

Contents

Abstract	i
Zusammenfassung	iii
Financial acknowledgments	v
Acknowledgments	vii
1 Introduction	1
2 Concepts	9
2.1 Classes of mathematical programs	9
2.2 Introduction to MINLP	13
2.2.1 LP-based branch-and-bound for MILP	13
2.2.2 Convexification	14
2.2.3 Branch-and-bound for MINLP: Spatial Branching	16
2.3 Robust Optimization	17
2.3.1 Multistage Robust Optimization	19
3 Reformulations and relaxations for quadratic programs	21
3.1 Definitions and notation	21
3.2 Convexification	23
3.2.1 McCormick relaxation	23
3.2.2 Convex relaxations by matrix decomposition	27
3.3 Reformulation-Linearization Technique (RLT)	29
3.3.1 Projected RLT inequalities	30
4 Motzkin-Straus inequalities for Standard Quadratic Programming and generalizations	33
4.1 Introduction	34
4.2 Q-Space reformulation for StQP	35
4.3 Motzkin-Straus Clique inequalities	37
4.4 Generalized MSC inequalities for bipartite graphs	42

4.5	Separation	44
4.5.1	Exact separation	44
4.5.2	Heuristic separations and strengthening	47
4.6	Computational Experiments	48
4.6.1	Instances	49
4.6.2	Optimizing over the bipartite closures	51
4.6.3	Combining the separation of MSC and GMSC bipartite inequalities	55
4.6.4	Motzkin-Straus Clique inequalities for higher clique numbers	60
4.6.5	Branch-and-cut results	64
4.6.6	Computational results on the instances from [ST08]	70
4.7	Generalization	78
4.7.1	Computational experiments	80
4.8	Conclusion	83
5	Strong Relaxations for the Pooling Problem	85
5.1	Introduction	86
5.2	Standard formulations	88
5.2.1	Notation and assumptions	88
5.2.2	The flow model	90
5.2.3	The p -formulation	92
5.2.4	The q -formulation	94
5.2.5	The pq -formulation	98
5.3	New convex relaxations for the pooling problem	100
5.3.1	A 5 variable relaxation	100
5.3.2	Extreme points	105
5.3.3	Valid inequalities	108
5.3.4	Convex hull analysis	114
5.4	Computational experiments	129
5.4.1	Computational setup	130
5.4.2	Adding the inequalities	130
5.4.3	Instances	131
5.4.4	Results	132
5.5	Conclusion	136
6	Models for deterministic gas network optimization	139
6.1	Introduction	139
6.2	Modeling gas transportation networks	141
6.3	Deterministic network extension	144

7 Gas network topology planning for multiple scenarios	147
7.1 A robust model for gas network extension	148
7.2 Scenario decomposition: A branch-and-bound approach	150
7.3 Dual bounds	152
7.4 Primal solutions	153
7.4.1 From the solutions of the subproblems	153
7.4.2 1-opt heuristic	153
7.4.3 Best-known heuristic	153
7.5 Reusing solutions	155
7.6 Computational Experiments	157
7.6.1 Computational Setup	157
7.6.2 Testsets and Instances	158
7.6.3 Results	163
7.7 Conclusion	167
8 Conclusion	169
Bibliography	173