

Contents

Preface	xiii
1. Introduction	1
1.1 Role of Statistics in Experiment Design	1
1.2 Organization of This Book	3
1.3 Representativeness and Experimental Units	4
1.4 Replication and Handling Unexplained Variability	7
1.5 Randomization: Why and How	8
1.6 Ethical Considerations	10
Review Exercises	12
2. Completely Randomized Design	13
2.1 Introduction	13
2.2 Completely Randomized Design	13
2.3 Assumption of Additivity	15
2.4 Factorial Treatment Combinations	18
2.5 Nested Factors	23
Review Exercises	26
3. Linear Models for Designed Experiments	28
3.1 Introduction	28
3.2 Linear Model	29
3.3 Principle of Least Squares	30
3.4 Parameterizations for Row–Column Models	37
Review Exercises	41
Appendix 3A: Linear Combinations of Random Variables	43
Appendix 3B: Simulating Random Samples	44

4	Testing Hypotheses and Determining Sample Size	45
4.1	Introduction	45
4.2	Testing Hypotheses in Linear Models with Normally Distributed Errors	46
4.3	Kruskal–Wallis Test	53
4.4	Randomization Tests	54
4.5	Power and Sample Size	58
4.6	Sample Size for Binomial Proportions	68
4.7	Confidence Interval Width and Sample Size	72
4.8	Alternative Analysis: Selecting and Screening	74
	Review Exercises	78
5.	Methods of Reducing Unexplained Variation	81
5.1	Randomized Complete Block Design	81
5.2	Blocking	81
5.3	Formal Statistical Analysis for the RCBD	87
5.4	Models and Assumptions: Detailed Examination	92
5.5	Statistical Analysis When Data Are Missing in an RCBD	101
5.6	Analysis of Covariance	109
	Review Exercises	112
	Appendix 5A: Interaction of a Random Block Effect and a Fixed Treatment Effect	116
6	Latin Squares	118
6.1	Introduction	118
6.2	Formal Structure of Latin Squares	119
6.3	Combining Latin Squares	126
6.4	Graeco–Latin Squares and Orthogonal Latin Squares	134
6.5	Some Special Latin Squares and Variations on Latin Squares	137
6.6	Frequency Squares	140
6.7	Youden Square	145
	Review Exercises	150
	Appendix 6A: Some Standard Latin Squares	153
	Appendix 6B: Mutually Orthogonal Latin Squares	155
	Appendix 6C: Possible Youden Squares	157
7	Split-Plot and Related Designs	158
7.1	Introduction	158
7.2	Background Material	158

7.3	Examples of Situations That Lead to Split-Plots	159
7.4	Statistical Analysis of Split-Plot Experiments	162
7.5	Split-Split-Plot Experiments	175
7.6	Strip-Plot Experiments	176
7.7	Comments on Further Variations	180
7.8	Analysis of Covariance in Split-Plots	181
7.9	Repeated Measures	193
	Review Exercises	195
8	Incomplete Block Designs	197
8.1	Introduction	197
8.2	Efficiency of Incomplete Block Designs	207
8.3	Distribution-Free Analysis for Incomplete Block Designs	209
8.4	Balanced Incomplete Block Designs	212
8.5	Lattice Designs	223
8.6	Cyclic Designs	225
8.7	α -Designs	229
8.8	Other Incomplete Block Designs	231
	Review Exercises	232
	Appendix 8A: Catalog of Incomplete Block Designs	235
9	Repeated Treatments Designs	242
9.1	Introduction	242
9.2	Repeated Treatments Design Model	242
9.3	Construction of Repeated Treatments Designs	245
9.4	Statistical Analysis of Repeated Treatments Design Data	255
9.5	Carryover Design for Two Treatments	260
9.6	Correlated Errors	265
9.7	Designs for More Complex Models	267
	Review Exercises	270
10	Factorial Experiments: The 2^N System	272
10.1	Introduction	272
10.2	2^N Factorials	272
10.3	General Notation for the 2^N System	280
10.4	Analysis of Variance for 2^N Factorials	284
11	Factorial Experiments: The 3^N System	288
11.1	Introduction	288

11.2	3×3 Factorial	288
11.3	General System of Notation for the 3^N System	295
12	Analysis of Experiments without Designed Error Terms	299
12.1	Introduction	299
12.2	Techniques That Look for Location Parameters	300
12.3	Analysis for Dispersion Effects	304
	Review Exercises	308
13	Confounding Effects with Blocks	310
13.1	Introduction	310
13.2	Confounding 2^3 Factorials	311
13.3	General Confounding Patterns	319
13.4	Double Confounding	325
13.5	3^N System	327
13.6	Detailed Numerical Example: 3^3 Factorial in Blocks of Nine	332
13.7	Confounding Schemes for the 3^4 System	337
	Review Exercises	338
14	Fractional Factorial Experiments	340
14.1	Introduction	340
14.2	Organization of This Chapter	343
14.3	Fractional Replication in the 2^N System	344
14.4	Resolution	351
14.5	Constructing Fractional Replicates by Superimposing Factors	356
14.6	Foldover Technique	360
14.7	Franklin–Bailey Algorithm for Constructing Fractions	361
14.8	Irregular Fractions of the 2^N System	364
14.9	Fractional Factorials with Compromised Resolution	371
14.10	A Caution About Minimum Aberration	376
14.11	Direct Enumeration Approach to Constructing Plans	378
14.12	Blocking in Small 2^{N-k} Plans	379
14.13	Fractional Replication in the 3^N System	383
	Review Exercises	387
	Appendix 14A: Minimum Aberration Fractions without Blocking	390
	Appendix 14B: Minimum Aberration Fractions with Blocking	393

15 Response Surface Designs	398
15.1 Introduction	398
15.2 Basic Formulation	399
15.3 Some Basic Designs	400
15.4 Rotatability	407
15.5 Statistical Analyses of Data from Response Surface Designs	408
15.6 Blocking in Response Surface Designs	409
15.7 Mixture Designs	411
15.8 Optimality Criteria and Parametric Modeling	412
15.9 Response Surfaces in Irregular Regions	413
15.10 Searching the Operability Region for an Optimum	416
15.11 Examination of an Experimental Problem	426
Review Exercise	427
16 Plackett–Burman Hadamard Plans	429
16.1 Introduction	429
16.2 Hadamard Matrix	429
16.3 Plackett–Burman Plans	430
16.4 Hadamard Plans and Interactions	436
16.5 Statistical Analyses	439
16.6 Weighing Designs	442
16.7 Projection Properties of Hadamard Plans	445
16.8 Very Large Factorial Experiments	449
17 General p^N and Nonstandard Factorials	451
17.1 Introduction	451
17.2 Organization of This Chapter	451
17.3 p^N System with p Prime	452
17.4 4^N System	456
17.5 4^N System Using Pseudofactors at Two Levels	469
17.6 6^N Factorial System	472
17.7 Asymmetrical Factorials	475
17.8 $2^N \times 3^M$ Plans	478
18 Plans for Which Run Order Is Important	484
18.1 Introduction	484
18.2 Preliminary Concepts	485
18.3 Trend-Resistant Plans	487

18.4	Generating Run Orders for Fractions	489
18.5	Extreme Number of Level Changes	492
18.6	Trend-Free Plans from Hadamard Matrices	498
18.7	Extensions to More Than Two Levels	502
18.8	Small One-at-a-Time Plans	503
18.9	Comments	507
19	Sequences of Fractions of Factorials	508
19.1	Introduction	508
19.2	Motivating Example	510
19.3	Foldover Techniques Examined	511
19.4	Augmenting a 2^{4-1} Fraction	516
19.5	Sequence Starting from a Seven-Factor Main Effect Plan	519
19.6	Augmenting a One-Eighth Fraction of 4^3	520
19.7	Adding Levels of a Factor	523
19.8	Double Semifold	528
19.9	Planned Sequences	530
19.10	Sequential Fractions	537
20	Factorial Experiments with Quantitative Factors: Blocking and Fractions	540
20.1	Introduction	540
20.2	Factors at Three Levels	540
20.3	Factors at Four Levels Based on the 2^N System	541
20.4	Pseudofactors and Hadamard Plans	552
20.5	Box–Behnken Plans	553
	Review Exercises	555
	Appendix 20A: Box–Behnken Plans	556
21	Supersaturated Plans	559
21.1	Introduction	559
21.2	Plans for Small Experiments	560
21.3	Supersaturated Plans That Include an Orthogonal Base	564
21.4	Model-Robust Plans	564
22	Multistage Experiments	569
22.1	Introduction	569
22.2	Factorial Structures in Split-Plot Experiments	570
22.3	Splitting on Interactions	573

22.4	Factorials in Strip-Plot or Strip-Unit Designs	578
22.5	General Comments on Strip-Unit Experiments	590
22.6	Split-Lot Designs	590
	Appendix 22A: Fractional Factorial Plans for Split-Plot Designs	595
23	Orthogonal Arrays and Related Structures	598
23.1	Introduction	598
23.2	Orthogonal Arrays and Fractional Factorials	602
23.3	Other Construction Methods	606
23.4	Nearly Orthogonal Arrays	620
23.5	Large Orthogonal Arrays	626
23.6	Summary	630
24	Factorial Plans Derived via Orthogonal Arrays	631
24.1	Introduction	631
24.2	Preliminaries	631
24.3	Product Array Designs	638
24.4	Block Crossed Arrays	641
24.5	Compound Arrays	644
25	Experiments on the Computer	652
25.1	Introduction	652
25.2	Stratified and Latin Hypercube Sampling	653
25.3	Using Orthogonal Arrays for Computer Simulation Studies	656
25.4	Demonstration Simulations	657
	References	661
	Index	677