

Contents

Preface to the Second Edition	xv
Chapter 1 Catalyzing the Generation of Knowledge	1
1.1. The Learning Process	1
1.2. Important Considerations	5
1.3. The Experimenter's Problem and Statistical Methods	6
1.4. A Typical Investigation	9
1.5. How to Use Statistical Techniques	13
References and Further Reading	14
Chapter 2 Basics (Probability, Parameters, and Statistics)	17
2.1. Experimental Error	17
2.2. Distributions	18
2.3. Statistics and Parameters	23
2.4. Measures of Location and Spread	24
2.5. The Normal Distribution	27
2.6. Normal Probability Plots	33
2.7. Randomness and Random Variables	34
2.8. Covariance and Correlation as Measures of Linear Dependence	37
2.9. Student's t Distribution	39
2.10. Estimates of Parameters	43
2.11. Random Sampling from a Normal Population	44
2.12. The Chi-Square and F Distributions	46
2.13. The Binomial Distribution	48
2.14. The Poisson Distribution	54
	ix

Appendix 2A. Mean and Variance of Linear Combinations of Observations	57
References and Further Reading	60
Chapter 3 Comparing Two Entities: Reference Distributions, Tests, and Confidence Intervals	67
3.1. Relevant Reference Sets and Distributions	67
3.2. Randomized Paired Comparison Design: Boys' Shoes Example	81
3.3. Blocking and Randomization	92
3.4. Reprise: Comparison, Replication, Randomization, and Blocking in Simple Experiments	94
3.5. More on Significance Tests	94
3.6. Inferences About Data that are Discrete: Binomial Distribution	105
3.7. Inferences about Frequencies (Counts Per Unit): The Poisson Distribution	110
3.8. Contingency Tables and Tests of Association	112
Appendix 3A. Comparison of the Robustness of Tests to Compare Two Entities	117
Appendix 3B. Calculation of reference distribution from past data	120
References and Further Reading	123
Chapter 4 Comparing a Number of Entities, Randomized Blocks, and Latin Squares	133
4.1. Comparing k Treatments in a Fully Randomized Design	133
4.2. Randomized Block Designs	145
4.3. A Preliminary Note on Split-Plot Experiments and their Relationship to Randomized Blocks	156
4.4. More than one blocking component: Latin Squares	157
4.5. Balanced Incomplete Block Designs	162
Appendix 4A. The Rationale for the Graphical ANOVA	166
Appendix 4B. Some Useful Latin Square, Graeco–Latin Square, and Hyper-Graeco–Latin Square Designs	167
References and Further Reading	168
Chapter 5 Factorial Designs at Two Levels	173
5.1. Introduction	173

5.2. Example 1: The Effects of Three Factors (Variables) on Clarity of Film	174
5.3. Example 2: The Effects of Three Factors on Three Physical Properties of a Polymer Solution	175
5.4. A 2^3 Factorial Design: Pilot Plant Investigation	177
5.5. Calculation of Main Effects	178
5.6. Interaction Effects	181
5.7. Genuine Replicate Runs	183
5.8. Interpretation of Results	185
5.9. The Table of Contrasts	186
5.10. Misuse of the ANOVA for 2^k Factorial Experiments	188
5.11. Eyeing the Data	190
5.12. Dealing with More Than One Response: A Pet Food Experiment	193
5.13. A 2^4 Factorial Design: Process Development Study	199
5.14. Analysis Using Normal and Lenth Plots	203
5.15. Other Models for Factorial Data	208
5.16. Blocking the 2^k Factorial Designs	211
5.17. Learning by Doing	215
5.18. Summary	219
Appendix 5A. Blocking Larger Factorial Designs	219
Appendix 5B. Partial Confounding	221
References and Further Reading	222

Chapter 6 Fractional Factorial Designs	235
6.1. Effects of Five Factors on Six Properties of Films in Eight Runs	235
6.2. Stability of New Product, Four Factors in Eight Runs, a 2^{4-1} Design	236
6.3. A Half-Fraction Example: The Modification of a Bearing	239
6.4. The Anatomy of the Half Fraction	240
6.5. The 2^{7-4}_{III} Design: A Bicycle Example	244
6.6. Eight-Run Designs	246
6.7. Using Table 6.6: An Illustration	247
6.8. Sign Switching, Foldover, and Sequential Assembly	249
6.9. An Investigation Using Multiple-Column Foldover	252
6.10. Increasing Design Resolution from III to IV by Foldover	257
6.11. Sixteen-Run Designs	258

6.12. The 2^{5-1} Nodal Half Replicate of the 2^5 Factorial: Reactor Example	259
6.13. The 2_{IV}^{8-4} Nodal Sixteenth Fraction of a 2^8 Factorial	263
6.14. The 2_{III}^{15-11} Nodal Design: The Sixty-Fourth Fraction of the 2^{15} Factorial	266
6.15. Constructing Other Two-Level Fractions	269
6.16. Elimination of Block Effects	271
References and Further Reading	273
Chapter 7 Additional Fractionals and Analysis	281
7.1. Plackett and Burman Designs	281
7.2. Choosing Follow-Up Runs	294
7.3. Justifications for the Use of Fractionals	303
Appendix 7A. Technical Details	305
Appendix 7B. An Approximate Partial Analysis for PB Designs	308
Appendix 7C. Hall's Orthogonal Designs	310
References and Further Reading	313
Chapter 8 Factorial Designs and Data Transformation	317
8.1. A Two-Way (Factorial) Design	317
8.2. Simplification and Increased Sensitivity from Transformation	320
Appendix 8A. Rationale for Data Transformation	329
Appendix 8B. Bartlett's χ_v^2 for Testing Inhomogeneity of Variance	329
References and Further Reading	329
Chapter 9 Multiple Sources of Variation	335
9.1. Split-Plot Designs, Variance Components, and Error Transmission	335
9.2. Split-Plot Designs	335
9.3. Estimating Variance Components	345
9.4. Transmission of Error	353
References and Further Reading	359
Chapter 10 Least Squares and Why We Need Designed Experiments	363
10.1. Estimation With Least Squares	364
10.2. The Versatility of Least Squares	378
10.3. The Origins of Experimental Design	397

10.4. Nonlinear Models	407
Appendix 10A. Vector Representation of Statistical Concepts	410
Appendix 10B. Matrix Version of Least Squares	416
Appendix 10C. Analysis of Factorials, Botched and Otherwise	418
Appendix 10D. Unweighted and Weighted Least Squares	420
References and Further Reading	424

Chapter 11 Modeling, Geometry, and Experimental Design	437
11.1. Some Empirical Models	441
11.2. Some Experimental Designs and the Design Information Function	447
11.3. Is the Surface Sufficiently Well Estimated?	453
11.4. Sequential Design Strategy	454
11.5. Canonical Analysis	461
11.6. Box–Behnken Designs	475
References and Further Reading	483

Chapter 12 Some Applications of Response Surface Methods	489
12.1. Iterative Experimentation To Improve a Product Design	489
12.2. Simplification of a Response Function by Data Transformation	503
12.3. Detecting and Exploiting Active and Inactive Factor Spaces for Multiple-Response Data	509
12.4. Exploring Canonical Factor Spaces	513
12.5. From Empiricism to Mechanism	518
12.6. Uses of RSM	526
Appendix 12A. Average Variance of \hat{y}	526
Appendix 12B.	528
References and Further Reading	530

Chapter 13 Designing Robust Products and Processes: An Introduction	539
13.1. Environmental Robustness	539
13.2. Robustness To Component Variation	549
Appendix 13A. A Mathematical Formulation for Environmental Robustness	556
Appendix 13B. Choice of Criteria	558
References and Further Reading	559

Chapter 14 Process Control, Forecasting, and Time Series: An Introduction	565
14.1. Process Monitoring	565
14.2. The Exponentially Weighted Moving Average	569
14.3. The CuSum Chart	574
14.4. Process Adjustment	576
14.5. A Brief Look At Some Time Series Models and Applications	585
14.6. Using a Model to Make a Forecast	588
14.7. Intervention Analysis: A Los Angeles Air Pollution Example	593
References and Further Reading	595
 Chapter 15 Evolutionary Process Operation	 599
15.1. More than One Factor	602
15.2. Multiple Responses	606
15.3. The Evolutionary Process Operation Committee	607
References and Further Reading	608
 Appendix Tables	 611
 Author Index	 625
 Subject Index	 629