## Contents

	Prej	Preface			
	Ack	Acknowledgments			
	Notation and Symbols				
I	INTRODUCTION TO THE CONSTRUCTION OF MODELS				
	la. lb. lc. ld.	Choice of a Model for the Given Data	2 4 7 8 10		
II	PRELIMINARY ANALYSIS OF STOCHASTIC DYNAMICAL SYSTEMS				
	2a. 2b. 2c. 2d. 2e. 2f. 2g. 2h. 2i. 2j.	Invertibility	11 11 13 14 15 20 23 27 29 31 36 39 39		
ш	STF	RUCTURE OF UNIVARIATE MODELS			
	3a. 3b. 3c. 3d. 3e.	Introduction Types of Dynamic Stochastic Models Types of Empirical Time Series Causality Choice of Time Scale for Modeling Conclusions Notes Problems	42 44 56 63 64 65 66		

viii Contents

IV	EST	TIMABILITY IN SINGLE OUTPUT SYSTEMS	
		Introduction	67
	4a.	Estimability of Systems in Standard Form	68
	4b.	Estimability in Systems with Noisy Observations	75
	4c.	Estimability in Systems with AR Disturbances	77
	4d.	The Estimation Accuracy	78
	4e.	Conclusions	85
		Appendix 4.1	86
		Appendix 4.2. Evaluation of the Cramér-Rao Matrix Lower Bound	
		in Single Output Systems Problems	91
			92
V STRUCTURE AND ESTIMABILITY IN MULTIVARIATE SYSTE			
		Introduction	93
	5a.	Characterization	95
	5b.	The Triangular Canonical Forms	99
	5c.	Diagonal Canonical Forms	102
	5d.	Pseudocanonical Forms	107
	5e. 5f.	Discussion of the Three Canonical Forms	108
	5g.	Estimation Accuracy Conclusions	109
	Jg.	Appendix 5.1. Proofs of Theorems	111
		Problems	112
			120
VI	EST	IMATION IN AUTOREGRESSIVE PROCESSES	
	_	Introduction	122
	6a.	Maximum Likelihood Estimators	123
	6b.	Bayesian Estimators	133
	6c.	Quasi-Maximum Likelihood (QML) Estimators in Single Output Systems	137
	6d.	Computational Methods	139
	6e.	Combined Parameter Estimation and Prediction	142
	6f.	Systems with Slowly Varying Coefficients	147
	6g.	Robust Estimation in AR Models	149
	6h.	Conclusions	151
		Appendix 6.1. Proofs of Theorems in Section 6a	151
		Appendix 6.2. The Expressions for the Posterior Densities	155
		Appendix 6.3. The Derivation of Computational Algorithms	156
		Appendix 6.4. Evaluation of the Cramér-Rao Lower Bound in Multi-	
		variate AR Systems	158
		Problems	159
VII	PAR M	AMETER ESTIMATION IN SYSTEMS WITH BOTH OVING AVERAGE AND AUTOREGRESSIVE TERMS	
		Introduction	160
	7a.	Maximum Likelihood Estimators	161
	7b.	Numerical Methods for CML Estimation	165
	7c.	Limited Information Estimates	171
	7d.	Numerical Experiments with Estimation Methods	174
	7e.	Conclusions	179
		Problems	179

Contents ix

VIII	CLASS SELECTION AND VALIDATION OF UNIVARIATE MODELS				
	Introduction  8a. The Nature of the Selection Problem  8b. The Different Methods of Class Selection  8c. Validation of Fitted Models  8d. Discussion of Selection and Validation  8e. Conclusions  Appendix 8.1. Mean Square Prediction Error of Redundant Models  Problems	180 181 183 201 214 216 216 217			
IX	CLASS SELECTION AND VALIDATION OF MULTIVARIATE MODELS				
	Introduction  9a. Nature of the Selection Problem  9b. Causality and the Construction of Preliminary Models  9c. Direct Comparison of Multivariate Classes of Models  9d. Validation of Models  9e. Conclusions  Appendix 9.1. Geometry of Correlation and Regression  Notes  Problems	219 220 222 227 232 234 235 236 237			
x	MODELING RIVER FLOWS				
	<ul> <li>10a. The Need and Scope of Modeling</li> <li>10b. Discussion of Data</li> <li>10c. Models for Monthly Flows</li> <li>10d. Modeling Daily Flow Data</li> <li>10e. Models for Annual Flow Data</li> <li>10f. Conclusions Notes</li> </ul>	238 239 248 254 260 281 281			
ХI	SOME ADDITIONAL CASE STUDIES IN MODEL BUILDING				
	Introduction 11a. Modeling Some Biological Populations 11b. Analysis of the Annual Sunspot Series 11c. The Sales Data of Company X: An Empirical Series with Both	283 285 304			
	Growth and Systematic Oscillations  11d. The Time Series E2: Role of Moving Average Terms	308 312			
	<ul> <li>11e. Causal Connection between Increases in Rainfall and Increased Urbanization</li> <li>11f. A Multivariate Model for Groundwater Levels and Precipitation</li> <li>11g. Conclusions</li> </ul>	314 318 324			
	References	325			
	Index	331			