

Contents

Preface	vii
References, xi	
1 Introduction	1
References, 12	
PART I. CURRENT MODELS AND MODELING METHODOLOGIES	13
2 Relational Models in Engineering and the Sciences (Monotone Convex/Concave Relationships)	15
2.1. Introduction, 15	
2.2. Chemistry and Chemical Engineering, 17	
2.3. Physics, 19	
2.4. Electrical Engineering, 22	
2.5. Hardware Reliability Engineering, 22	
2.6. Software Reliability-Growth Modeling, 23	
2.7. Growth Models, 25	
References, 26	
3 Shared Features and "The Ladder"	29
3.1. Introduction, 29	
3.2. Shared Features, 30	
3.3. "The Ladder of Fundamental Uniformly Convex/Concave Functions", 34	

4 Approaches to Model Systematic Variation	37
4.1. Introduction, 37	
4.2. Linear Regression Analysis, 39	
4.3. Box-Cox Power Transformations, 41	
4.4. Generalized Linear Models, 44	
4.5. Conclusions, 49	
References, 51	
5 Approaches to Model Random Variation	53
5.1. Introduction, 53	
5.2. Parameter-Rich Families of Distributions, Transformations and Expansions, 57	
5.2.1. The Pearson family of distributions, 58	
5.2.2. Other families of distributions (Burr, Tukey's g- and h-systems, generalized Lambda, Shore, the exponential family), 59	
5.2.3. Transformations (Johnson, Box-Cox) and expansions, 63	
5.3. Moments and Their Role in Empirical Modeling of a Distribution, 65	
5.3.1. Why moment matching?, 65	
5.3.2. How many moments to match, 67	
5.4. Heuristic Methods in Empirical Modeling of Random Variation, 70	
5.5. An Alternative Approach to Four-Moment Matching, 73	
References, 74	
6 The Requirements and Evaluation of Compliance	79
6.1. Introduction, 79	
6.2. Desirable Requirements of a General Methodology for Empirical Modeling, 81	
6.3. An Evaluation of Compliance of Current Methodologies, 91	
6.3.1. Modeling systematic variation, 91	
6.3.2. Modeling random variation, 95	
References, 98	

PART II. RMM- DEVELOPING AND EVALUATING THE GENERAL APPROACH	99
7 The RMM Model	101
7.1. Introduction, 101	
7.2. An Axiomatic Derivation of the RMM Model, 103	
7.2.1. The model assumptions, 103	
7.2.2. The general model, 104	
7.2.3. Deriving f_2 , 105	
7.2.4. Deriving f_1 , 106	
7.2.5. The RMM Model, 107	
7.3. The Response Moments, 110	
7.4. Exploring the Relationship between the CV and η , 114	
References, 115	
8 Estimating the Relational Model	117
8.1. Introduction, 117	
8.2. Phase 1- Estimating the Linear Predictor (LP), 120	
8.2.1. Introduction and motivation, 120	
8.2.2. Stage I- Approximating a transformed response via a Taylor series expansion and estimating the parameters via CCA, 123	
8.2.3. Stage II- Stepwise linear regression analysis with canonical scores as response values, 125	
8.3. Issues Related to Implementation of Phase 1, 125	
8.4. Phase 2- Estimating the RMM Model, 133	
8.4.1. Introduction, 133	
8.4.2. Stage I- Estimating the RMM parameters $\{ \alpha, \lambda, \mu_2 \}$, 134	
8.4.3. Stage II- Estimating the RMM "Error Parameters" $\{ \rho, \sigma_{\varepsilon 1}, \sigma_{\varepsilon 2} \}$, 137	
8.4.4. Summary of the estimation procedure (Phase 2), 138	
8.5. Two Numerical Examples, 139	
8.5.1. Example 1- The Wave-Soldering Process, 139	
8.5.2. Example 2- The Resistivity Data, 144	
References, 147	
Appendix A- Canonical Correlation Analysis- Background, 148	
Appendix B- The Assumptions of CCA and Major Threats to	

the Reliability and Validity of Results, 149

9 The RMM Error Distribution 151

- 9.1. Introduction, 151
- 9.2. Derivation of the RMM Error Distribution, 152
- 9.3. Properties of the Error Distribution, 154
- 9.4. Variations of the RMM Error Distribution, 159
- References, 160

10 Fitting Procedures (for the Error Distribution) 161

- 10.1. Introduction, 161
- 10.2. Brief Review of Current Methodologies, 163
- 10.3. Fitting via "Moment Matching", 166
- 10.4. Fitting via "Quantile Matching", 171
- 10.5. Two Numerical Examples, 173
 - 10.5.1. A moment-matching example, 173
 - 10.5.2. A quantile-matching example, 174
- References, 176

11 Estimating the Error Distribution 177

- 11.1. Introduction, 177
- 11.2. Percentile-Based Estimation, 180
 - 11.2.1. The estimation procedure, 180
 - 11.2.2. Two numerical examples (percentile-based estimation), 184
- 11.3. Moment-Based Estimation, 191
 - 11.3.1. Introduction, 191
 - 11.3.2. Procedure I, 194
 - 11.3.3. Procedure II, 196
 - 11.3.4. Two numerical examples (moment-based estimation), 198
- References, 202

12 Special Cases of the RMM Model 203

- 12.1. Current Relational Models as Special Cases of RMM, 203

- 12.1.1. Chemistry and Chemical Engineering, 204
- 12.1.2. Physics, 207
- 12.1.3. Electrical engineering, 208
- 12.1.4. Growth models, 209
- 12.2. Current Models of Random Variation as RMM Models, 209
 - 12.2.1. The Johnson families of distributions, 209
 - 12.2.2. Tukey g- and h-Systems of distributions, 211
 - 12.2.3 Fisher's transformation of the sample correlation, 211
 - 12.2.4. Haldane power-transformation and Wilson-Hilferty approximation to χ^2 , 212
 - 12.2.5. Box-Cox normalizing transformation, 213
 - 12.2.6. Cauchy distribution, 214
 - 12.2.7. Generalized Inverse Gaussian distribution and the Levy distribution, 215
 - 12.2.8. Generalized Gamma distributions, 216
- References, 217

13 Evaluating RMM for Compliance 219

- 13.1. Introduction, 219
- 13.2. Compliance for Modeling Systematic Variation, 219
- 13.3. Compliance in Modeling Random Variation, 223
- References, 226

PART III. MODELING SYSTEMATIC VARIATION-APPLICATIONS 227

14 Comparative Solutions for Relational Models 229

- 14.1. Introduction, 229
- 14.2. Two New Problems, 230
 - 14.2.1. Example 1- The Windshield Experiment, 230
 - 14.2.2. Example 2- The Economist Big Mac Parity Index, 235
- 14.3. Two Familiar Problems (Cont'd from Chapter 8), 241
 - 14.3.1. Example 3- The Wave-Soldering Process, 241
 - 14.3.2. Example 4- The Resistivity data, 244
- 14.4. Comparison of Models, 246
 - 14.4.1. Mallow's C_p , 246
 - 14.4.2. Akaike's Information Criterion (AIC), 247
- References, 248

15 Reliability Engineering (with Censoring)	251
15.1. Introduction, 251	
15.2. RMM Estimating with Censored Data, 252	
15.3. A Numerical Example- The RFL model, 257	
References, 263	
16 Software Reliability-Growth Models	265
16.1. Introduction, 265	
16.2. Example 1- Musa's M_1 Data-Set, 266	
16.3. Example 2- Musa's M_3 Data-Set, 271	
References, 276	
17 Modeling a Chemo-Response	277
17.1. Introduction, 277	
17.2. Applying RMM to a Chemo-Response- First Variation, 278	
17.2.1. Example 1- Temperature dependence of vapor pressure, 278	
17.2.2. Example 2- Temperature dependence of solid heat capacity, 284	
17.3. Applying RMM to a Chemo-Response- Second Variation, 287	
17.3.1. Example 1- Temperature dependence of vapor pressure, 288	
17.3.2. Example 2- Heat capacity of solids and liquids, 290	
17.3.3. Other temperature-dependent properties, 293	
References, 294	
18 Forecasting S-Shaped Diffusion Processes	297
18.1. Introduction, 297	
18.2. Theoretical Background for S-shaped Diffusion Processes, 298	
18.3. Modeling and Forecasting S-shaped Processes, 303	

18.4. Numerical Examples, 307	
18.4.1. Forecasting T_P , given P , 307	
18.4.2. Forecasting P_T , given T , 310	
References, 310	
Appendix A. Current Forecasting Models, 311	
Appendix B. Description of Data Sets, 312	

PART IV. MODELING RANDOM VARIATION- APPLICATIONS 315

19 RMM Distributional Approximations 317

19.1. Introduction, 317	
19.2. Fitting RMM with Normal or Log-normal Errors, 318	
19.3. Fitting with a Logistic Error Term, 322	
19.4. Approximations for the Normal and the Poisson Distributions, 323	
19.4.1. Approximating the Poisson quantile, 324	
19.4.2. Approximating the CDF of the Standard Normal, 325	
References, 334	

20 Inverse Normalizing Transformations 335

20.1. Introduction, 335	
20.2. Derivation of the "Origin" INT, 336	
20.3. Four-Moment Matching- The Problem and a Solution, 337	
20.4. Parameter-Reduced INTs, 342	
20.4.1. Off-spring INT I, 342	
20.4.2. Off-spring INT II, 343	
20.4.3. Off-spring INT III, 343	
20.4.4. Off-spring INT IV, 345	
20.5. Distribution Fitting Procedures, 345	
20.5.1. Fitting procedures for INT I (Section 20.4.1), 346	
20.5.2. A fitting procedure for INT II (Section 20.4.2), 346	
20.5.3. A fitting procedure for INT III (Section 20.4.3), 347	
20.5.4. Fitting procedures for INT IV (Section 20.4.4), 348	
20.6. Normalizing Transformations, 350	
References, 351	

21 Piece-Wise Linear Approximations 353

21.1. Introduction, 353	
-------------------------	--

21.2. The Basic Modified (Normal) Approximation, 356	
21.3. A Variation of the Basic Model with a Fitting Procedure, 357	
21.4. A Simplified Fitting Procedure, 361	
21.5. A Fitting Procedure Using First- and Second-Degree Moments, 363	
21.6. Review of Related Published References, 364	
21.7. A Numerical Example, 365	
References, 367	

22 General Control Charts 369

22.1. Introduction, 369	
22.2. General Control Schemes for Attributes, 370	
22.2.1. Introduction, 370	
22.2.2. Modified control limits for attributes, 373	
22.2.3. Simplified limits, 375	
22.2.4. Probability limits with "inflated" skewness, 377	
22.2.5. Probability limits for some attribute distributions, 379	
22.2.6. Numerical assessment, 380	
22.3. General Control Schemes for Variables, 384	
22.3.1. Introduction, 384	
22.3.2. INT-based control schemes for variables, 387	
References, 395	

23 Inventory Analysis 397

23.1. Introduction, 397	
23.2. First Approach- The Quantile Function and the Loss Function, 398	
23.3. Second Approach- The Quantile Function and Loss Function, 401	
23.4. First Approach- Newsboy Problem with Order-up-to Policy, 407	
23.5. Second Approach- Two Examples, 409	
23.5.1. The Continuous-Review (Q,R) Model, 409	
23.5.2. Safety lead-times for purchased components, 412	
References, 415	

Review Questions 417

Index 421

Author Index 427