

Contents

Preface	xv
1 The statistical approach	1
1.1 Problem definition	3
1.2 System identification	3
1.3 Statistical model formulation	4
1.4 Data collection	5
1.5 Statistical analysis	6
1.6 An application	6
Exercises	14
References	15
2 Basic statistical concepts	16
2.1 Introduction	16
2.2 Basic statistics and their distributions	17
2.2.1 The Z -statistic	17
2.2.2 The χ^2 -statistic	17
2.2.3 The t -statistic	18
2.2.4 The F -statistic	18
2.3 Estimation	18
2.3.1 Point estimates	19
Example 2.1	19
Example 2.2	22
2.3.2 Interval estimates	23
Example 2.3	25
2.4 Testing of hypotheses	26
2.4.1 Hypothesis tests and appropriate statistics	29
Example 2.4	29
Example 2.5	31
Example 2.6	31
2.4.2 Generalized likelihood ratio test	32
Example 2.7	33
2.5 Power curves	34
Example 2.8	34
Example 2.9	36
Example 2.10	36

CONTENTS

2.6	Sample size	37
	Example 2.11	38
	Example 2.12	38
	Example 2.13	39
	Exercises	40
	References	41
	Further reading	42
3	Statistical analysis of completely randomized one-factor experiments	43
3.1	Fundamental assumptions of the analysis of variance	43
	Example 3.1	46
3.2	Analysis of variance (ANOVA)	50
3.2.1	The fixed-effect ANOVA model	52
	Example 3.2	58
3.2.2	The random-effect ANOVA model	59
	Example 3.3	63
3.3	Least-squares regression significance test	65
3.3.1	An example of a nonlinear model	65
	Example 3.4	68
3.3.2	Linear models (ANOVA)	71
	Example 3.5	75
	Exercises	77
	References	81
	Further reading	82
4	After-ANOVA tests	83
4.1	Orthogonal contrasts	83
	Example 4.1	87
4.2	Scheffé's method	89
	Example 4.2	94
4.3	Studentized range test	94
4.3.1	Studentized range distribution	95
4.3.2	Basic testing procedure	96
	Example 4.3	98
4.4	Mean separation procedures	100
4.4.1	Least significant difference method	101
	Example 4.4	102
4.4.2	Tukey's range procedure	103
	Example 4.5	103
4.4.3	Duncan's multiple range test	104
	Example 4.6	104
4.4.4	Dunnett's procedure	105
	Example 4.7	106

CONTENTS

Exercises	107
References	109
Further reading	109
5 Analysis of single-factor experiments using randomized block designs	
5.1 Introduction	110
5.2 Analysis of variance for complete blocks	112
Example 5.1	118
Example 5.2	120
5.3 Balanced incomplete block designs	121
Example 5.3	123
Example 5.4	124
5.4 Special ANOVA for balanced incomplete block designs	125
Example 5.5	131
5.5 After-ANOVA tests	133
Example 5.6	134
5.6 Least-squares significance test	135
5.6.1 Two-way ANOVA with no interactions	135
Example 5.7	136
5.6.2 Balanced incomplete block design	139
Example 5.8	139
5.6.3 Two-way ANOVA with interactions	140
Example 5.9	143
5.7 Missing values	146
Example 5.10	148
Exercises	151
References	153
Further reading	153
6 Latin, Graeco-Latin and Youden squares	154
6.1 Latin squares	155
6.1.1 Analysis of variance	155
Example 6.1	158
Example 6.2	159
6.1.2 Replication of Latin square designs	160
Example 6.3	164
6.1.3 Missing values	166
6.1.4 Orthogonal squares	167
6.2 Graeco-Latin squares	168
Example 6.4	170
Example 6.5	172
6.3 Youden squares	173
6.3.1 Analysis of variance	174

CONTENTS

Example 6.6	174
6.3.2 Construction of Youden squares	176
Example 6.7	177
Exercises	179
References	183
Further reading	184
7 Factorial experiments	185
7.1 Introduction	185
7.2 Analysis of variance	187
7.2.1 Procedure A: analysis of main effects	188
7.2.2 Procedure B: analysis of interaction effects	189
Example 7.1	189
7.3 Normal equations approach	192
Exercises	192
References	196
8 Two-level factorial experiments	197
8.1 Definitions and notation	198
8.2 Geometric representation of 2^2 and 2^3 designs	200
8.3 Effect estimation methodology for 2^n factorial experiments	202
8.3.1 Analysis of main effects	203
8.3.2 Analysis of interaction effects	206
Example 8.1	210
8.4 ANOVA methodology for 2^n designs	212
Example 8.2	215
8.5 Yates algorithm	216
8.6 An application: a study of weld strength	217
Exercises	219
References	221
9 Blocking in two-level factorial experiments	223
9.1 Introduction	223
9.2 Block size and blocking variables	225
9.2.1 Use of blocking variables	227
9.2.2 Use of defining contrasts in blocking	228
Example 9.1	229
9.3 Partial confounding	231
Example 9.2	233
9.4 Some recommended blocking strategies	235
Exercises	237
References	238

10 Special topics in the analysis of unreplicated two-level factorial experiments	239
10.1 Use of a reference distribution	239
10.2 Use of normal probability plots	245
10.2.1 The reverse Yates algorithm	246
10.2.2 Analysis of effects	249
10.2.3 Analysis of residuals	249
Exercises	251
References	252
11 Two-level fractional factorial designs	253
11.1 Fundamental concepts	253
11.2 Computation and analysis of effects	256
11.3 An application: a study of air conditioner noise level	256
11.4 Complementary fractional factorials: mirror image designs	260
11.5 Resolution of fractional factorial designs	263
11.6 Blocking in fractional factorial designs	265
Example 11.1	266
11.7 Major and minor variables in fractional factorials	268
Exercises	270
References	273
Further reading	274
12 Three-level factorial designs	275
12.1 Introduction	275
12.2 The 3^2 design	276
12.2.1 Main effects	276
12.2.2 Interaction effect	278
Example 12.1	279
12.3 The 3^k design	281
12.3.1 Notation	281
12.3.2 Design matrix of a 3^3 experiment with quantitative factors	282
12.3.3 Main effects of a 3^3 experiment	282
12.3.4 Interaction effects of a 3^3 experiment	283
Example 12.2	286
12.3.5 The general 3^k design	288
12.3.6 Yates algorithm for the 3^k design	288
12.4 Three-level fractional factorial design	289
12.4.1 Basic concepts	290
12.4.2 Determination of the generators	290
12.4.3 Determination of the fraction	291
12.4.4 Determination of the aliases	292

CONTENTS

12.5	ANOVA for fractional designs	293
12.5.1	Degrees of freedom	295
12.5.2	Blocking in fractional factorial designs	295
12.6	Application	297
	Appendix 12.A: Experimental results for the application	301
	Exercises	302
	References	303
	Further reading	303
13	Response surface methodology	304
13.1	Introduction	304
13.2	Basic RSM procedure	305
13.3	RSM steps	309
13.3.1	Phase I: first-order analysis	310
13.3.2	Phase II: second-order analysis	310
13.4	An application of RSM to pavement design	310
13.4.1	Phase I: first-order analysis	312
13.4.2	Phase II: second-order analysis	316
	Appendix 13.A Canonical analysis	320
	Example 13.1	321
	Example 13.2	323
	Exercises	324
	References	327
14	Taguchi methods	328
14.1	Basic concepts and definitions	329
14.1.1	The loss function	330
14.1.2	The target value	331
14.1.3	Signal-to-noise ratio	332
14.1.4	Factor classification	333
14.1.5	Orthogonal arrays	334
14.2	The parameter design procedure	337
	Example 14.1	340
14.3	Critical analysis of Taguchi methods	348
14.3.1	Signal-to-noise ratios	349
14.3.2	Loss functions	349
14.3.3	Accumulation analysis	349
	Exercises	349
	References	351
	Further reading	351
15	Nested factor and split plot experimental designs	352
15.1	Nested designs	352
	Example 15.1	352

CONTENTS

15.1.1	Definitions and assumptions	352
15.1.2	Analysis of variance calculations	354
15.1.3	Hypothesis testing	356
15.2	Split plot designs	356
	Example 15.2	356
15.2.1	Definitions and assumptions	357
15.2.2	Analysis of variance calculations	357
15.2.3	Hypothesis testing	361
	Exercises	361
	References	363
	Further reading	363
16	Procedures for selecting fractional factorial designs	364
16.1	Selection of fractional factorial designs given a list of feasible observations	365
16.2	Total number of possible 2^{k-p} fractional factorial designs	369
16.3	Cost-optimal fractional factorial designs	372
	Exercises	377
	References	377
	Further reading	377
Appendix A	An interactive microcomputer methodology	378
A.1	Introduction	378
A.2	Description of files	378
A.3	Basic purpose of each program	380
A.4	User manual	382
A.4.1	How to run the code	382
A.4.2	One-way analysis of variance	384
Appendix B	Statistical tables	390
Figure B.1	Scales for normal plots	390
Table B.1	Tail area of unit normal distribution	391
Table B.2	Probability points of the <i>t</i> -distribution	392
Table B.3	Ordinates of the <i>t</i> -distribution	393
Table B.4	Probability points of the chi-square distribution	394
Table B.5	Percentage points of the F-distribution	395
Table B.6	Upper 5-percent points of studentized range <i>q</i>	400
Table B.7	Upper 1-percent points of studentized range <i>q</i>	401
Table B.8	Values for Duncan's multiple range test, $\alpha = 0.01$	402
Table B.9	Values for Duncan's multiple range test, $\alpha = 0.05$	403
Table B.10	Values for Dunnett's two-sided comparison test	404
Table B.11	Values for Dunnett's one-sided comparison test	405
Index		407