

Contents

Introduction	1
Martin Grötschel, Klaus Lucas, and Volker Mehrmann	

Processes

Predictive Planning and Systematic Action—On the Control of Technical Processes	9
Lars Grüne, Sebastian Sager, Frank Allgöwer, Hans Georg Bock, and Moritz Diehl	
1	Executive Summary 9
2	A Long Success Story 10
2.1	The Stability Criterion of Hurwitz 10
2.2	Pontryagin's Maximum Principle 12
2.3	Conclusion 13
3	State-of-the-Art and Current Developments: The Example "Model Predictive Control" 14
3.1	A Short Introduction to Control Engineering 14
3.2	The Principle of Model Predictive Control 17
3.3	Stability of MPC 19
3.4	Application Fields 20
3.5	Direct Optimal Control Methods 22
4	Challenges 27
4.1	Modeling 27
4.2	Robustness of Solutions, Uncertainties 30
4.3	Further Challenges 31
5	Visions and Recommendations 32
5.1	Theory and Praxis 33
5.2	Interdisciplinary in Education 34
	References 34

Data Compression, Process Optimization, Aerodynamics:

A Tour Through the Scales	39
Wolfgang Dahmen and Wolfgang Marquardt	
1 Executive Summary	39
2 Some Guiding Ideas	40
3 Success Stories	42
3.1 Information Retrieval from Huge Datasets	42
3.2 Information Retrieval from Huge Datasets	42
3.3 Adaptively Optimized	43
3.4 Aerodynamics under a Mathematical Microscope	47
4 Status Quo	50
4.1 Multiscale-Decomposition: Wavelets	50
4.2 Multiscale Methods for Process Data Analysis	56
4.3 Solving Optimal Control Problems with Adaptive Wavelet Discretization	59
4.4 Adaptive Methods for Partial Differential Equations in Fluid Mechanics	62
5 Analysis of Strengths and Weaknesses	69
6 Visions and Recommended Course of Action	70
References	70

Active Flow Control—A Mathematical Challenge 73

Rudibert King, Volker Mehrmann, and Wolfgang Nitsche	
1 Executive Summary	73
2 Success Stories	74
3 Active Flow Control, Status Quo	75
3.1 Modelling	77
4 Analysis of Strengths and Weaknesses, Challenges	79
5 Visions and Recommendations	79
References	80

Data Mining for the Category Management in the Retail Market 81

Jochen Garcke, Michael Griebel, and Michael Thess	
1 Executive Summary	81
2 Category Management in the Retail Market: Overview and Status Quo	82
2.1 Optimization of Campaigns	83
2.2 Cross- and Up-Selling	85
3 Outlook	89
4 Visions and Suggested Actions	91
References	91

Networks

Planning Problems in Public Transit	95
Ralf Borndörfer, Martin Grötschel, and Ulrich Jäger	
1 Executive Summary	95
2 Success Stories	96
3 PT Planning Problems: Survey and Status Quo	99
3.1 Scheduling	100
3.2 Control	103
3.3 Service Design	106
3.4 Regulation	108
4 Strengths, Weaknesses, and Challenges	108
4.1 General Conditions for the Use of Mathematics	109
4.2 Mathematical Models and Algorithms	112
4.3 Transfer and Education	115
4.4 Conclusion	116
5 Visions and Recommendations	117
5.1 Discrete Optimal Control: Real-Time Re-Planning of Traffic Systems in Case of Disruptions	117
5.2 Model Integration: Service Design in Bus and Rail Traffic	119
References	119
Towards More Intelligence in Logistics with Mathematics	123
Rolf H. Möhring and Michael Schenk	
1 Executive Summary	123
2 Examples of Success	125
2.1 Logistics Chains	125
2.2 Shipping	126
2.3 Production Logistics	127
2.4 Controlling Logistical Networks	129
3 Logistics and Mathematics: the Status Quo	132
3.1 On the Development of Logistics	132
3.2 Mathematics in Logistics	133
4 Future Challenges	133
5 Visions and Recommendations for Action	135
References	136
Optimization of Communication Networks	139
Jörg Eberspächer, Moritz Kiese, and Roland Wessäly	
1 Executive Summary	139
2 Mathematics as the Foundation of Every Network	140
2.1 Routing in the Internet	140
2.2 Quality Control in Phone Networks and the Internet	141
2.3 Cost Optimization of Network Investments	142
3 Networks, Planning and Methods	143
3.1 Network Architecture and Planning Aspects	143

3.2	Strategic Planning	144
3.3	Tactical Planning	145
3.4	Operational Planning	147
3.5	Status Quo: Summary	148
4	Influences and Challenges	149
4.1	Market Influence, Competitive Conditions, Regulations . .	149
4.2	Data Basis	149
4.3	Convergence and System Complexity	150
4.4	Planning Processes and Planning Tools	150
4.5	Collaboration Between Industry and Science, Engineers and Mathematicians	151
4.6	Selected Challenges	151
5	What Has to be Done? Proposals and Initiatives	154
5.1	Education	154
5.2	Economy	155
5.3	Research Proposal	155
	References	156
	Mathematics in Wireless Communications	157
	Holger Boche and Andreas Eisenblätter	
1	Executive Summary	157
2	Success Stories	158
2.1	Mobile Communications Needs Mathematics	159
2.2	The Foundations of Communications Theory	159
2.3	Key technologies	161
2.4	Optimization of GSM Networks	162
3	Knowledge Brings Progress	163
3.1	Optimized Resource Allocation in Cellular Radio Networks	164
3.2	Controlling Transmission Power	165
3.3	Axiomatics for Interference Limited Radio Systems	167
3.4	Capacity Planning for UMTS Radio Networks	170
3.5	Hardware Development	170
4	Reinforcing Collaboration	172
4.1	Interdisciplinary Collaboration	172
4.2	International Collaboration	173
4.3	Transfer	173
4.4	Sponsoring Research from Young Talent	174
5	Prospects	174
5.1	Information Theory and the Digital World	174
5.2	Network Information Theory	175
5.3	Quantum Information Theory	175
5.4	New Approaches to Frequency Use	176
5.5	Self-Organizing Networks	176
	References	177

Mathematics of Chip Design 179

Jürgen Koehl, Bernhard Korte, and Jens Vygen

1 Executive Summary 179

2 Success Stories 181

3 Status Quo in Chip Design 190

3.1 Placement 194

3.2 Timing Optimization 197

3.3 Routing 202

4 Analysis of Strengths / Weaknesses, Challenges 204

5 Visions of, and Recommendations for the Future 205

References 206

Materials and Mechanics

Chances and Visions of Advanced Mechanics 209

Wolfgang Ehlers and Peter Wriggers

1 Executive Summary 209

2 Success Stories 210

2.1 Continuum Mechanics of Multi-Field and Multi-Physical
Materials 210

2.2 Simulation Techniques for the Description
of Heterogeneous Materials (Multi-Scale Modelling) 214

3 Synopsis and Status Quo 220

3.1 Facts 220

3.2 Summary 225

4 Strengths-Weaknesses Analysis, Challenges 225

4.1 Basis and Visions 225

4.2 How Does Mathematics Come into Play? 227

4.3 Strengths, Weaknesses and Challenges 228

5 Recommendations on Possible Actions 229

References 230

Mathematics for Machine Tools and Factory Automation 231

Berend Denkena, Dietmar Hömberg, and Eckart Uhlmann

1 Executive Summary 231

2 Success Stories 232

2.1 Mathematics for the Development of New Machine
Concepts: Parallel Kinematics 232

2.2 Mathematics for the Layout of Machine Tools: Cutting
Processes 233

3 Mathematical Concepts in Production Engineering 235

3.1 Modeling of Process Chains 235

3.2 Adaptive Numerics 237

3.3 Optimal Control 238

4	Challenges	240
4.1	Interaction Between Structure and Process	240
4.2	Interactions in Milling	242
4.3	Reconfiguration of Production Facilities	244
5	Perspectives	245
	References	246
	Production and Use of Novel Materials	249
	Wolfgang Dreyer	
1	Executive Summary	249
2	Success Stories	250
3	Status Quo	259
4	Analysis of Strengths/Weaknesses, Challenges	260
5	Visions and Recommendations	261
	References	261
	Topology and Dynamic Networks: Optimization with Application in Future Technologies	263
	Günter Leugering, Alexander Martin, and Michael Stingl	
1	Executive Summary	263
2	From Properties to Optimal Structures	264
3	Success Story: Structure-, Topology- and Material-Optimization	268
3.1	Resume/Recommendations	270
4	Optimization of Transportation Networks	270
4.1	Resume/Recommendations	274
	References	275
	Energy and Structural Engineering	
	Capacity Planning and Scheduling in Electrical Power Systems and in Chemical and Metallurgical Production Plants	279
	Sebastian Engell, Edmund Handschin, Christian Rehtanz, and Rüdiger Schultz	
1	Executive Summary	279
2	Success Stories	281
2.1	Supply and Distribution of Electrical Power	281
2.2	Capacity Planning and Scheduling in Chemical and Metallurgical Production	284
3	Status Quo	287
3.1	Power Supply	287
3.2	Chemical and Metallurgical Production Processes	291
3.3	Mathematical Methods	293
4	Perspectives and Challenges	295
4.1	Power Supply	295
4.2	Chemical Production Processes	299

4.3	Mathematical Methods	300
5	Visions and Recommended Courses of Action	302
	References	303

Simulation-Based Optimization in Structural Engineering—New

	Concepts from Computer Science	307
	Dietrich Hartmann, Matthias Baitsch, and Van Vinh Nguyen	
1	Executive Summary	307
2	Success Stories	308
3	Optimization of Non-Standard Problems with Multi-Agent Systems (MAS): The Status Quo	318
	3.1 Agent Systems	318
	3.2 Strategy Networks	319
4	Strong Points, Weak Points and Challenges	323
	4.1 Practical Aspects	323
	4.2 New Optimization Strategies/Algorithms	324
	4.3 Extension of Mathematical Fundamentals for Engineers	324
5	Visions and Courses of Action	325
	References	326

Object-Oriented Modelling for Simulation and Control of Energy

	Transformation Processes	327
	Dirk Abel	
1	Introduction and Overview	327
2	Application in Power Plant Domain: Project OXYCOAL-AC	328
	2.1 Goals and Requirements	328
	2.2 Object-Oriented Modelling of Power Plant Processes	329
	2.3 Object-Oriented Modelling of the Oxycoal Power Plant	330
	2.4 Results	334
	2.5 Conclusions	335
3	Application in the Field of Combustion Engines	336
	3.1 Model-Based Control of Combustion Engines	336
	3.2 Structure of the Control Path	337
	3.3 Comparison of Object-Oriented and Signal-Oriented Modelling on the Example of Air Path Components	338
	3.4 Conclusions	342
4	Summary	343
	References	343

Design Tools for Energy Efficient Architecture 345

	Dirk Müller	
1	Executive Summary	345
2	Development of a Novel Cooling System by Means of a Thermohydraulic Building Simulation	346
	2.1 Application of the Object-Oriented Programming Language Modelica	347

2.2	Extension of a Complex Simulation Model	347
2.3	Results of the Calculations	349
3	Strengths and Weaknesses Analysis, Challenges	351
4	Visions and Recommended Actions	352
	References	352

Medicine

More Mathematics into Medicine! 357

Peter Deuffhard, Olaf Dössel, Alfred K. Louis, and Stefan Zachow

1	Executive Summary	357
2	Mathematics in Medical Imaging	358
2.1	History of a Success	358
2.2	Mathematics as Innovation Factor	361
2.3	Perspective: New Imaging Methods	361
3	Mathematics in Cardiology and Cardial Surgery	365
3.1	Success Stories: ECG and Biosignal Processing	365
3.2	Mathematics as Innovation Factor	366
3.3	Perspective: The Virtual Heart	367
4	Mathematics in Therapy and Operation Planning	370
4.1	Success Story: CMF Surgery	370
4.2	Mathematics as Innovation Factor	371
4.3	Perspective: The Virtual Patient	376
5	Vision and Options	377
	References	377

Compounds, Drugs and Mathematical Image Processing 379

Günter J. Bauer, Dirk A. Lorenz, Peter Maass, Hartwig Preckel,
and Dennis Trede

1	Executive Summary: From the Image to the Drug	379
2	Success Stories	381
2.1	Automated Analysis of Cell Images in the High-Content, High-Throughput Screening	383
2.2	Statistical Evaluation of the Data	384
3	Status Quo: Mathematical Methods for the High-Content, High-Throughput Analysis	386
3.1	Parameter Optimization and Inverse Problems	386
3.2	Enhanced Cell Segmentation	388
4	Strengths and Weaknesses Analysis: The Disciplinary Thinking Dilemma	389
5	Visions and Policy Recommendations	390
5.1	Tangible Challenges	390
5.2	Cooperation	391
	References	391

Contributors 393