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Problems in gas network optimization

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2016-03-01

WIRTSCHAFTS
MATHEMATIK

Goal of this talk

- Present experiences from gas network optimization projects
- . . . and how they relate to the wiki

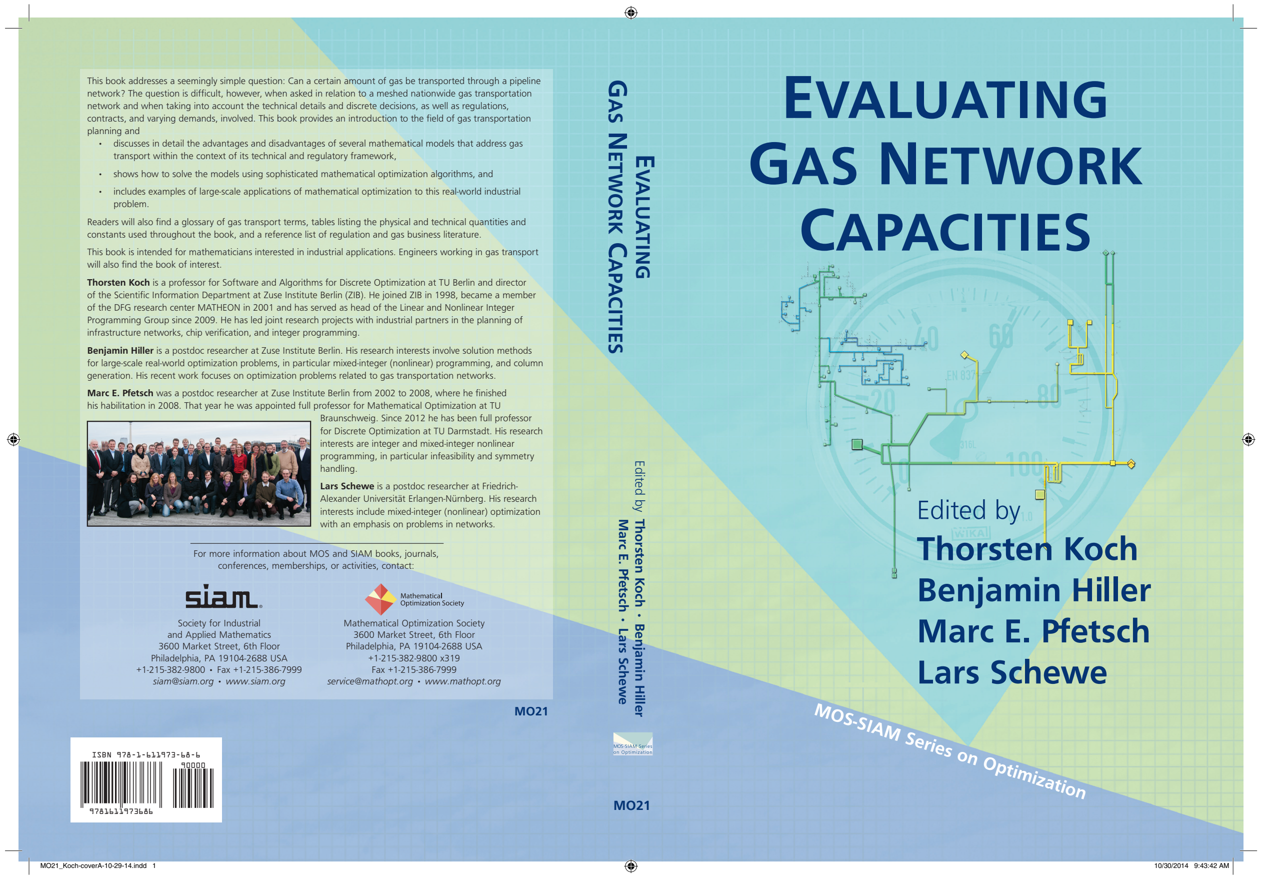
Projects

ForNe

TRR 154

EnCN

Book



EVALUATING GAS NETWORK CAPACITIES
Edited by
Thorsten Koch
Benjamin Hiller
Marc E. Pfetsch
Lars Schewe
MOS-SIAM Series on Optimization
This book addresses a seemingly simple question: Can a certain amount of gas be transported through a pipeline network? The question is difficult, however, when asked in relation to a meshed nationwide gas transportation network and when taking into account the technical details and discrete decisions, as well as regulations, contracts, and varying demands, involved. This book provides an introduction to the field of gas transportation planning and
• discusses in detail the advantages and disadvantages of several mathematical models that address gas transport within the context of its technical and regulatory framework,
• shows how to solve the models using sophisticated mathematical optimization algorithms, and
• includes examples of large-scale applications of mathematical optimization to this real-world industrial problem.
Readers will also find a glossary of gas transport terms, tables listing the physical and technical quantities and constants used throughout the book, and a reference list of regulation and gas business literature.
This book is intended for mathematicians interested in industrial applications. Engineers working in gas transport will also find the book of interest.
Thorsten Koch is a professor for Software and Algorithms for Discrete Optimization at TU Berlin and director of the Scientific Information Department at Zuse Institute Berlin (ZIB). He joined ZIB in 1998, became a member of the DFG research center MATHEON in 2001 and has served as head of the Linear and Nonlinear Integer Programming Group since 2009. He has led joint research projects with industrial partners in the planning of infrastructure networks, chip verification, and integer programming.
Benjamin Hiller is a postdoc researcher at Zuse Institute Berlin. His research interests involve solution methods for large-scale real-world optimization problems, in particular mixed-integer (nonlinear) programming, and column generation. His recent work focuses on optimization problems related to gas transportation networks.
Marc E. Pfetsch was a postdoc researcher at Zuse Institute Berlin from 2002 to 2008, where he finished his habilitation in 2008. That year he was appointed full professor for Mathematical Optimization at TU Braunschweig. Since 2012 he has been full professor for Discrete Optimization at TU Darmstadt. His research interests are integer and mixed-integer nonlinear programming, in particular infeasibility and symmetry handling.
Lars Schewe is a postdoc researcher at Friedrich-Alexander Universität Erlangen-Nürnberg. His research interests include mixed-integer (nonlinear) optimization with an emphasis on problems in networks.
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Model hierarchies

Different physical models

- No agreement on the "right" model
- Everthing from PDAE models to linear flow w/o pressure drop
- Difficult to quantify the error of different levels

What does this mean for the wiki?

- Do we discuss this and if we do, how?
- Difficulty for optimization-based methods: How do we discuss infeasibility?

Euler equations

1d-Euler equations for cylindrical pipes

$$
\begin{aligned}
\frac{\partial \rho}{\partial t} + \frac{1}{A}\frac{\partial q}{\partial x} &= 0 \\
\frac{1}{A}\frac{\partial q}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial \left(\rho v^2\right)}{\partial x} + g\rho s + \lambda(q)\frac{|v|\, v}{2D}\rho &= 0 \\
A\rho c_p \left(\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial x}\right) - A\left(1 + \frac{T}{z}\frac{\partial z}{\partial T}\right)\frac{\partial p}{\partial t} & \\
- A\, v\frac{T}{z}\frac{\partial z}{\partial T}\frac{\partial p}{\partial x} + A\rho v g s + \pi D c_{\mathrm{HT}}\left(T - T_{\mathrm{soil}}\right) &= 0.
\end{aligned}
$$

and

$$
\rho R_{\mathrm{s}} T z(p, T) = p.
$$

Algebraic model

Solution of a simplified model for the stationary, isothermal case

$$p_{\mathrm{out}}^2 = \quad p_{\mathrm{in}}^2 - \Lambda\,|q|\,q$$

with

$$\Lambda = \left(\frac{4}{\pi}\right)^2 \lambda(q)\frac{R_{\mathrm{s}} z_{\mathrm{m}} T_{\mathrm{m}} L}{D^5},$$

Algebraic model

Solution of a simplified model for the stationary, isothermal case

$$p_{\mathrm{out}}^2 = \left(p_{\mathrm{in}}^2 - \Lambda \, |q| \, q \frac{e^S - 1}{S} \right) e^{-S}$$

with

$$\Lambda = \left(\frac{4}{\pi} \right)^2 \lambda(q) \frac{R_{\mathrm{s}} z_{\mathrm{m}} T_{\mathrm{m}} L}{D^5},$$

$$S = \frac{2gsL}{R_{\mathrm{s}} z_{\mathrm{m}} T_{\mathrm{m}}}.$$

What does this mean for the wiki?

Problems

- No well-understood relation between different "levels"
- Infeasibility
- What to tell practioners?
- When is the data error larger than the model error?

Challenges

- Can we construct an integrated hierarchy? (TRR 154)
- How do we explain that it works?

Market regulations

Different regulations, different problems

- Europe: Entry-exit system
- Other places: Integrated Operators

In the following:

- Entry-exit system

Entry-Exit system (simplified)

Standard contract

On any given day you are allowed to supply/demand up to X units of gas at node v if you have matching partners at some other nodes.

Problems

- Given a supply/demand situation on a given day, is it technically feasible? (Validation of nominations)
- How large may X be? (Validation of bookings)
- Given a set of nodes, how large may we choose each X_v such they can be satisfied simultaneously? (Computing the technical capacity)
- If one of the above problems has no satisfying solution, where can we build a network extension to ameliorate the situation? (Extension planning)

Entry-Exit-System

Goals

To enhance competition through liquid wholesale markets for gas, it is vital that gas can be traded independently of its location in the system. The only way to do this is to give network users the freedom to book entry and exit capacity independently, thereby creating gas transport through zones instead of along contractual paths. [. . .]

(EC-Regulation No 715/2009 (19))

What is *technical capacity*?

'[T]echnical capacity' means the maximum firm capacity that the transmission system operator can offer to the network users, taking account of system integrity and the operational requirements of the transmission network;

(EC-Regulation No 715/2009 Art.2; P. 1, (18))

Comparison with the European electricity market

Electricity market

- Trade first, . . .
- restore feasibility later via redispatch

Gas market

- Determine capacities first, . . .
- trade later.

Main difference

- no redispatch in the gas market necessary
- easier trading, more work for the TSO

Problem

Nomination

A *nomination* is a balanced load flow $\omega \in \mathbb{R}_{\geq 0}$. It is feasible, if it can be transported in the network.

Booking

A *booking* is a vector $B = (B_v)_{v \in} \in \mathbb{R}_{\geq 0}$.

$$\begin{aligned} \max \quad & \sum_{v \in} B_v \\ \text{s.t.} \quad & \omega \text{ is feasible for all } \omega \text{ with } \omega \leq B \end{aligned}$$

Hardness of Validation of Bookings

Problem

Is a booking feasible?

Theorem: Deciding feasibility of a booking is coNP-hard

- . . . even when only linear flows are considered
- Follows e.g. from results on robust network design
- 2-Inapproximability under unique games conjecture (Chekuri et al. 2007)

Hardness of Validation of Bookings

Given a network, arc capacities c, and a booking, answer

- **Yes,** if the booking is feasible for capacities c;
- **No,** if the booking in infeasible for capacities $2c$.

Otherwise any answer is allowed.

This problem is coNP-hard under UGC (follows from Chekuri et al. 2007)

What does this mean for the wiki?

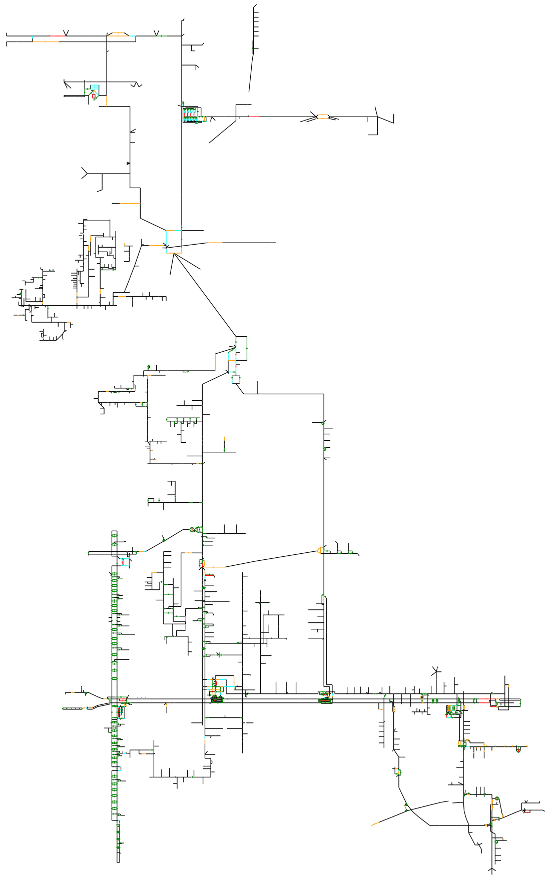
Regulation drives the mathematical questions

- Different regulation leads to different problems
- Certain problems only regionally relevant

Policy analysis

- Is the wiki also addressed towards policy makers?
- Or is the focus on the technical side?

Example



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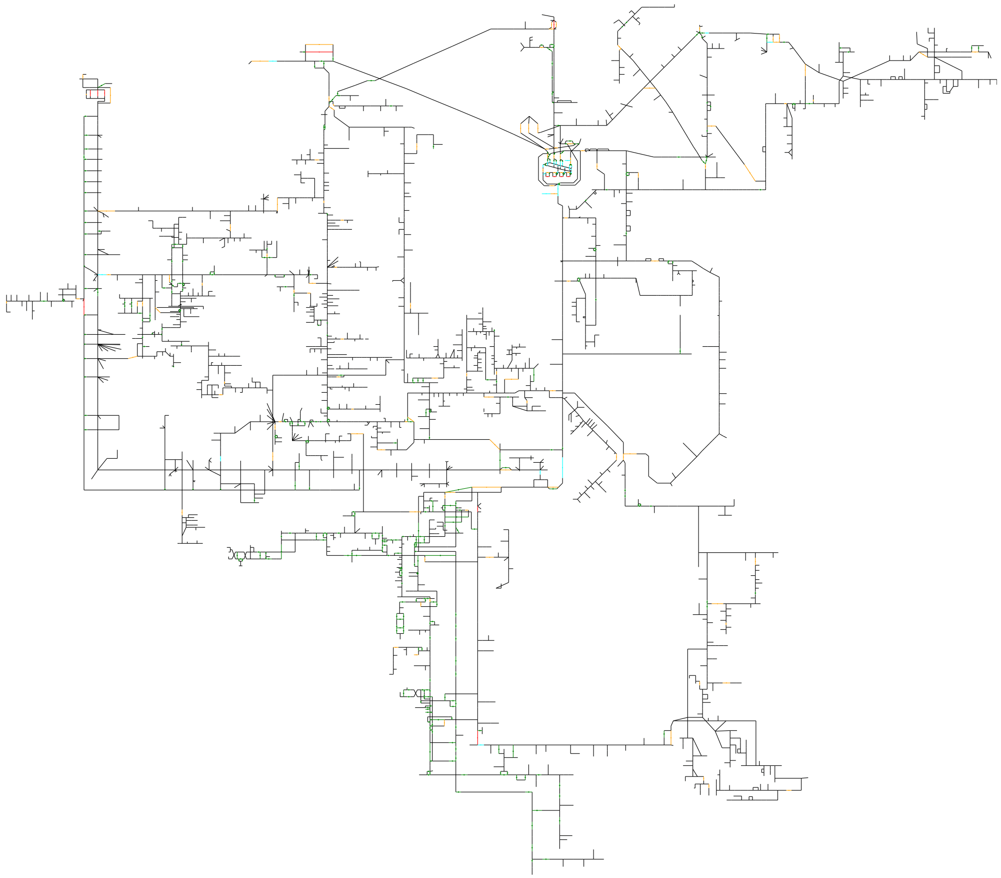

Network topologies

Gun-barrel networks common (e.g. US)

- Dynamic programming the preferred approach

More complex networks (e.g. Germany, France)

- Many other ideas . . . see before

Data sets

Gaslib

`http://gaslib.zib.de`

Content

- Technical description of problem instances
- only one set of instances ready for solvers (as GAMS files)

Questions?