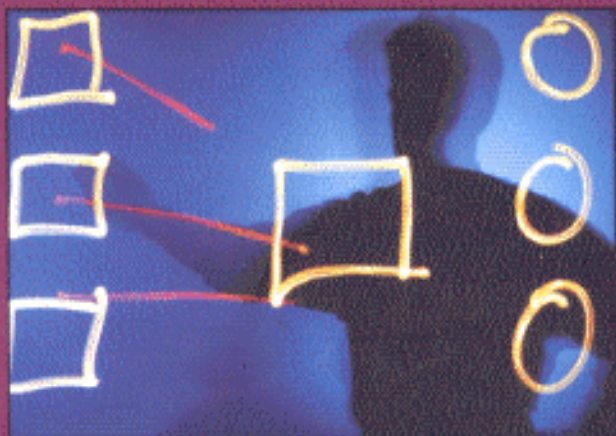


EXPERIMENTAL DESIGN

with Applications in
Management, Engineering,
and the Sciences



PAUL D. BERGER, ROBERT E. MAURER

Contents

CHAPTER 1

Introduction to Experimental Design	1
1.1 What Is Experimentation?	1
1.2 The Growth in Experimental Design	2
1.3 The Six Steps of Experimental Design	3
Plan the Experiment	3
Design the Experiment	5
Perform the Experiment	7
Analyze the Data from the Experiment	7
Confirm the Results of the Experiment	8
Evaluate the Conclusions of the Experiment	8
1.4 Experimental-Design Applications in Management	9
Corporate Environmental Behavior	9
Supermarket Decision Variables	11
Financial Services Menu	12
The Qualities of a Superior Motel	13
Time and Ease of Seatbelt Use: A Public Sector Example	15
Emergency Assistance Service for Travelers	15
1.5 Perspective	17

PART ONE

Primary Focus on Factors Under Study 19

CHAPTER 2

One-Factor Designs and the Analysis of Variance	21
2.1 One-Factor Designs	22
The Statistical Model	25
Estimation of the Parameters of the Model	26
Sums of Squares	28
2.2 Analysis of (the) Variance (ANOVA)	31
2.3 Forming the F Statistic: Logic and Derivation	35
The Key Fifth Column of the ANOVA Table	35
2.4 A Comment	48
Exercises	49

CHAPTER 3

Some Further Issues in One-Factor Designs and ANOVA

59

- 3.1 Introduction 59
- 3.2 Basic Assumptions of ANOVA 59
- 3.3 Kruskal-Wallis Test 63
- 3.4 Review of Hypothesis Testing 66
 - p Value 70
 - Type I and Type II Errors 71
 - Back to ANOVA 73
- 3.5 Power
 - Power Considerations in Determination of Required Sample Size 76
- 3.6 Confidence Intervals 82
 - Exercises 84

CHAPTER 4

Multiple-Comparison Testing

87

- 4.1 Logic of Multiple-Comparison Testing 88
- 4.2 Type I Errors in Multiple-Comparison Testing 90
- 4.3 Pairwise Comparisons 93
 - Fisher's Least Significant Difference Test 93
 - Tukey's Honestly Significant Difference Test 99
 - Newman-Keuls Test with Example 103
 - Two Other Tests Comparing All Pairs of Column Means 105
 - Dunnnett's Test 106
- 4.4 Post Hoc Exploratory Comparisons—The Scheffé Test 108
 - Carrying Out the Test 109
 - Discussion of Scheffé Test 111
 - Exercises 125

CHAPTER 5

Orthogonality, Orthogonal Decomposition, and Their Role in Modern Experimental Design 129

- 5.1 Introduction 130
- 5.2 Forming an Orthogonal Matrix 131
 - Exercises 151

CHAPTER 6

Two-Factor Cross-Classification Designs

155

- 6.1 Introduction to Studying Two Factors 156

6.2	Designs with Replication	157
	The Model	159
	Parameter Estimates	159
	Interaction	160
	Back to the Statistical Model: Sums of Squares	164
6.3	Fixed Levels versus Random Levels	177
6.4	Two Factors with No Replication and No Interaction	182
6.5	Blocking	187
6.6	Friedman Nonparametric Test	188
	Perspective on Friedman Test	191
	Exercises	192

CHAPTER 7

Nested, or Hierarchical, Designs 201

7.1	Introduction to Nested Designs	202
7.2	The Model	204
7.3	Discussion	213
	Exercises	214

CHAPTER 8

Designs with Three or More Factors: Latin-Square and Related Designs 221

8.1	Introduction to Multifactor Designs	222
8.2	Latin-Square Designs	223
	The Latin-Square Model and ANOVA	227
8.3	Graeco-Latin-Square Designs	234
8.4	Other Designs with Three or More Factors	237
	Exercises	240

PART TWO

Primary Focus on the Number of Levels of a Factor 245

CHAPTER 9

Two-Level Factorial Designs 247

9.1	Introduction	248
-----	--------------	-----

9.2	Two-Factor Experiments	249
9.3	Remarks on Effects and Interactions	252
9.4	Symbolism, Notation, and Language	252
9.5	Table of Signs	253
9.6	Modern Notation and Yates' Order	257
9.7	Three Factors, Each at Two Levels	258
	Estimating Effects in Three-Factor, Two-Level Designs	259
9.8	Number and Kinds of Effects	264
9.9	Yates' Forward Algorithm	266
9.10	A Note on Replicated 2^k Experiments	268
9.11	Main Effects in the Face of Large Interactions	271
9.12	Levels of Factors	273
9.13	Factorial Designs versus Designs Varying Factors One at a Time	274
9.14	Factors Not Studied	277
9.15	Errors of Estimates in 2^k Designs	278
9.16	Comment on Testing the Effects in 2^k Designs	280
	Exercises	281

CHAPTER 10

Confounding/Blocking in 2^k Designs 289

10.1	Introduction	290
10.2	Simple Confounding	290
10.3	Partial Confounding	295
10.4	Multiple Confounding	298
10.5	Mod-2 Multiplication	299
10.6	Determining the Blocks	301
10.7	Number of Blocks and Confounded Effects	304
10.8	Comment on Calculating Effects	306
	Appendix: Detailed Example of Error Reduction through Confounding	307
	Exercises	308

CHAPTER 11

Two-Level Fractional-Factorial Designs 311

11.1	Introduction	313
11.2	2^{k-p} Designs	314
11.3	Yates' Algorithm Revisited	324
11.4	Quarter-Replicate Designs	327
11.5	Orthogonality Revisited	331
11.6	Power and Minimum Detectable Effects in 2^{k-p} Designs	345
	Appendix: Selection of a Workable Set of Dead Letters	353
	Exercises	354

CHAPTER 12**Designs with Factors at Three Levels 358**

- 12.1 Introduction 359
- 12.2 Design with One Factor at Three Levels 359
- 12.3 Design with Two Factors, Each at Three Levels 361
- 12.4 Nonlinearity Recognition and Robustness 371
- 12.5 Three Levels versus Two Levels 372
- 12.6 Unequally Spaced Levels 374
- 12.7 Comment 375
- Exercises 375

CHAPTER 13**Introduction to Taguchi Methods 378**

- 13.1 Introduction 379
- 13.2 Taguchi's Quality Philosophy and Loss Function 379
- 13.3 Control of the Variability of Performance 382
- 13.4 Taguchi Methods: Designing Fractional-Factorial Designs 384
 - Experiments without Interactions 386
 - Experiments with Interactions 388
- 13.5 Taguchi's L_{16} 394
- 13.6 Experiments Involving Nonlinearities or Factors with Three Levels 394
- 13.7 Further Analyses 400
- 13.8 Perspective on Taguchi Methods 406
- Exercises 407

PART THREE

**Response-Surface Methods,
Other Topics, and the Literature
of Experimental Design
411**

CHAPTER 14**Introduction to Response-Surface Methodology 413**

- 14.1 Introduction 413
- 14.2 The Underlying Philosophy of RSM 416
- 14.3 Method of Steepest Ascent 418
 - Testing the Plane: Center Points 424

14.4	Method of Local Exploration	427
	Central-Composite Designs	427
	Box-Behnken Designs	429
	Comparison of Central-Composite and Box-Behnken Designs	430
	Issues in the Method of Local Experimentation	431
14.5	Perspective on RSM	432
14.6	Concluding Remark	451
	Exercises	451

CHAPTER 15

Literature on Experimental Design, and Discussion of Some Topics Not Covered in the Text 454

15.1	Introduction	454
15.2	Literature Discussion	455
	Some Classics	455
	Recommendations for Specific Topics	456
15.3	Discussion of Some Topics Not Covered in the Text	459
	Outliers	459
	Missing Data	460
	Power and Sample Size	460
	Time-Series and Failure-Time Experiments	460
	Plackett-Burman Designs	461
	Repeated-Measures Designs	461
	Crossover Designs	462
	Mixture Designs	462
	Bibliography	463
15.4	References	463
	Statistical Tables	467

Index	477
-------	-----