

Contents

Summary	iii
Zusammenfassung	v
1 Introduction	1
1.1 Background	1
1.2 Motivation	1
1.3 State of research and proposed approach	2
1.4 Thesis outline	9
2 Structured decision making for sustainable water infrastructure planning under four future scenarios	11
2.1 Introduction	11
2.1.1 Structured decision making.....	11
2.1.2 Combining scenario planning with MCDA.....	12
2.1.3 Water infrastructure planning.....	13
2.1.4 Objectives of this paper.....	14
2.2 Materials and Methods	14
2.2.1 Step (1) Clarify decision context.....	14
2.2.2 Step (2) Define objectives and attributes.....	15
2.2.3 Future scenarios.....	17
2.2.4 Step (3) Develop alternatives	17
2.3 Results	18
2.3.1 Step (2) Define objectives and attributes.....	18
2.3.2 Future scenarios.....	23
2.3.3 Step (3) Develop alternatives.....	24
2.3.4 Feedback about the SDM-procedure	25
2.4 Discussion.....	27
2.4.1 Step (1) Clarify decision context.....	27
2.4.2 Step (2) Define objectives and attributes.....	28
2.4.3 Future scenarios.....	29
2.4.4 Step (3) Develop alternatives.....	29
2.4.5 Conclusions and Outlook.....	30
2.5 Acknowledgements	31
3 Combining expert knowledge and local data for improved service life modeling of water supply networks	33
3.1 Introduction	34

3.1.1 Challenge.....	34
3.1.2 Network rehabilitation and survival modeling with scarce data.....	34
3.1.3 Background on expert knowledge elicitation and aggregation.....	34
3.1.4 Elicitation of the parameters from a multivariate survival function.....	35
3.1.5 Goal and structure of the paper.....	36
3.2 Methods.....	37
3.2.1 Choice of the survival model.....	37
3.2.2 Expert Elicitation.....	37
3.2.3 Derivation of experts' priors of survival function parameters and aggregation.....	40
3.2.4 Model parameter estimation.....	42
3.2.5 Utility data.....	44
3.3 Results and Discussion.....	45
3.3.1 Expert elicitation.....	45
3.3.2 Parametric model identification.....	46
3.3.3 Expert prior aggregation.....	48
3.3.4 Maximum likelihood estimation from data.....	51
3.3.5 Bayesian inference.....	54
3.4 Summary and Conclusions.....	56
3.4.1 Improved service life modeling under scarce data.....	56
3.4.2 Expert elicitation and prior aggregation.....	56
3.4.3 Frequentist and Bayesian inference.....	56
3.4.4 Ambiguity of model selection.....	57
3.4.5 Consideration of uncertainty.....	57
3.5 Acknowledgements.....	57
3.6 Appendices.....	58
Appendix A- Expert elicitation.....	58
Appendix B- Parametric model fit and parameter uncertainty.....	63
4 Extension of pipe failure models to consider the absence of data from replaced pipes.....	65
4.1 Introduction.....	65
4.2 Methods.....	67
4.2.1 Pipe failure model.....	67
4.2.2 Replacement model.....	69
4.2.3 Joint likelihood.....	69
4.2.4 Consideration of covariables.....	70
4.2.5 Parameter inference.....	70
4.2.6 Predictions.....	70
4.3 Example: Weibull-exponential model.....	71

4.3.1 Likelihood for completely observed pipes.....	72
4.3.2 Consideration of replacement.....	72
4.3.3 Predictions.....	74
4.3.4 Implementation.....	74
4.4 Application examples.....	74
4.4.1 Simulated data.....	74
4.4.2 Real data.....	77
4.5 Discussion.....	78
4.6 Conclusions.....	80
4.7 Acknowledgments.....	80
5 Strategic rehabilitation planning of piped water networks using multi-criteria decision analysis	81
5.1 Introduction.....	81
5.1.1 Strategic Asset Management (SAM).....	81
5.1.2 Failure models.....	82
5.1.3 Comparing rehabilitation alternatives.....	82
5.1.4 Decision support.....	82
5.1.5 Uncertainty assessment.....	83
5.1.6 Goal and structure.....	83
5.2 Material and methods.....	84
5.2.1 Data preparation.....	84
5.2.2 Pipe failure and replacement model.....	84
5.2.3 Network rehabilitation model.....	86
5.2.4 MCDA framework.....	87
5.2.5 Objectives and attributes.....	88
5.2.6 Strategic rehabilitation alternatives.....	89
5.2.7 Modeling preferences.....	90
5.2.8 Dominance and ranking of alternatives under uncertainty.....	92
5.2.9 Robustness under four future scenarios.....	92
5.2.10 Implementation.....	93
5.3 Results.....	94
5.3.1 Network data.....	94
5.3.2 Failure model.....	95
5.3.3 Outcomes of strategic alternatives.....	96
5.3.4 Outcomes of strategic alternatives and dominance.....	99
5.3.5 Ranking and sensitivity under different preference assumptions.....	99
5.4 Discussion.....	100

5.4.1 Data preparation.....	100
5.4.2 Failure and rehabilitation model	101
5.4.3 Outcomes of strategic planning alternatives	102
5.4.4 Ranking of alternatives and sensitivity	102
5.4.5 Outcome of the case study	103
5.5 Conclusions.....	103
5.6 Acknowledgements.....	104
5.7 Appendices.....	105
Appendix A) Length homogenization procedure.....	105
Appendix B) Future scenarios	105
Appendix C) First-degree stochastic dominance- risk profiles.....	107
6 Tackling uncertainty in multi-criteria decision analysis – An application to water supply infrastructure planning.....	109
6.1 Introduction.....	110
6.1.1 Consideration of uncertainty in MAUT applications	110
6.1.2 Sources of uncertainty	110
6.1.3 Uncertainty and sensitivity analysis	112
6.1.4 Application of MAUT to water supply infrastructure planning	112
6.1.5 Aim of the study and main research questions.....	113
6.2 Material and methods.....	113
6.2.1 Case study “Mönchaltorfer Aa”.....	113
6.2.2 Elicitation of preferences	116
6.2.3 Preference modeling	118
6.2.4 Uncertainty analysis.....	118
6.2.5 Global sensitivity analysis (GSA).....	121
6.2.6 Implementation	122
6.3 Results of the case study.....	122
6.3.1 Attribute outcomes	122
6.3.2 Stakeholder preferences.....	123
6.3.3 Ranking of alternatives and uncertainty analysis	124
6.4 Results of the global sensitivity analysis	128
6.5 Discussion	132
6.5.1 Water infrastructure planning in the case study	132
6.5.2 Preference elicitation.....	133
6.5.3 Uncertainty analysis.....	134
6.5.4 Global sensitivity analysis.....	134
6.6 Conclusions.....	135

6.7 Acknowledgements	136
6.8 Appendix.....	137
7 Conclusions and outlook	139
7.1 Conclusions	139
7.1.1 Pipe survival, failure, and rehabilitation modeling	139
7.1.2 Multi-criteria decision analysis (MCDA) for water infrastructure planning under uncertainty	141
7.1.3 Findings and recommendations for the Mönchaltorfer Aa case study	144
7.2 Outlook.....	146
Acknowledgements	151
References	153
SI-A) Additional Information for “Structured decision making for sustainable water infrastructure planning under four future scenarios”	169
A1 Step (2) Define objectives and attributes.....	170
A2 Future scenarios.....	191
A3 Step (3) Develop alternatives.....	194
A4 Stakeholder feedback and recommendations	203
SI-B) Supporting Material to: Combining expert knowledge and local data for improved service life modeling of water supply networks	209
SI-C) Supporting Material to: Strategic rehabilitation planning of piped water networks using multi-criteria decision analysis	219
C1 Symbols and abbreviations.....	219
C2 Prediction of unrecorded failures.....	220
C3 Estimated failure model parameters for runs with fixed π in water utilities B and C.....	221
C4 Second-degree stochastic dominance analysis	222
C5 MCDA results for all alternatives.....	225
C6 Additional figures	226
SI-D) Supporting Information to: Tackling uncertainty in multi-criteria decision analysis- An application to water supply infrastructure planning.....	233
D1 Stakeholder identification	233
D2 Decision attributes.....	235
D3 Decision alternatives.....	242
D4 Stakeholder preferences	257
D5 Uncertainty analysis	275
D6 Global sensitivity analysis (GSA).....	278
Curriculum Vitae	281