

# Contents

|          |                                                                                       |           |
|----------|---------------------------------------------------------------------------------------|-----------|
| <b>1</b> | <b>Introduction</b>                                                                   | <b>1</b>  |
| <b>2</b> | <b>Basics and Problems of Model-Building</b>                                          | <b>5</b>  |
| 2.1      | Introduction .....                                                                    | 5         |
| 2.2      | Definitions of Systems, Models and Related Ideas, System Morphisms.....               | 5         |
| 2.3      | Model Classification .....                                                            | 17        |
| 2.3.1    | Direct and inverse models.....                                                        | 17        |
| 2.3.2    | Qualitative and quantitative models.....                                              | 22        |
| 2.3.3    | Verified, validated and usable models.....                                            | 23        |
| 2.3.4    | Holistic models.....                                                                  | 27        |
| 2.4      | Summary .....                                                                         | 29        |
| 2.5      | Problems.....                                                                         | 29        |
| <b>3</b> | <b>Basics of Systems Theory</b>                                                       | <b>31</b> |
| 3.1      | Introduction, Framework .....                                                         | 34        |
| 3.2      | Cross-Impact Analysis.....                                                            | 37        |
| 3.3      | Theoretical System Analysis and Simulation.....                                       | 64        |
| 3.3.1    | System Analysis.....                                                                  | 64        |
| 3.3.2    | Simulation.....                                                                       | 67        |
| 3.3.3    | Some Elements in Simulation and their Interpretations...                              | 68        |
| 3.4      | Experimental System Analysis: System Identification.....                              | 77        |
| 3.4.1    | Conceptual Approach.....                                                              | 77        |
| 3.4.2    | Alternative Procedures.....                                                           | 79        |
| 3.4.3    | Test Requirements .....                                                               | 93        |
| 3.5      | System/Model Decomposition and Synthesis.....                                         | 97        |
| 3.5.1    | Decomposition by Energy .....                                                         | 100       |
| 3.5.2    | Decomposition by Means of the Hilbert Transformation and the Modulation Theorem ..... | 101       |
| 3.5.3    | Decomposition by Summand Matrices.....                                                | 103       |
| 3.5.4    | Hierarchical Decomposition and Synthesis for Second Order ODEs .....                  | 104       |
| 3.6      | Some Remarks on Planning .....                                                        | 114       |
| 3.7      | Decision-Making.....                                                                  | 118       |
| 3.7.1    | Decision under Certainty .....                                                        | 119       |
| 3.7.2    | Fundamentals of Group-Dynamic Decision .....                                          | 120       |
| 3.7.3    | Decision Evaluation Approaches.....                                                   | 124       |
| 3.7.4    | Decision under Uncertainty .....                                                      | 124       |
| 3.8      | Summary .....                                                                         | 127       |
| 3.9      | Problems.....                                                                         | 128       |

|          |                                                                                      |            |
|----------|--------------------------------------------------------------------------------------|------------|
| <b>4</b> | <b>Model-Building within Theoretical System Analysis</b>                             | <b>137</b> |
| 4.1      | The Challenge of Mathematical Formalization and Model-Building.....                  | 138        |
| 4.2      | Modelling Principles.....                                                            | 141        |
| 4.2.1    | Model Classes.....                                                                   | 142        |
| 4.2.2    | Based on Basic Laws.....                                                             | 145        |
| 4.2.3    | Based on Hypotheses.....                                                             | 156        |
| 4.3      | Model-Building and Morphisms.....                                                    | 162        |
| 4.3.1    | Definitions.....                                                                     | 162        |
| 4.3.2    | Some Statements and Approximations.....                                              | 163        |
| 4.4      | Uncertainties and Errors.....                                                        | 166        |
| 4.4.1    | Direct and Deterministic Modelling of the System Matrix Uncertainty.....             | 168        |
| 4.4.2    | Through Use of the Solution of the State Space Equation.....                         | 172        |
| 4.5      | Summary.....                                                                         | 174        |
| 4.6      | Problems.....                                                                        | 176        |
| <b>5</b> | <b>Theoretical System Analysis: Examples and Tools</b>                               | <b>181</b> |
| 5.1      | Introduction.....                                                                    | 184        |
| 5.2      | Growth and Population Models.....                                                    | 185        |
| 5.2.1    | Population Models.....                                                               | 185        |
| 5.2.2    | Interacting Growth.....                                                              | 187        |
| 5.2.3    | Remarks on Discretization.....                                                       | 195        |
| 5.2.4    | Example of a Partial Differential Equation for Growth....                            | 196        |
| 5.3      | Econometric Models.....                                                              | 197        |
| 5.3.1    | Business Cycles.....                                                                 | 199        |
| 5.3.2    | Supply-Demand Models.....                                                            | 201        |
| 5.4      | Biological Models.....                                                               | 211        |
| 5.4.1    | Controlled Growth of Cancer Cells.....                                               | 211        |
| 5.4.2    | Population Ecology.....                                                              | 214        |
| 5.4.3    | Some Human Models.....                                                               | 215        |
| 5.5      | Technical Models.....                                                                | 219        |
| 5.5.1    | Two Variational Methods: Variational Calculus and Local Approximation.....           | 220        |
| 5.5.2    | Mechanical Models.....                                                               | 230        |
| 5.5.3    | A Flight Mechanics Model.....                                                        | 233        |
| 5.5.4    | Recycling: An Energy Model of the Societal System with Production and Recycling..... | 236        |
| 5.5.5    | Symptom-Based Diagnostic Model.....                                                  | 244        |
| 5.6      | Holistic Models.....                                                                 | 257        |

|          |                                                                                 |            |
|----------|---------------------------------------------------------------------------------|------------|
| 5.6.1    | Some Exact Formulations of Time-Variant Models .....                            | 258        |
| 5.6.2    | Approximate Methods .....                                                       | 262        |
| 5.6.3    | State Space Description .....                                                   | 265        |
| 5.6.4    | Some Remarks on Underspread Systems, STFT, Gabor<br>Expansion and Wavelets..... | 266        |
| 5.6.5    | Approximation of Time-Dependent Coefficients.....                               | 266        |
| 5.7      | Models for Technology Assessment.....                                           | 267        |
| 5.7.1    | A Brief Introduction .....                                                      | 267        |
| 5.7.2    | Methods of Model-Building.....                                                  | 269        |
| 5.7.3    | Example .....                                                                   | 271        |
| 5.8      | Summary .....                                                                   | 273        |
| 5.9      | Problems.....                                                                   | 273        |
| <b>6</b> | <b>System Identification: Test-Supported Model-Building</b>                     | <b>287</b> |
| 6.1      | Basics of Model Correction .....                                                | 287        |
| 6.1.1    | Measures between Model and System.....                                          | 289        |
| 6.1.2    | Estimators.....                                                                 | 289        |
| 6.1.3    | Procedures and Algorithms.....                                                  | 294        |
| 6.1.4    | Error Considerations of the Parameter Estimates.....                            | 298        |
| 6.2      | Approximate Morphisms: Verification, Validation, Usability .....                | 300        |
| 6.2.1    | Basis.....                                                                      | 300        |
| 6.2.2    | Approaches.....                                                                 | 301        |
| 6.3      | Regularization .....                                                            | 302        |
| 6.3.1    | Approaches.....                                                                 | 303        |
| 6.3.2    | Measuring Errors as Additional Information .....                                | 304        |
| 6.4      | Application.....                                                                | 305        |
| 6.5      | Summary .....                                                                   | 309        |
| 6.6      | Problems.....                                                                   | 311        |
| <b>7</b> | <b>Generalized View and Outlook</b>                                             | <b>313</b> |
| 7.1      | The Design Problem.....                                                         | 314        |
| 7.2      | Attempt at Quantitative Aesthetics .....                                        | 318        |
| 7.3      | A Note on Nonlinearities.....                                                   | 323        |
| 7.4      | Epilogue.....                                                                   | 323        |
| <b>A</b> | <b>Alphabetical Abbreviations</b>                                               | <b>325</b> |
| <b>B</b> | <b>Some Mathematical Notations</b>                                              | <b>326</b> |
| <b>C</b> | <b>Mathematical Terminology</b>                                                 | <b>329</b> |
| C.1      | Some Set-Theoretical Definitions, Bases .....                                   | 329        |

|     |                                                                       |            |
|-----|-----------------------------------------------------------------------|------------|
| C.2 | Corresponding Statements in Set Theory and<br>Probability Theory..... | 331        |
| C.3 | Estimation.....                                                       | 332        |
|     | C.3.1 Expectation.....                                                | 332        |
|     | C.3.2 Basics of Estimators.....                                       | 333        |
|     | C.3.3 Parameter Estimation.....                                       | 334        |
| C.4 | Inverse Matrices.....                                                 | 340        |
| C.5 | Eigenvalue Problems and Singular Value Decomposition.....             | 342        |
| C.6 | Integral Transformations.....                                         | 345        |
|     | C.6. 1 Fourier Transformation (FT).....                               | 346        |
|     | C.6.2 Laplace Transformation (LT).....                                | 349        |
|     | C.6.3 z-Transformation (ZT).....                                      | 353        |
|     | <b>References</b>                                                     | <b>355</b> |
|     | <b>Index</b>                                                          | <b>368</b> |