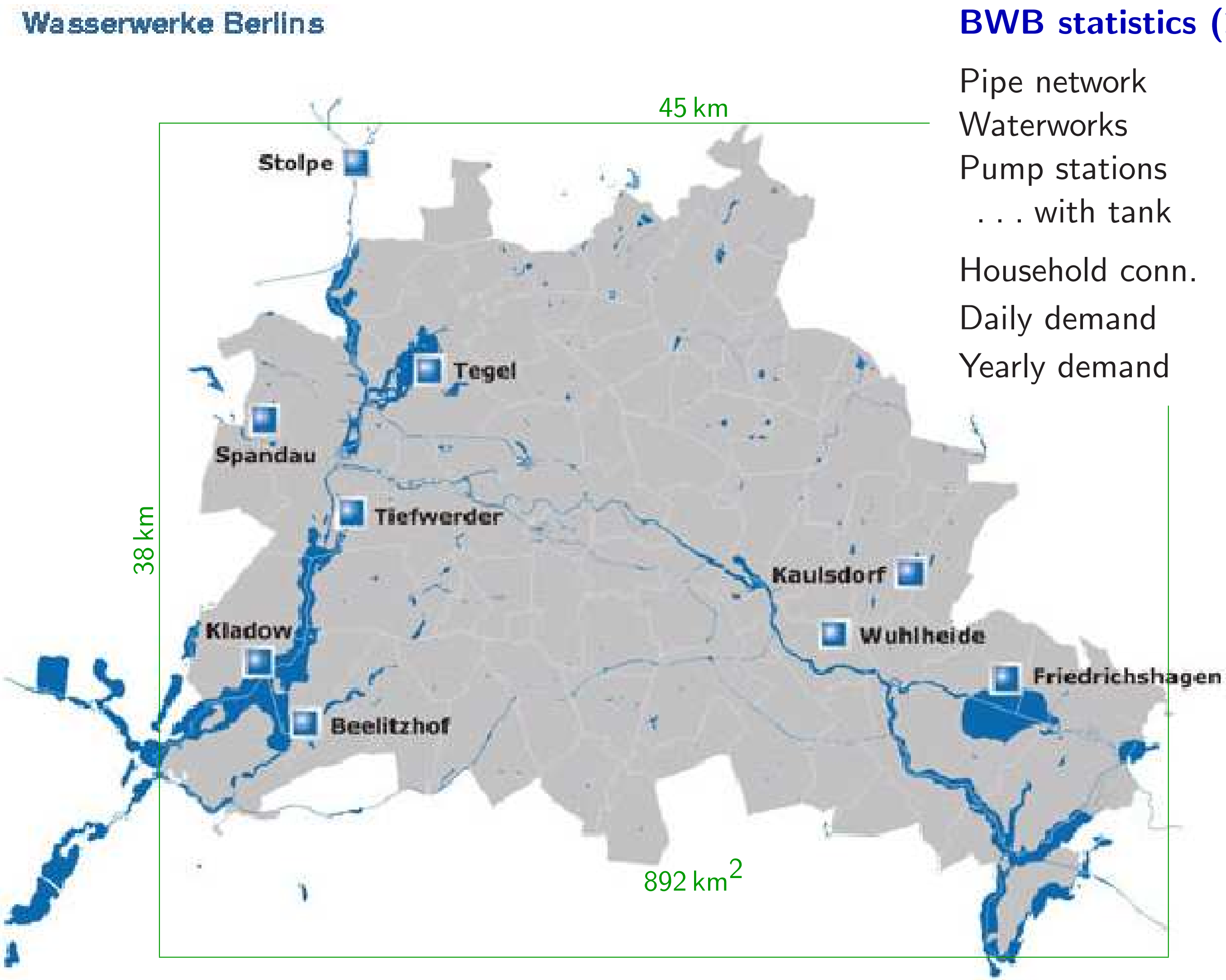
Overview

- Application Background
- Optimization Model
- MINLP
- Gas Management
- Summary

Application Background

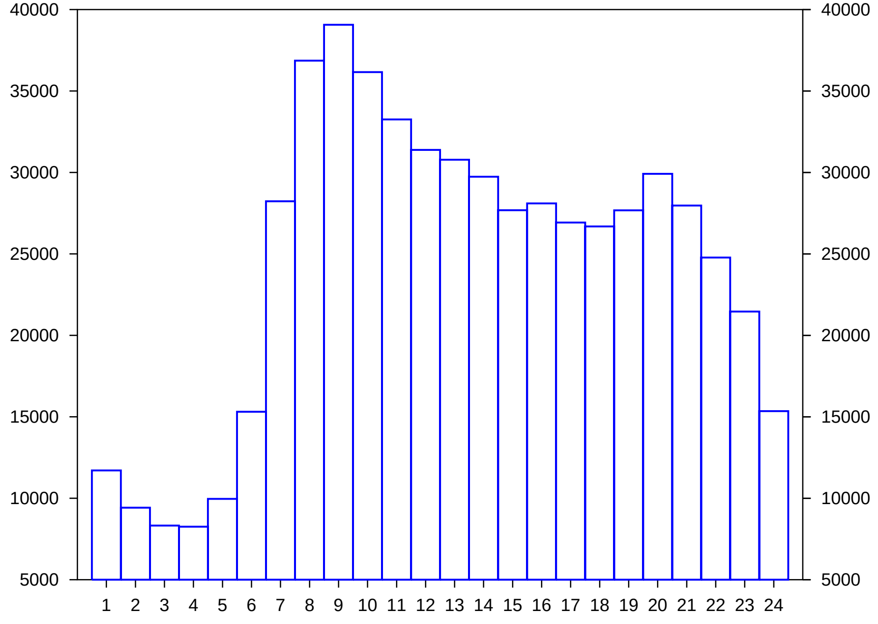


BWB statistics (2005)

Pipe network	7843 km
Waterworks	9
Pump stations	8
. . . with tank	6
Household conn.	258000
Daily demand	$\leq 1.14 \times 10^6$ m^3
Yearly demand	206×10^6 m^3

Task

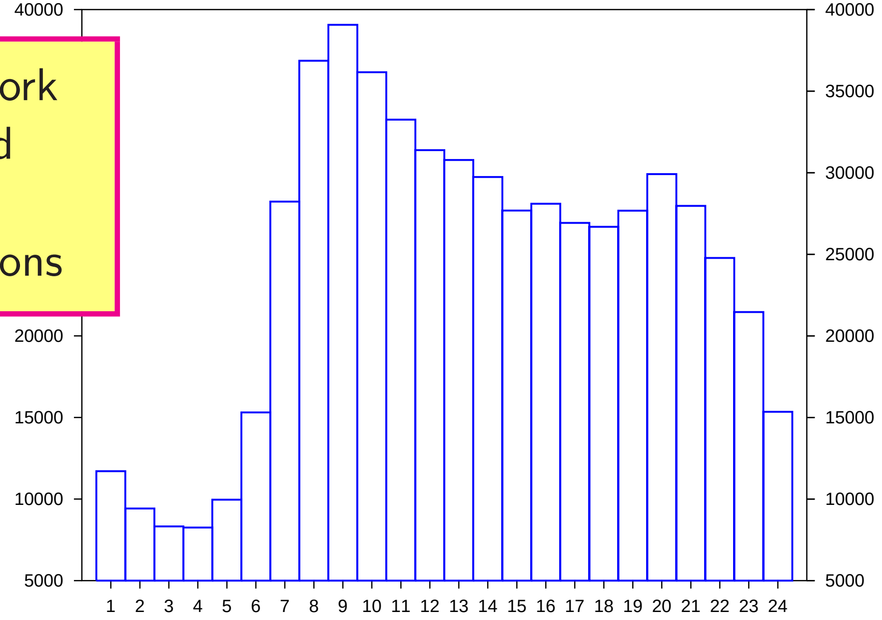
Operative Planning



Task

Operative Planning

Find: Operating schedule of network satisfying the predicted demand subject to physical, technical, contractual, and hygienic restrictions



Application Background

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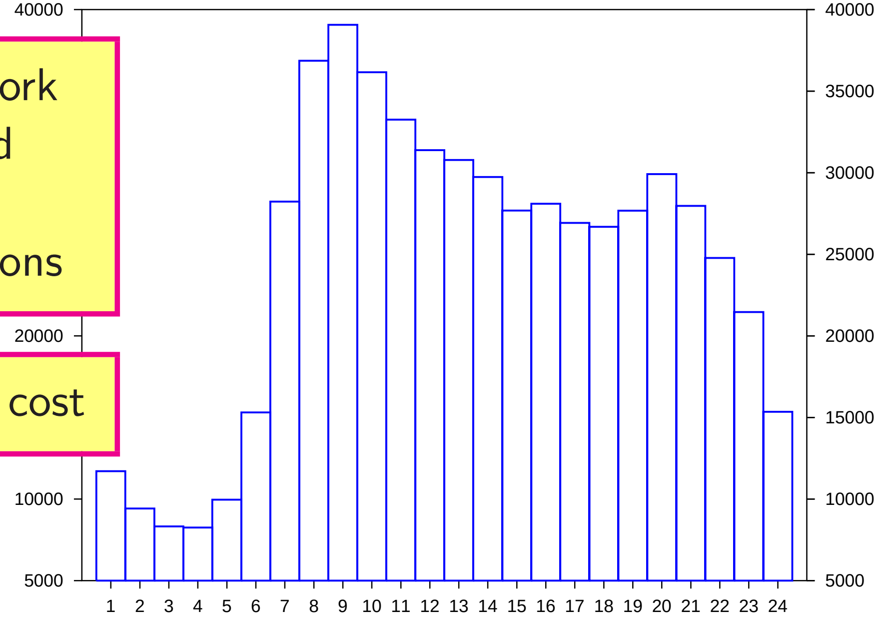
Operative Planning

Find: Operating schedule of network satisfying the predicted demand subject to physical, technical, contractual, and hygienic restrictions

Goal: Reduction of daily operating cost



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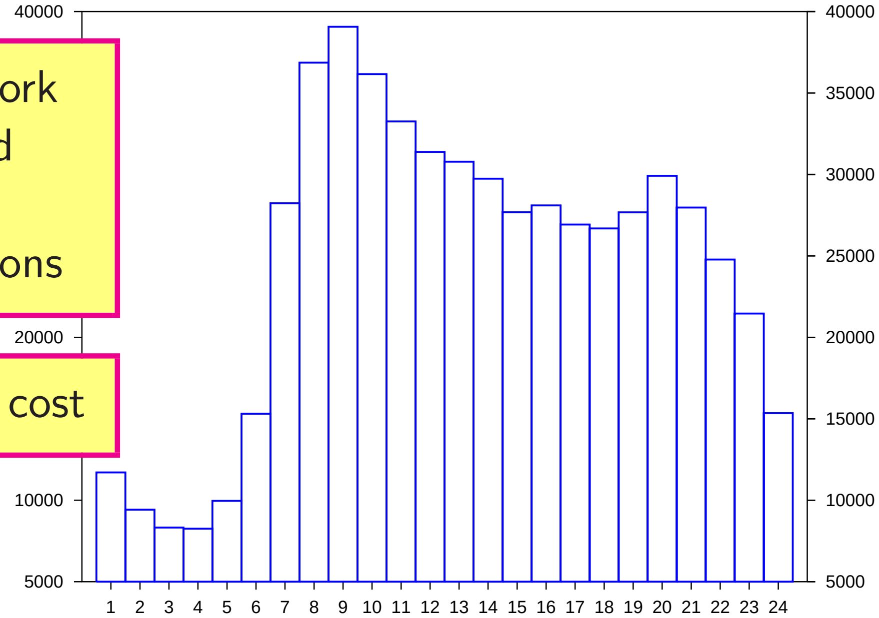
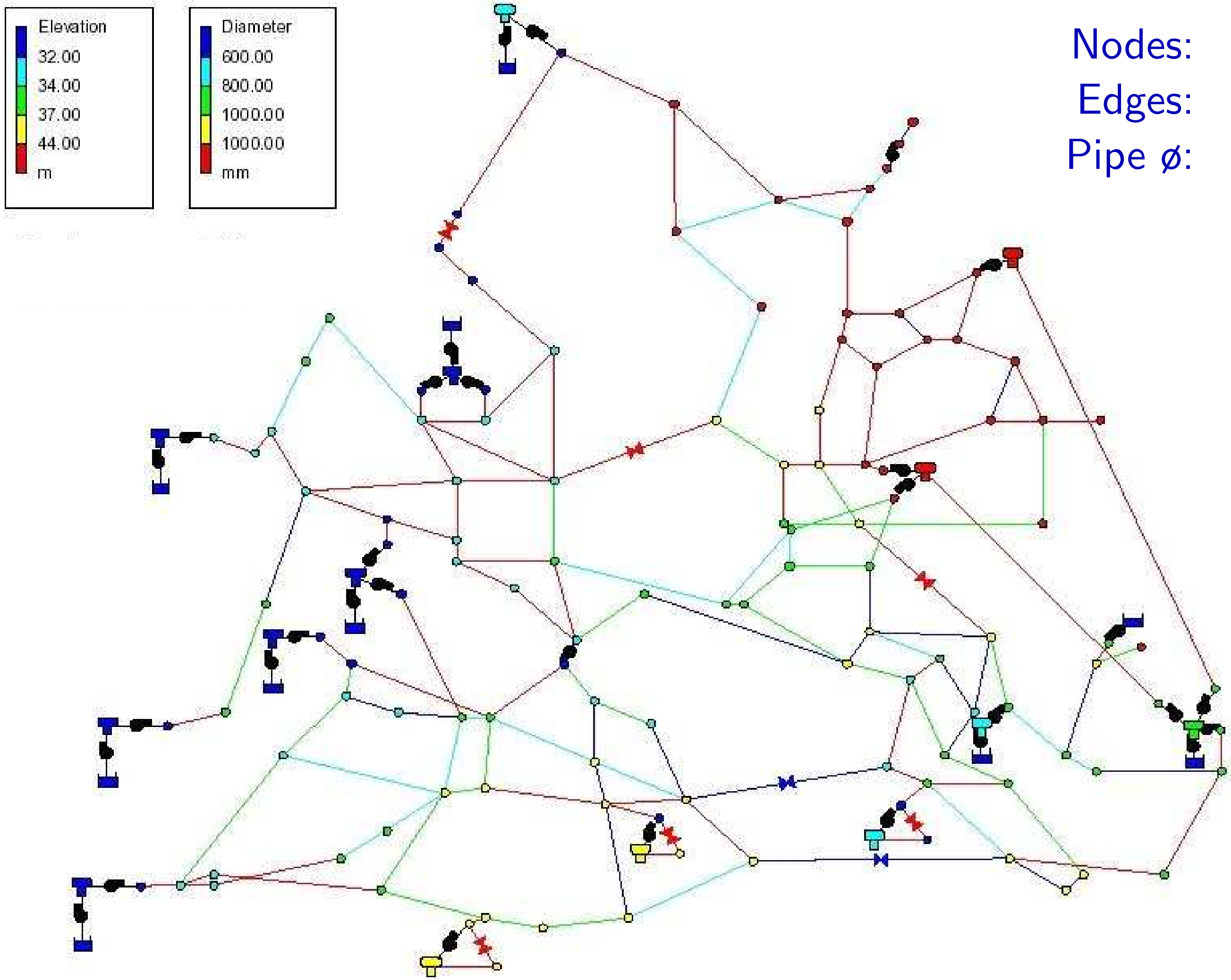


Optimization Project

BWB – Berliner Wasserbetriebe	(Berlin)
ABB Utilities GmbH	(Mannheim)
Bernd Gnädig, M. Steinbach	(ZIB)

Application Background

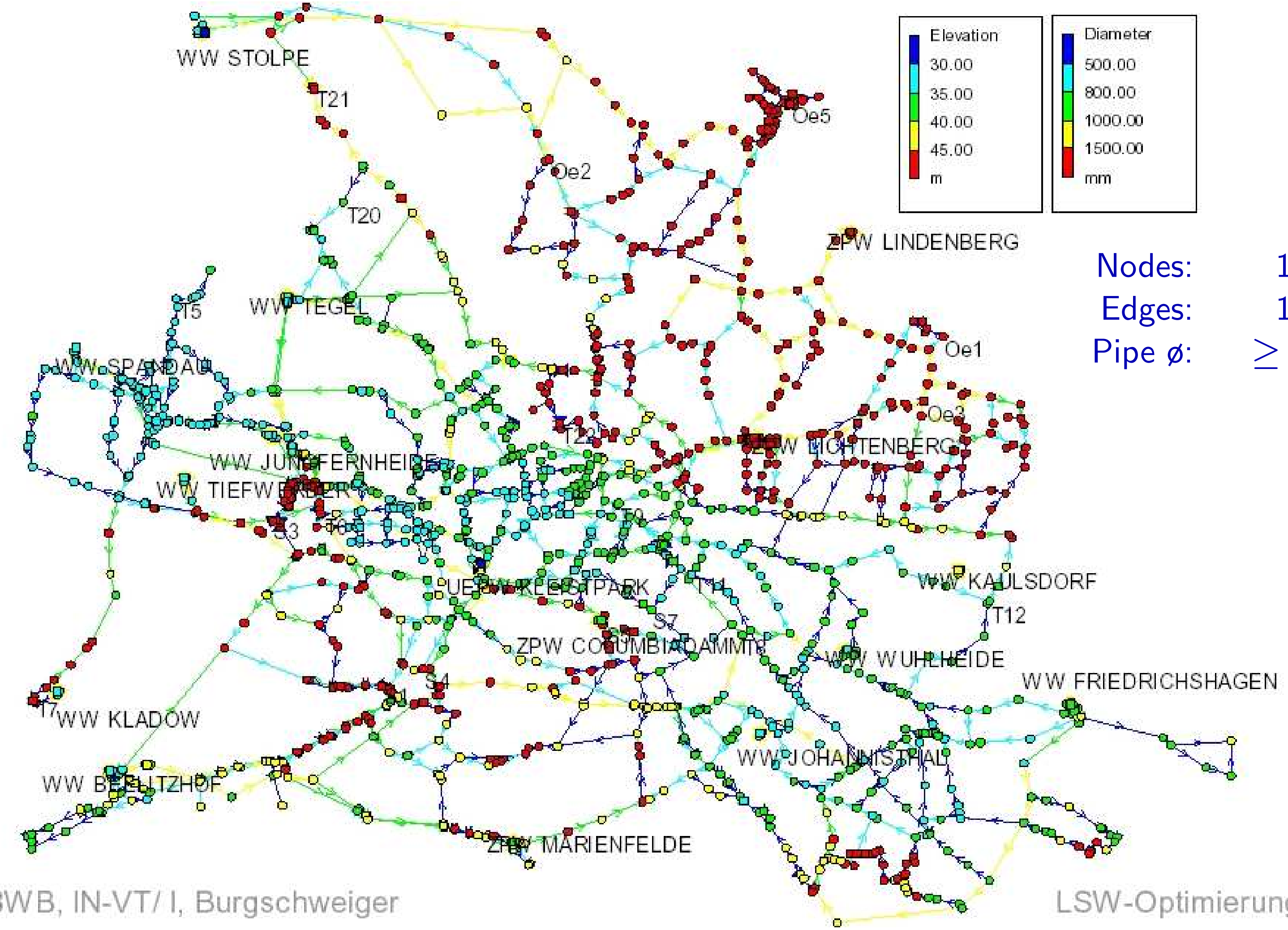
Test Configuration



Nodes:	144
Edges:	162
Pipe ø:	$\geq$ 400 mm

Application Background

BWB Main Network



Nodes:	1481
Edges:	1935
Pipe ø:	$\geq$ 300 mm

Application Background

Hardware

⟵ Drinking water network

Household connection ⟶

Application Background

Hardware

⟵ Drinking water network

Household connection ⟶

This is *not* Berlin, it is Tenerife!

Photographs by Mr. Bald (Stadtwerke Plettenberg) `http://www.wasser.de`

Optimization Model

Network Topology

Directed Graph $G = (\mathcal{N}, \mathcal{A})$

Node types

$\mathcal{N}_{rs}$ reservoir (source)

$\mathcal{N}_{tk}$ tank (buffer)

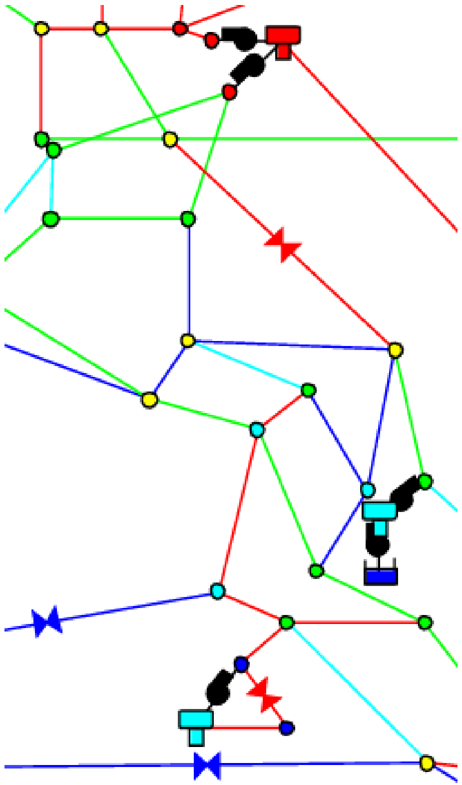
$\mathcal{N}_{jc}$ junction (demand)

Arc types

$\mathcal{A}_{pi}$ pipe

$\mathcal{A}_{pu}$ pump

$\mathcal{A}_{vl}$ valve



Optimization Model

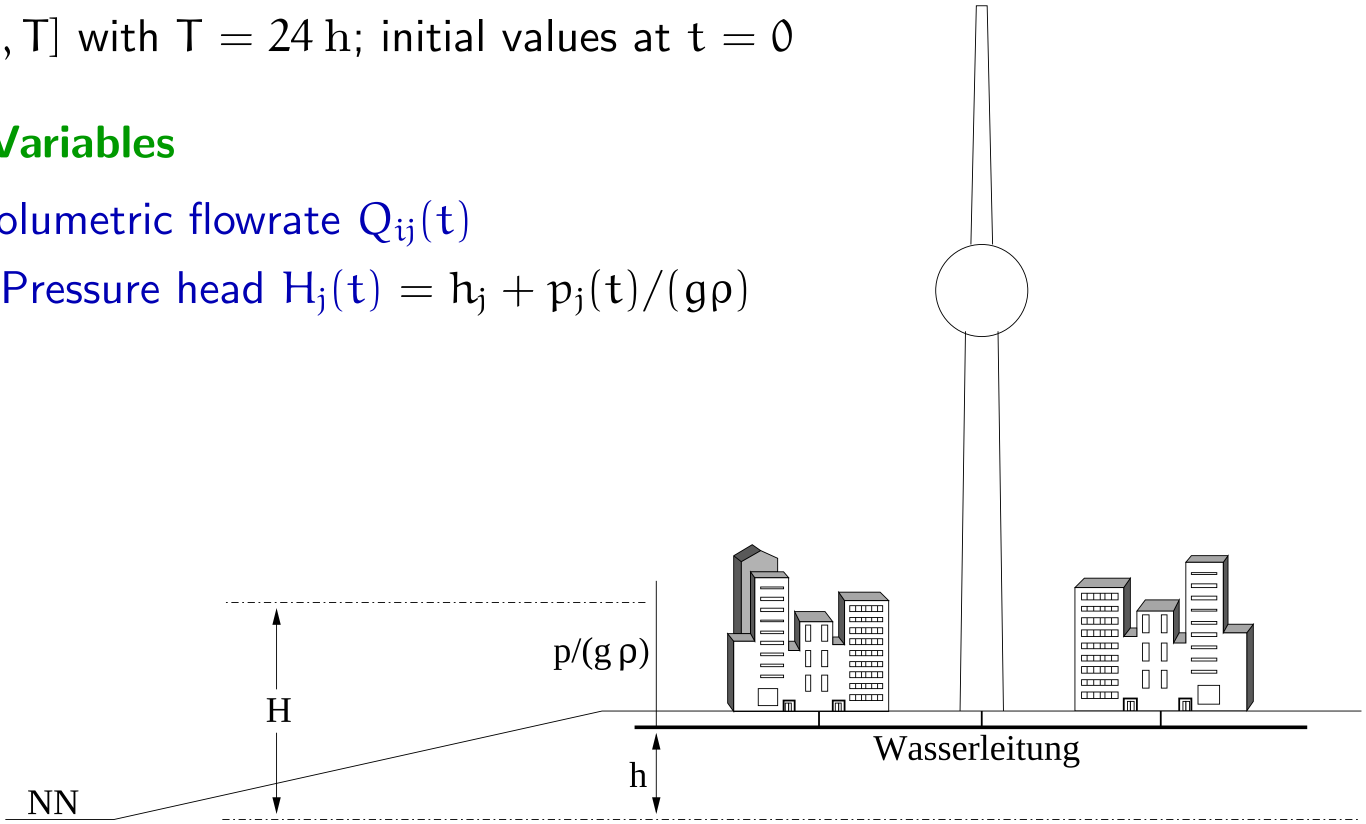
Hydrodynamics

Planning Horizon

$t \in I := [0, T]$ with $T = 24\,\mathrm{h}$; initial values at $t = 0$

Dynamic Variables

- Arcs: Volumetric flowrate $Q_{ij}(t)$
- Nodes: Pressure head $H_j(t) = h_j + p_j(t)/(g\rho)$



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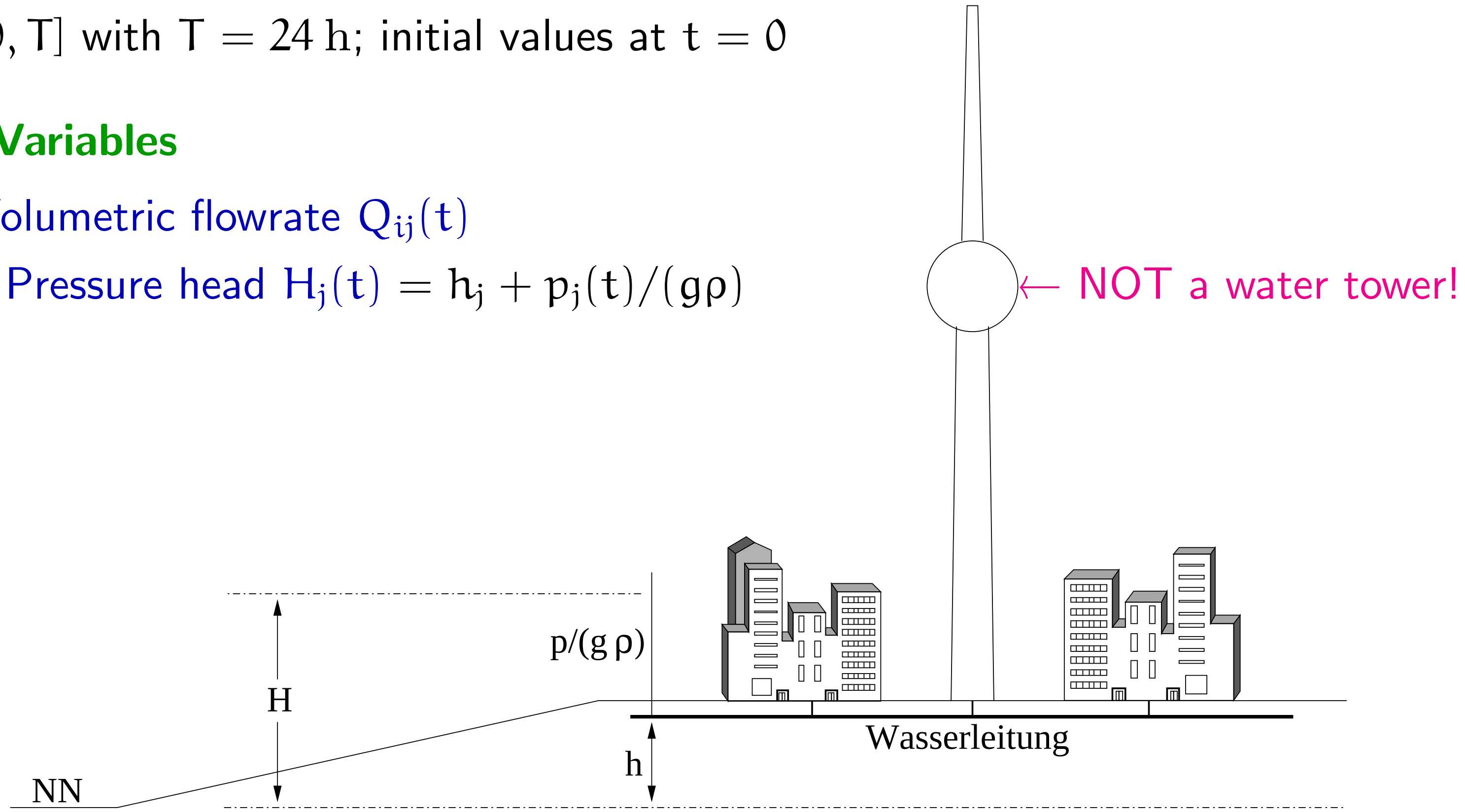

Optimization Model

Network Elements

Nodes

- Reservoir (source): linear
- Junction (demand): linear
- Tank (buffer): inflow $A_j(H_j, t)\dot{H}_j$

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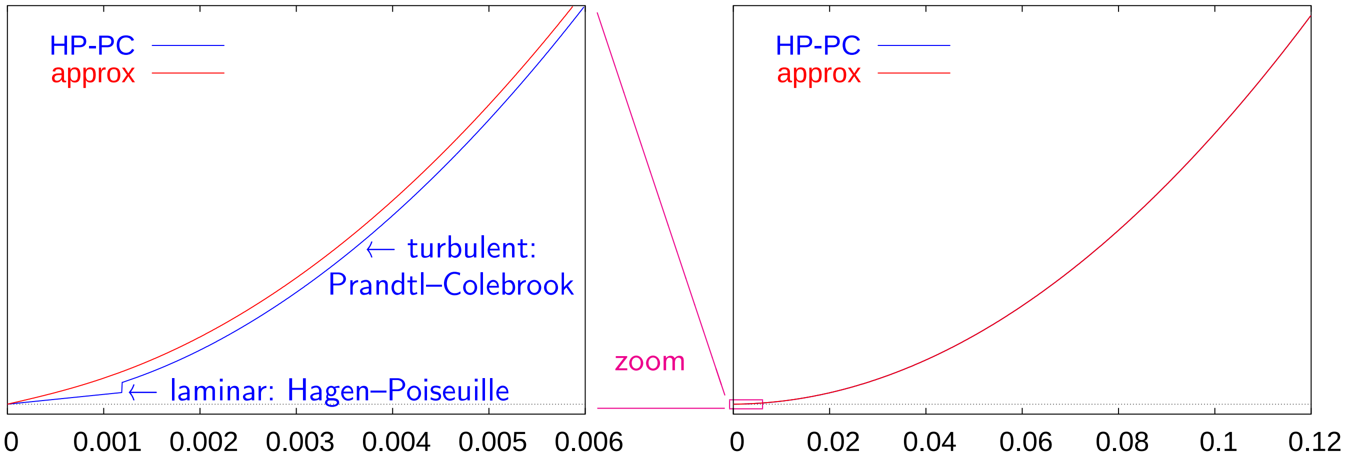
Arcs

- Pipe: Hydraulic pressure loss $\Delta H_{ij}(Q_{ij}) \approx \varphi_{ij}(Q_{ij})$



Optimization Model

Network Elements

Nodes

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- Junction (demand): linear
- Tank (buffer): inflow $A_j(H_j, t)\dot{H}_j$

Arcs

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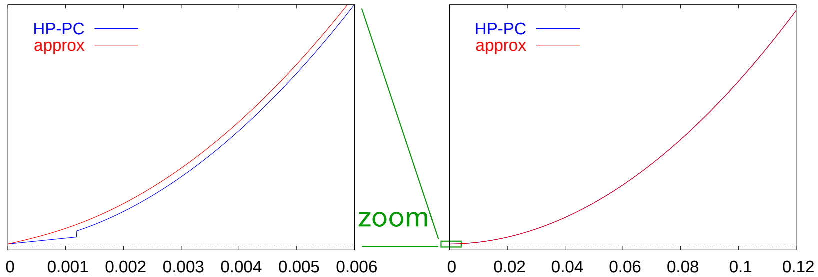

- Valve: pressure decrease $\Delta H_{ij}(t)$, bilinear consistency condition $\Delta H_{ij} Q_{ij} \geq 0$
- Pump: pressure increase $\Delta H_{ij}(t)$, char. diagrams (pressure, flow, speed, power)

Optimization Model

Boundary Value Problem

Basic Model (Burgschweiger, Gnädig, St. 2004)

Reservoir j	$H_j \equiv \bar{H}_j \in C^0(I, \mathbf{R}_{\geq 0})$	water level
Junction j	$\sum_{i:\, ij \in \mathcal{A}} Q_{ij} - \sum_{k:\, jk \in \mathcal{A}} Q_{ij} = D_j \in C^0(I, \mathbf{R}_{\geq 0})$	demand
Tank j	$\sum_{i:\, ij \in \mathcal{A}} Q_{ij} - \sum_{k:\, jk \in \mathcal{A}} Q_{ij} = A_j(H_j, t)\dot{H}_j, \quad H_j \in C^1(I, \mathbf{R})$	tank inflow
Pipe ij	$H_j - H_i = -\varphi_{ij}(Q_{ij}), \quad \varphi_{ij} \in C^1(\mathbf{R}, \mathbf{R})$ odd, strictly $\nearrow$	pressure loss
Pump ij	$H_j - H_i = +\Delta H_{ij} \in C^0(I, \mathbf{R}_{\geq 0})$	control
Valve ij	$H_j - H_i = -\Delta H_{ij} \in C^0(I, \mathbf{R})$	control
	$Q_{ij}\Delta H_{ij} \geq 0$	consistency
Costs	$\int_0^T \sum_{ij \in \mathcal{A}_{pu}} \left[k^0_{ij} Q_{ij} + k^1_{ij} P_{ij}(Q_{ij}, \Delta H_{ij}) \right] dt \rightarrow \min$	
	$k^0_{ij}, k^1_{ij} \in C^0(I, \mathbf{R}_{\geq 0}), \quad P_{ij} \in C^1(\mathbf{R}^2, \mathbf{R}_{\geq 0})$ power	
	+ initial/final conditions, bounds, inequality constraints	

Optimization Model

Boundary Value Problem

Basic Model (Burgschweiger, Gnädig, St. 2004)

Reservoir j	$H_j \equiv \bar{H}_j \in L^\infty(I, \mathbf{R}_{\geq 0})$	water level
Junction j	$\sum_{i:\, ij \in \mathcal{A}} Q_{ij} - \sum_{k:\, jk \in \mathcal{A}} Q_{ij} = D_j \in L^\infty(I, \mathbf{R}_{\geq 0})$	demand
Tank j	$\sum_{i:\, ij \in \mathcal{A}} Q_{ij} - \sum_{k:\, jk \in \mathcal{A}} Q_{ij} = A_j(H_j, t)\dot{H}_j, \quad H_j \in H^{1,\infty}(I, \mathbf{R})$	tank inflow
Pipe ij	$H_j - H_i = -\varphi_{ij}(Q_{ij}), \quad \varphi_{ij} \in C^1(\mathbf{R}, \mathbf{R})$ odd, strictly $\nearrow$	pressure loss
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	$Q_{ij} \Delta H_{ij} \geq 0$	consistency
Costs	$\int_0^T \sum_{ij \in \mathcal{A}_{pu}} \left[k_{ij}^0 Q_{ij} + k_{ij}^1 P_{ij}(Q_{ij}, \Delta H_{ij}) \right] dt \to \min$	
	$k_{ij}^0, k_{ij}^1 \in L^\infty(I, \mathbf{R}_{\geq 0}), \quad P_{ij} \in C^1(\mathbf{R}^2, \mathbf{R}_{\geq 0})$ power	
	$+$ initial/final conditions, bounds, inequality constraints	

Boundary Value Problem

Structure

Semi-explicit DAE-BVP with discontinuities over graph

$$A(x,t)\dot{x} = f(x,z,u,t) \qquad x = H_{tk}$$

$$0 = g(x,z,u,t) \qquad z = (Q, H_{rs}, H_{jc})$$

where $A \in L^\infty(\mathbb{R}^{n_x} \times I, \mathbf{R}^{n_x}_{>0})$, loc. Lipschitz w.r.t. x $\qquad u = \Delta H$

Questions

- Index 1? (otherwise stabilization by invariants: Schulz, Bock, St. 1998)
- Consistent initial values?
- Existence/uniqueness of IVP solution?
- Numerical behavior?
- Algebraic structure?
- Special solvers?

Optimization Model

Boundary Value Problem

Structure

Semi-explicit DAE-BVP with discontinuities over graph

$$A(x,t)\dot{x} = f(x,z,u,t) \qquad x = H_{tk}$$

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where $A \in L^\infty(\mathbb{R}^{n_x} \times I, \mathbf{R}^{n_x}_{>0})$, loc. Lipschitz w.r.t. x $\qquad u = \Delta H$

Answers (St. 2005)

✓ Index 1

✓ Consistent initial values

✓ Existence/uniqueness of IVP solution

✓ Numerical behavior

✓ Algebraic structure

✓ Special solvers (coarse structure)

DAE Index

Node-Arc Incidence Matrix

$$E(G) \equiv E = \begin{pmatrix} E_{rs} \\ E_{jc} \\ E_{tk} \end{pmatrix} = \begin{pmatrix} E_{pi} & E_{pu} & E_{vl} \end{pmatrix} = \begin{pmatrix} E_{rs,pi} & E_{rs,pu} & E_{rs,vl} \\ E_{jc,pi} & E_{jc,pu} & E_{jc,vl} \\ E_{tk,pi} & E_{tk,pu} & E_{tk,vl} \end{pmatrix}$$

DAE with Incidence Matrix

$$\begin{matrix} \mathcal{A}_{pi} \\ \mathcal{A}_{pu} \\ \mathcal{A}_{vl} \\ \mathcal{N}_{rs} \\ \mathcal{N}_{jc} \\ \mathcal{N}_{tk} \end{matrix} \qquad \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ A(t, H_{tk})\dot{H}_{tk} \end{pmatrix} = \begin{pmatrix} \varphi_{pi}(Q_{pi}) + & E_{pi}^{*}H & \\ & E_{pu}^{*}H & -\Delta H_{pu} \\ & E_{vl}^{*}H & +\Delta H_{vl} \\ & H_{rs} & \\ E_{jc}Q & & \\ E_{tk}Q & & \end{pmatrix} - \begin{pmatrix} 0 \\ 0 \\ 0 \\ \bar{H}_{rs} \\ D_{jc} \\ 0 \end{pmatrix}$$

Optimization Model

DAE Index

Control Variables

$\Delta H_{pu}, \Delta H_{vl}$

Wronskian

$$
\underbrace{\left(\begin{array}{ccc|cc}
\varphi'_{pi}(Q_{pi}) & & & E^*_{rs,pi} & E^*_{jc,pi} \\
 & 0 & & E^*_{rs,pu} & E^*_{jc,pu} \\
 & & 0 & E^*_{rs,vl} & E^*_{jc,vl} \\
\hline
0 & 0 & 0 & I & \\
E_{jc,pi} & E_{jc,pu} & E_{jc,vl} & & 0 \\
E_{tk,pi} & E_{tk,pu} & E_{tk,vl} & &
\end{array}\right.}_{x}
\underbrace{\begin{array}{c}
E^*_{tk,pi} \\ E^*_{tk,pu} \\ E^*_{tk,vl} \\ \hline \\ \\ 0
\end{array}}_{z}
\underbrace{\left.\begin{array}{|cc}
0 & 0 \\
-I & \\
 & +I \\
\hline
 & \\
E_{jc,pu} & E_{jc,vl} \\
E_{tk,pu} & E_{tk,vl}
\end{array}\right)}_{u}
$$

Optimization Model

DAE Index

Control Variables

$\mathcal{A}^Q_{\mathrm{pu}}, \mathcal{A}^Q_{\mathrm{vl}}$ = flow controlled elements, $\mathcal{A}^H_{\mathrm{pu}}, \mathcal{A}^H_{\mathrm{vl}}$ = pressure controlled elements.

Projection Matrices $\Pi^H_{\mathrm{pu}}, \Pi^Q_{\mathrm{pu}}$ on $\mathbf{R}^{|\mathcal{A}_{\mathrm{pu}}|}$ and $\Pi^H_{\mathrm{vl}}, \Pi^Q_{\mathrm{vl}}$ on $\mathbf{R}^{|\mathcal{A}_{\mathrm{vl}}|}$

Wronskian

$$
\left(\begin{array}{ccc|ccc|cc}
\varphi'_{\mathrm{pi}}(Q_{\mathrm{pi}}) & & & E^*_{\mathrm{rs,pi}} & E^*_{\mathrm{jc,pi}} & E^*_{\mathrm{tk,pi}} & 0 & 0 \\
 & -\Pi^Q_{\mathrm{pu}} & & E^*_{\mathrm{rs,pu}} & E^*_{\mathrm{jc,pu}} & E^*_{\mathrm{tk,pu}} & -\Pi^H_{\mathrm{pu}} & \\
 & & +\Pi^Q_{\mathrm{vl}} & E^*_{\mathrm{rs,vl}} & E^*_{\mathrm{jc,vl}} & E^*_{\mathrm{tk,vl}} & & +\Pi^H_{\mathrm{vl}} \\
\hline
0 & 0 & 0 & I & & & & \\
E_{\mathrm{jc,pi}} & E_{\mathrm{jc,pu}}\Pi^H_{\mathrm{pu}} & E_{\mathrm{jc,vl}}\Pi^H_{\mathrm{vl}} & & 0 & & E_{\mathrm{jc,pu}}\Pi^Q_{\mathrm{pu}} & E_{\mathrm{jc,vl}}\Pi^Q_{\mathrm{vl}} \\
E_{\mathrm{tk,pi}} & E_{\mathrm{tk,pu}}\Pi^H_{\mathrm{pu}} & E_{\mathrm{tk,vl}}\Pi^H_{\mathrm{vl}} & & & 0 & E_{\mathrm{tk,pu}}\Pi^Q_{\mathrm{pu}} & E_{\mathrm{tk,vl}}\Pi^Q_{\mathrm{vl}}
\end{array}\right)
$$

$$\underbrace{\qquad\qquad\qquad\qquad}_{z}\qquad\underbrace{\quad}_{x}\qquad\underbrace{\qquad\qquad}_{u}$$

Optimization Model

DAE Index

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$\mathcal{A}^{Q}_{pu}$, $\mathcal{A}^{Q}_{vl}$ = flow controlled elements, $\mathcal{A}^{H}_{pu}$, $\mathcal{A}^{H}_{vl}$ = pressure controlled elements.

Projection Matrices Π^{H}_{pu}, Π^{Q}_{pu} on $\mathbf{R}^{|\mathcal{A}_{pu}|}$ and Π^{H}_{vl}, Π^{Q}_{vl} on $\mathbf{R}^{|\mathcal{A}_{vl}|}$

Wronskian constant rank on $\mathbf{R}^{|\mathcal{A}_{pi}|}$

$$
\underbrace{\left(\begin{array}{ccc|cc}
\varphi'_{pi}(Q_{pi}) & & & E^*_{rs,pi} & E^*_{jc,pi} \\
 & -\Pi^Q_{pu} & & E^*_{rs,pu} & E^*_{jc,pu} \\
 & & +\Pi^Q_{vl} & E^*_{rs,vl} & E^*_{jc,vl} \\
\hline
0 & 0 & 0 & I & \\
E_{jc,pi} & E_{jc,pu}\Pi^H_{pu} & E_{jc,vl}\Pi^H_{vl} & & 0 \\
E_{tk,pi} & E_{tk,pu}\Pi^H_{pu} & E_{tk,vl}\Pi^H_{vl} & &
\end{array}\right.}_{z}
\underbrace{\begin{array}{c}
E^*_{tk,pi} \\ E^*_{tk,pu} \\ E^*_{tk,vl} \\ \hline \\ \\ 0
\end{array}}_{x}
\underbrace{\left.\begin{array}{|cc}
0 & 0 \\
-\Pi^H_{pu} & \\
 & +\Pi^H_{vl} \\
\hline
 & \\
E_{jc,pu}\Pi^Q_{pu} & E_{jc,vl}\Pi^Q_{vl} \\
E_{tk,pu}\Pi^Q_{pu} & E_{tk,vl}\Pi^Q_{vl}
\end{array}\right)}_{u}
$$

Optimization Model

DAE Index

Theorem

$$\nu_D = \nu_P = \nu_T = 1 \iff \frac{\partial g}{\partial z} \text{ nonsingular}$$

Theorem

Let $\mathcal{A}_{pu}^{H} \cup \mathcal{A}_{vl}^{H}$ pressure-controlled, $G_0 = G(\mathcal{A}_{pu}^{H} \cup \mathcal{A}_{vl}^{H})$, $\tilde{G}_0 = G(\mathcal{A}_{pi} \cup \mathcal{A}_{pu}^{H} \cup \mathcal{A}_{vl}^{H})$.
The DAE is index-1 $\iff$

(a) G_0 is acyclic and contains in every component ≤ 1 element of $\mathcal{N}_{rs} \cup \mathcal{N}_{tk}$

(b) $\tilde{G}_0$ contains $\mathcal{N}_{jc}$ and in every component ≥ 1 element of $\mathcal{N}_{rs} \cup \mathcal{N}_{tk}$

Remarks

- Conditions necessary: physical explanations
- Special cases immediate . . .

Boundary Value Problem

Time Discretization

- Grid $t = 1, 2, \dots, T$
- Initial values at $t = 0$
- Variables:

$$x = (x_1, \dots, x_T) \qquad x_t = H_{tk,t}$$

$$v = (v_1, \dots, v_T) \qquad v_t = (Q_t, H_{rs,t}, H_{jc,t}, \Delta H_t) = (u_t, z_t)$$

Discretized Optimization Problem (NLP)

$$\underset{(x,v)}{\text{Minimize}} \quad \sum_{t=1}^{T} \phi_t(x_t, v_t) = \sum_{t=1}^{T} \sum_{ij \in \mathcal{A}_{pu}} \left[k^0_{ijt} Q_{ijt} + k^1_{ijt} P_{ij}(Q_{ijt}, \Delta H_{ijt}) \right]$$

$$\text{subject to} \quad A_t(x_{t-1}, x_t) = f_t(x_t, v_t) \qquad t = 1, \dots, T$$

$$0 = g_t(x_t, v_t) \qquad t = 1, \dots, T$$

$+$ further restrictions

Boundary Value Problem

KKT System (Newton step for NLP-optimality)

$$(*) \qquad \begin{bmatrix} H^{xx} & H^{x\nu} & C^{x*} \\ H^{\nu x} & H^{\nu\nu} & C^{\nu *} \\ C^{x} & C^{\nu} & \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta \nu \\ -\Delta\lambda \end{bmatrix} = \begin{bmatrix} f \\ d \\ h \end{bmatrix}$$

where

$$H^{xx} = \mathrm{Diag}(H_t^{xx}) \qquad H^{\nu x} = \mathrm{Diag}(H_t^{\nu x}) \qquad H^{\nu\nu} = \mathrm{Diag}(H_t^{\nu\nu})$$

$$C^{x} = \begin{bmatrix} C_1^x & & & & \\ F_1^x & & & & \\ L_2^x & C_2^x & & & \\ & F_2^x & & & \\ & L_3^x & \ddots & C_{T-1}^x & \\ & & & F_{T-1}^x & \\ & & & L_T^x & C_T^x \\ & & & & F_T^x \end{bmatrix} \qquad C^{\nu} = \begin{bmatrix} C_1^\nu & & \\ F_1^\nu & & \\ & \ddots & \\ & & C_T^\nu \\ & & F_T^\nu \end{bmatrix}$$

Optimization Model

Boundary Value Problem

Lemma: DAE is index-1 $\iff$ F_t^ν has full row rank

Algorithm: Decoupling of space and time

Eliminate control components Δz_t by time-parallel projections (most variables!)

Basically recursion over spanning tree of G

$\rightarrow$ local feedback laws $\Delta z_t = M_t \Delta x_t + N_t \Delta u_t + \Delta z_t^0$

Reduced KKT system like (*) where

$$H^{xx} = \mathrm{Diag}(H_t^{xx}) \qquad H^{ux} = \mathrm{Diag}(H_t^{ux}) \qquad H^{uu} = \mathrm{Diag}(H_t^{uu})$$

$$C^x = \begin{bmatrix} C_1^x & & & \\ L_2^x & \ddots & & \\ & \ddots & C_{T-1}^x & \\ & & L_T^x & C_T^x \end{bmatrix} \qquad C^u = \begin{bmatrix} C_1^u & & \\ & \ddots & \\ & & C_T^u \end{bmatrix}$$

DP recursion: solve in $O(n^3 T)$ where $n = |\mathcal{N}_{tk}| + |\mathcal{A}_{pu} \cup \mathcal{A}_{vl}|$

BWB: $\dim(z_t) = 3346$, $n = 70$

Discrete Decisions

Types of Discrete Decisions

- Direction of flow in valves – harmless
- Switching of pumps
- Alternative outlets

Pump Switching

Dynamic Variables

- Pump $ij \in \mathcal{A}_{\mathsf{pu}}$
- Flow Q_{ijt}
- Power P_{ijt}
- Pressure increase $\Delta H_{ijt} = H_{jt} - H_{it}$

Pump Switching

Dynamic Variables

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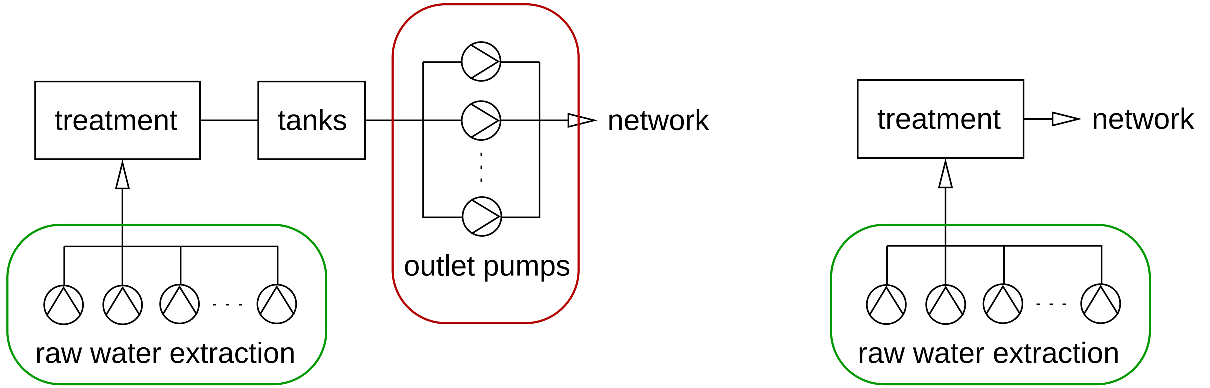
Aggregation: arcs $ij \in \mathcal{A}_{pu}$ actually represent groups of pumps operated in parallel



Pump Switching

Aggregate Variables

- Pump group $ij \in \mathcal{A}_{pu}$
- Total flow Q_{ijt}
- Total power P_{ijt}
- Common pressure increase $\Delta H_{ijt} = H_{jt} - H_{it}$

Individual Variables

- Pump $ij\nu$, $\nu \in \{1, \ldots, N_{ij}\}$
- Flow $Q_{ij\nu t} \in \{0\} \cup [Q^-_{ij\nu t}, Q^+_{ij\nu t}]$: pump status $Y_{ij\nu t} \in \{0, 1\}$
- Speed $n_{ij\nu t}$
- Power $P_{ij\nu t}$

Pump Switching

Aggregate Variables

- Pump group $ij \in \mathcal{A}_{\text{pu}}$
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- Common pressure increase $\Delta H_{ijt} = H_{jt} - H_{it}$

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- Speed $n_{ij\nu t}$
- Power $P_{ij\nu t}$

Minimum Up and Down Times (K periods)

$$K(Y_{ij\nu 1} - Y_{ij\nu 0}) \leq Y_{ij\nu 1} + \cdots + Y_{ij\nu K} \leq 2K(Y_{ij\nu 1} - Y_{ij\nu 0}) + K$$

Pump Aggregation

Essential for Practical Success

- Approximation of hydraulic pressure loss (asymptotically correct, globally smooth)
- Reduction of network graph (parallel pipes, pipe sequences, small subnetworks)
- Initial estimate by Sequential Linear Programming
- Automatic feasibility analysis via penalty approach

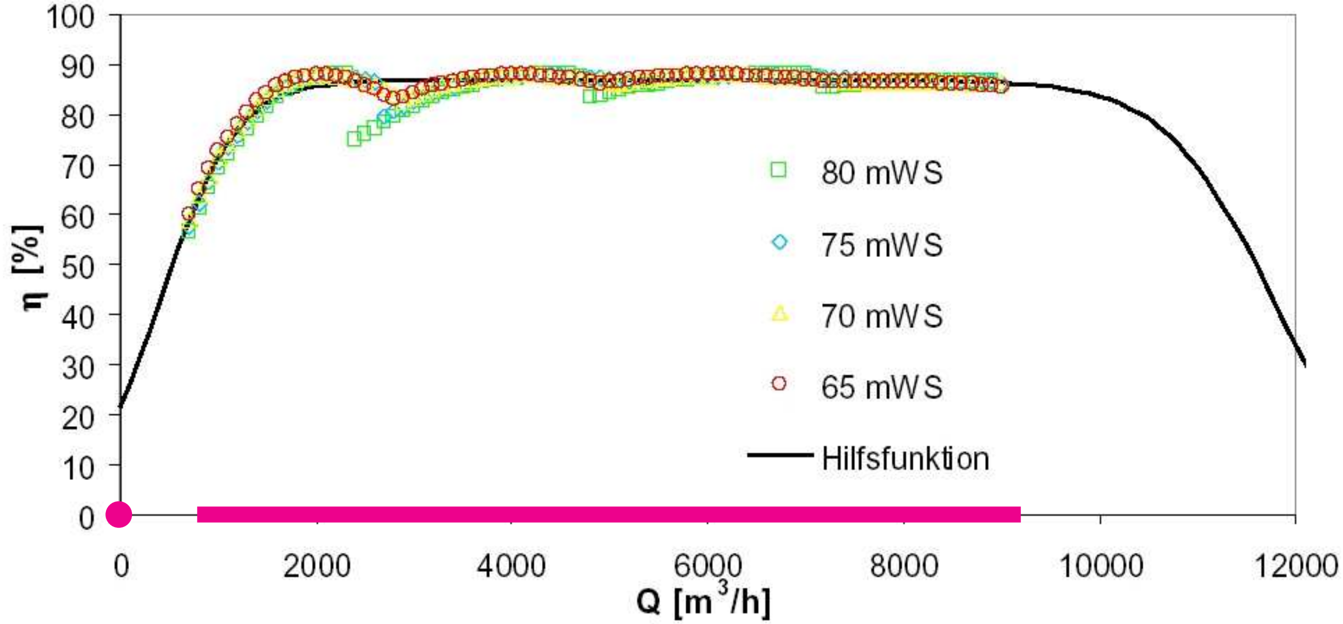
▷ Pump switching, min up/down times
  - aggregate pump model in network-wide daily planning (NLP model)
  - disaggregate in postprocessing using genuine MINLP per pump group
  - logical constraints by linear model or smooth NCP functions

Pump Aggregation

BWB

- Waterworks have 3 – 6 parallel outlet pumps
- Model as single aggregated unit with $Q = \sum Q_\nu \in \{0\} \cup [\min_\nu Q_\nu^-, \sum_\nu Q_\nu^+]$
- Replace power model + switching with efficiency model

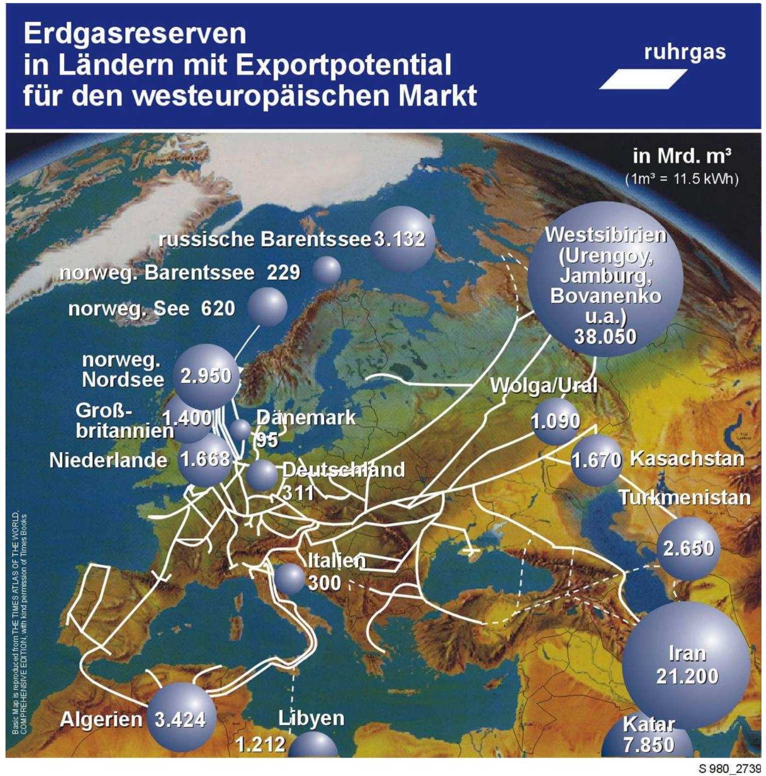
Combined Efficiency of Pump Collection



Gas Management

Project

Optimization of the Load Distribution

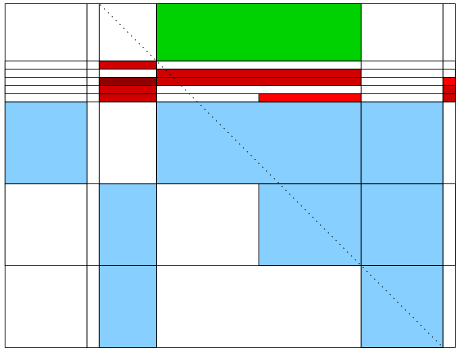


Cooperation: K. Ehrhardt (ZIB), R. Schultz (U Duisburg), A. Martin (TU Darmstadt), Ruhrgas AG (Essen), PSI AG (Berlin) – Support: BMBF

Gas vs. Water

Differences

- Breathing horizon $T \in [24\,\mathrm{h}, 48\,\mathrm{h}]$
- Finer time discretization $\Delta t \in [10\,\mathrm{min}, 30\,\mathrm{min}]$
- More coarsely meshed networks
- Compressibility
  - PDE for real gas dynamics
  - Pressure and density replace head
  - Extended incidence matrix
  - More complex Wronskian
  - Very ill-conditioned
  - More complex combinatorics (compressor stations, regulators, stop valves)



→ Further research needed

Project

Main Results (Ehrhardt, St. 2004/2005, St. 2006)

- Theory
  - Structure of extended incidence matrix
  - Structure of Wronskian (upwind method)
  - Structure of full KKT system
- Algorithmics
  - Control space factorization
  - Locally projecting null space factorization (sparse ✓, tree recursion?)
  - Comparison with multifrontal solver MA27
    for realistic network (Ruhrgas backbone network)
    * up to 93% CPU time reduction (factor 13)
    * up to 75% memory reduction
    * slightly less accurate

Future

Cooperation with WINGAS? (computation of capacities, operative planning)

Summary

Results

- Complete DAE theory with topological index criteria
- Treat combinatorial aspects by NLP techniques
  - Pump switching by aggregated efficiency model
  - Minimum up/down times by linear constraints and smoothed NCP functions
- Obtain practically satisfactory solutions
- CPU time 15 – 25 minutes for main network
  (down from ≈ 1 hour for test configuration!)
- GAMS optimization module at BWB in operation since 2005

Challenges

- Custom NLP solver: work in progress
- Genuine MINLP solver???

Summary

Practice: be careful . . .

PWN-proef oorzaak ravage Beverwijk

Waterleidingbedrijf PWN heeft een mislukte proef in Beverwijk, vorig jaar, geheim gehouden. Tot voor kort had de gemeente geen idee wat de oorzaak van de ravage op 19 februari was.

Toen stroomden er miljoenen liters water op straat, sprong een gasleiding en reed een bestelbusje in een gat in de weg. De schade was ruim 100.000 euro.

Recent bleek uit een intern PWN-rapport dat een mislukte proef om een nieuwe computerprogramma te testen, de oorzaak was. Toen monteurs de verkeerde buizen dichtdraaiden, sprongen er verschillende leidingen. Het computerprogramma zou een deel van het personeel overbodig maken.

(from Arie Koster, no source mentioned)