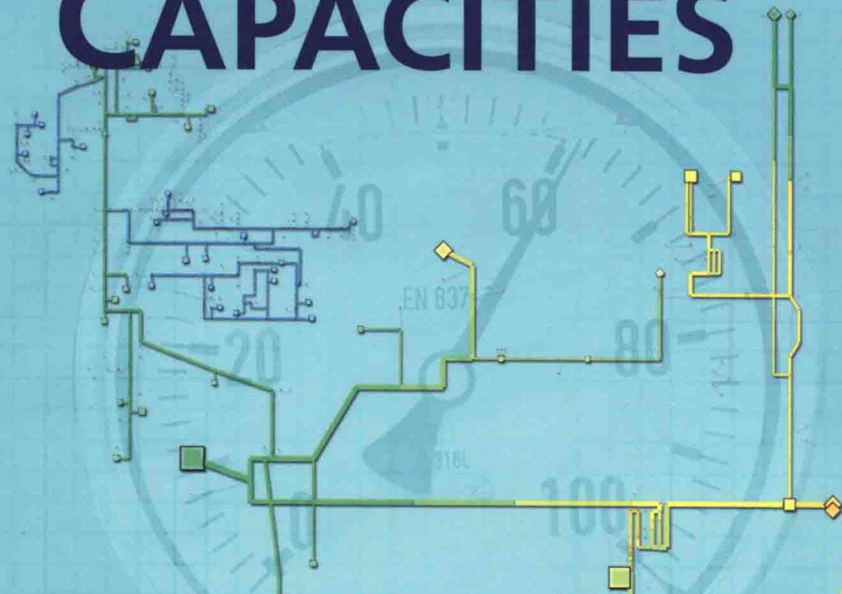
EVALUATING GAS NETWORK CAPACITIES



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MOS-SIAM Series on Optimization

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10 9 8 7 6 5 4 3 2 1

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Library of Congress Cataloging-in-Publication Data

Evaluating gas network capacities / edited by Thorsten Koch, Technische Universität Berlin, Berlin, Germany [and 3 others].
pages cm. – (MOS-SIAM series on optimization)
Includes bibliographical references and index.
Summary: "This book deals with a simple sounding question whether a certain amount of gas can be transported by a given pipeline network. While well studied for a single pipeline, this question gets extremely difficult if we consider a meshed nation wide gas transportation network, taking into account all the technical details and discrete decisions, as well as regulations, contracts, and varying demand. This book describes several mathematical models to answer these questions, discusses their merits and disadvantages, explains the necessary technical and regulatory background, and shows how to solve this question using sophisticated mathematical optimization algorithms."– Provided by publisher.

ISBN 978-1-611973-68-6

1. Gas pipelines–Mathematical models. 2. Gasses–Transport properties. 3. System analysis. 4. Mathematical optimization. I. Koch, Thorsten, 1967- editor.

TN879.5.E93 2015

665.7'44–dc23 2014035425

Evaluating Gas Network Capacities

MOS-SIAM Series on Optimization

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Foreword

If you have tried it for yourself . . .

When setting up the rules for the gas grid access, the Federal Network Agency had to deal with the following argument again and again: "With the new rules of the game you will only alter the financial relations, not the gas flows. Gas will still come from Russia, Norway, and The Netherlands, and consumers will not change their behavior anyway." On these grounds we were asked to completely abolish any management of capacities in the gas grid altogether and to just collect the costs of the network operation from the end-consumers—as is the practice with electricity.

We had our doubts in this respect. More precisely, we were much more optimistic. We assumed that competition would well be able to bring about lasting changes in supply relationships: The operational mode of storage facilities, but also import flows, would undergo dramatic changes during our transition from the old world of monopolies to the new, heterogeneous world of competition.

We proved to be right. Gas flows are constantly changing and capacity bookings are still an important factor. Instead of abolishing the management of capacities in the gas grid we further developed and differentiated them. The aim was and still is to design capacity products such that they hamper trade as little as possible but at the same time account for network requirements in a safe way.

In order to understand these network requirements, we have made a small and incomplete attempt to calculate for ourselves how much fixed capacity a network operator can offer its customers. The result was simple: Zero. Due to the high number of entries and exits, every meshed network has so many conceivable use cases that it is easy to substantiate that at least one use case is not representable.

The result was not satisfactory and we have started to look for assumptions and methods that improve the situation. It became clear pretty soon that we had to be careful with any kind of simplification, because it is the extreme individual case that must remain controllable or be excluded. Otherwise it is not possible to offer fixed capacities.

We soon got stuck in the jungle of possibilities and combinations. And our appreciation for the technicians at the gas network operators grew even more. In the control and marketing decisions they make every day, these people take up responsibility to operate the gas grid in ever-growing market areas according to the needs and requirements of transport customers as well as adjoining and downstream networks. They do this on the basis of their experience of what the grid is capable of and how it reacts to certain conditions. There is no standardized methodology for this.

This book changes little for the technician on site. However, it means vast changes for theoretical considerations of the capabilities of a gas grid. What we have tried once on a very small scale has been done from A to Z by a really huge team of mathematicians: This involves research on the border of the capability of today's methods, and is therefore interesting and challenging for mathematicians. We do believe this and we are enthusiastic about their method: Millions of possible supply relationships are combined with millions of system settings and checked for permissibility. The fact that these calculations do not take millions of years is really great art.

The result is reassuring: There are indeed fixed capacities that the network operators can offer their customers.

Peter Stratmann
Federal Network Agency

Preface

Structure of this book and how to read it

This book is divided into three parts:

Part I Fundamentals,
Part II Validation of nominations,
Part III Verification of booked capacities.

Part I gives fundamental information about the planning problems arising in gas transport and is structured as follows: Chapter 1 gives an introduction to the main topics of this book and describes the overall setting. Chapter 2 will define the notation and technical basics of *gas networks* as used throughout the book. Chapter 3 explains why we have to deal with the evaluation of gas network capacities in the first place (other than for technical reasons) by giving all the legal background needed. (Appendix A provides further details.) Chapter 4 describes the state of the art of gas transport planning using simulation.

Part II deals with approaches for the validation of nominations problem. In Chapter 5 we move from simulation to optimization in order to deal with the validation of nominations (NoVa) problem. Chapters 6–9 describe different approaches for obtaining discrete decisions, which are validated by a high precision nonlinear program (NLP), presented in Chapter 10. Chapter 11 reviews the methodology and puts it into perspective, discussing the interpretation of the results. Chapter 12 gives computational results using all the methods described in Chapters 6–10.

Part III discusses approaches for the verification of bookings. Chapters 13 and 14 deal with the generation of realistic nominations, taking into account past, future, and legal aspects; this will lead to an approach to deal with the verification of bookings. We will also present some computational results for the verification of bookings. Finally, Chapter 15 will provide an outlook on what further, more involved questions might be answered by building upon the results presented in this book.

As a rule of thumb, the following combinations of chapters can be read independently:

- ▷ Chapter 2 gives an independent introduction to gas transport modeling.
- ▷ Chapters 3 and 4 give an introduction into the current legal conditions and state of the art. Appendix A provides further background into the legal setup.
- ▷ Chapter 5 provides the basic setting for Chapters 6–10. Each of the five latter chapters is independent from the others.
- ▷ Chapter 11 requires some knowledge about Chapters 5 and 6–10; in particular requires Chapters 6 and 10.
- ▷ The computations presented in Chapter 12 require knowledge about the individual approaches, i.e., Chapters 6–10.

▹ Chapters 13 and 14 describe the approach for the verification of bookings and present some computational results.

Let us finally list some additional information on the structure of this book:

▹ A glossary for terminology of gas transport starts on page 331.
▹ An index is given starting on page 361.
▹ There are two tables inside the front and back covers of this book, respectively, that contain a list of physical and technical quantities and constants that are used throughout this book.
▹ Moreover, this book contains two lists of literature. The first starting on page 339 contains references for legal or gas business related information; the corresponding citations are marked in brackets, e.g., [GasNZV 2005]. The second starting on page 345 contains mathematical literature; its citations use parentheses, e.g., Domschke et al. (2011).

Goals of this book

The main goal of this book is to provide an introduction to the field of gas transport planning. We highlight the many interesting mathematical questions that arise in this context. Moreover, we describe the above mentioned new approach for evaluating the capacity of a gas network in detail.

In particular, this book provides the following information:

▹ Chapter 2 provides a compact description of the main mathematical concepts and formulas needed to describe gas transport.
▹ We describe the legal framework for gas transport (Chapter 3) and the state of the art (Chapter 4).
▹ Four approaches to find (discrete) decisions for the active elements in order to transport a given load situation are developed (Chapters 6–10). The outcome of these methods is used in order to find a solution of a more accurate NLP model (Chapter 10).
▹ Chapters 13 and 14 provide an approach to automatically generate stressing load situations.
▹ Finally, we present computational results of the proposed methods in Chapters 12 and 14.

We thus see this book just as a first step towards the development of mathematical concepts and results that arise in this area with the goal of providing practically useful methods.

Acknowledgments

This book is one of the results of the research project

Untersuchung der technischen Kapazität von Gasnetzen
(Investigation of the technical capacity of gas networks)

supported by the German Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie – BMWi).

The goal of the project was to improve the mathematical methods used for mid- to long-term capacity planning of gas transportation networks. It was conducted between 2009 and 2012 and has been triggered by another project, called *Forschungskooperation Netzoptimierung* (ForNe) (Research cooperation network optimization) that was initiated

by Germany's largest gas transport system operator Open Grid Europe GmbH (OGE) due to the challenges imposed by new regulations on gas transportation. ForNe has been executed by OGE and Friedrich-Alexander-Universität Erlangen-Nürnberg, Humboldt-Universität zu Berlin, Technische Universität Darmstadt, Leibniz Universität Hannover, Universität Duisburg-Essen, Weierstraß Institut für Angewandte Analysis und Stochastik (WIAS), and Zuse Institute Berlin (ZIB). In particular, the authors of this book were involved. As of this writing ForNe is still running, working on bringing the results obtained into daily practice.

We would like to express our gratitude to

- the Bundesnetzagentur (BNetzA) for their support of the project, in particular Peter Stratmann, Stefan Wolff, and Markus Backes;
- Projektträger Jülich for their support, in particular Rainer Schneider, Christoph Jessen, and Johannes Tambornino;
- OGE for making available the data used for the computational experiments;
- Thomas Liebling for his support from the MOS-SIAM series on optimization side.
- the people at SIAM, in particular Sara Murphy, Elizabeth Greenspan, and Lisa Briggeman, who supported us and waited faithfully for the manuscript;
- Henrik Pilz and Jakob Witzig for their help with preparing the figures;
- Siemens (Andrea Klottig) for allowing us to use the picture in Figure 2.6.

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