

Table of Contents

PREFACE XII

CHAPTER 1 PRESENTING AND SUMMARIZING DATA	1
1.1 DATA AND VARIABLES.....	1
1.2 GRAPHICAL PRESENTATION OF QUALITATIVE DATA	2
1.3 GRAPHICAL PRESENTATION OF QUANTITATIVE DATA	3
1.3.1 Construction of a Histogram	3
1.4 NUMERICAL METHODS FOR PRESENTING DATA.....	6
1.4.1 Symbolic Notation	6
1.4.2 Measures of Central Tendency.....	7
1.4.3 Measures of Variability.....	8
1.4.4 Measures of the Shape of a Distribution	9
1.4.5 Measures of Relative Position.....	11
1.5 SAS EXAMPLE	12
EXERCISES	13
CHAPTER 2 PROBABILITY	15
2.1 RULES ABOUT PROBABILITIES OF SIMPLE EVENTS	15
2.2 COUNTING RULES	16
2.2.1 Multiplicative Rule.....	17
2.2.2 Permutations.....	17
2.2.3 Combinations	18
2.2.4 Partition Rule	18
2.2.5 Tree Diagram	18
2.3 COMPOUND EVENTS.....	19
2.4 BAYES THEOREM	23
EXERCISES	25
CHAPTER 3 RANDOM VARIABLES AND THEIR DISTRIBUTIONS	26
3.1 EXPECTATIONS AND VARIANCES OF RANDOM VARIABLES	26
3.2 PROBABILITY DISTRIBUTIONS FOR DISCRETE RANDOM VARIABLES	28
3.2.1 Expectation and Variance of a Discrete Random Variable	29
3.2.2 Bernoulli Distribution	30
3.2.3 Binomial Distribution.....	31
3.2.4 Hyper-geometric Distribution	33
3.2.5 Poisson Distribution.....	34
3.2.6 Multinomial Distribution.....	35
3.3 PROBABILITY DISTRIBUTIONS FOR CONTINUOUS RANDOM VARIABLES.....	36
3.3.1 Uniform Distribution.....	37
3.3.2 Normal Distribution	37
3.3.3 Multivariate Normal Distribution.....	45
3.3.4 Chi-square Distribution.....	47
3.3.5 Student <i>t</i> Distribution	48

3.3.6	<i>F</i> Distribution	50
EXERCISES		51
CHAPTER 4 POPULATION AND SAMPLE		53
4.1	FUNCTIONS OF RANDOM VARIABLES AND SAMPLING DISTRIBUTIONS	53
4.1.1	Central Limit Theorem	54
4.1.2	Statistics with Distributions Other than Normal	54
4.2	DEGREES OF FREEDOM	55
CHAPTER 5 ESTIMATION OF PARAMETERS		56
5.1	POINT ESTIMATION	56
5.2	MAXIMUM LIKELIHOOD ESTIMATION	57
5.3	INTERVAL ESTIMATION	58
5.4	ESTIMATION OF PARAMETERS OF A NORMAL POPULATION	60
5.4.1	Maximum Likelihood Estimation	60
5.4.2	Interval Estimation of the Mean	61
5.4.3	Interval Estimation of the Variance	62
EXERCISES		64
CHAPTER 6 HYPOTHESIS TESTING		65
6.1	HYPOTHESIS TEST OF A POPULATION MEAN	66
6.1.1	<i>P</i> value	69
6.1.2	A Hypothesis Test Can Be One- or Two-sided	70
6.1.3	Hypothesis Test of a Population Mean for a Small Sample	71
6.2	HYPOTHESIS TEST OF THE DIFFERENCE BETWEEN TWO POPULATION MEANS	72
6.2.1	Large Samples	72
6.2.2	Small Samples and Equal Variances	74
6.2.3	Small Samples and Unequal Variances	75
6.2.4	Dependent Samples	75
6.2.5	Nonparametric Test	76
6.2.6	SAS Examples for Hypotheses Tests of Two Population Means	79
6.3	HYPOTHESIS TEST OF A POPULATION PROPORTION	81
6.4	HYPOTHESIS TEST OF THE DIFFERENCE BETWEEN PROPORTIONS FROM TWO POPULATIONS	82
6.5	CHI-SQUARE TEST OF THE DIFFERENCE BETWEEN OBSERVED AND EXPECTED FREQUENCIES	84
6.5.1	SAS Example for Testing the Difference between Observed and Expected Frequencies	85
6.6	HYPOTHESIS TEST OF DIFFERENCES AMONG PROPORTIONS FROM SEVERAL POPULATIONS	86
6.6.1	SAS Example for Testing Differences among Proportions from Several Populations	88
6.7	HYPOTHESIS TEST OF POPULATION VARIANCE	90
6.8	HYPOTHESIS TEST OF THE DIFFERENCE OF TWO POPULATION VARIANCES	90
6.9	HYPOTHESIS TESTS USING CONFIDENCE INTERVALS	91

6.10	STATISTICAL AND PRACTICAL SIGNIFICANCE	92
6.11	TYPES OF ERRORS IN INFERENCES AND POWER OF TEST	92
6.11.1	SAS Examples for the Power of Test	99
6.12	SAMPLE SIZE	103
6.12.1	SAS Examples for Sample Size	104
	EXERCISES	107
CHAPTER 7 SIMPLE LINEAR REGRESSION		109
7.1	THE SIMPLE REGRESSION MODEL	109
7.2	ESTIMATION OF THE REGRESSION PARAMETERS – LEAST SQUARES ESTIMATION	113
7.3	MAXIMUM LIKELIHOOD ESTIMATION	116
7.4	RESIDUALS AND THEIR PROPERTIES	117
7.5	EXPECTATIONS AND VARIANCES OF THE PARAMETER ESTIMATORS	119
7.6	STUDENT <i>t</i> TEST IN TESTING HYPOTHESES ABOUT THE PARAMETERS	120
7.7	CONFIDENCE INTERVALS OF THE PARAMETERS	121
7.8	MEAN AND PREDICTION CONFIDENCE INTERVALS OF THE RESPONSE VARIABLE	122
7.9	PARTITIONING TOTAL VARIABILITY	124
7.9.1	Relationships among Sums of Squares	126
7.9.2	Theoretical Distribution of Sum of Squares	127
7.10	TEST OF HYPOTHESES - <i>F</i> TEST	128
7.11	LIKELIHOOD RATIO TEST	130
7.12	COEFFICIENT OF DETERMINATION	132
7.12.1	Shortcut Calculation of Sums of Squares and the Coefficient of Determination	133
7.13	MATRIX APPROACH TO SIMPLE LINEAR REGRESSION	134
7.13.1	The Simple Regression Model	134
7.13.2	Estimation of Parameters	135
7.13.3	Maximum Likelihood Estimation	138
7.14	SAS EXAMPLE FOR SIMPLE LINEAR REGRESSION	139
7.15	POWER OF TESTS	140
7.15.1	SAS Examples for Calculating the Power of Test	142
	EXERCISES	144
CHAPTER 8 CORRELATION		146
8.1	ESTIMATION OF THE COEFFICIENT OF CORRELATION AND TESTS OF HYPOTHESES	147
8.2	NUMERICAL RELATIONSHIP BETWEEN THE SAMPLE COEFFICIENT OF CORRELATION AND THE COEFFICIENT OF DETERMINATION	149
8.2.1	SAS Example for Correlation	150
8.3	RANK CORRELATION	151
8.3.1	SAS Example for Rank Correlation	152
	EXERCISES	153

CHAPTER 9	MULTIPLE LINEAR REGRESSION	154
9.1	TWO INDEPENDENT VARIABLES	155
9.1.1	Estimation of Parameters	156
9.1.2	Student <i>t</i> test in Testing Hypotheses	159
9.1.3	Partitioning Total Variability and Tests of Hypotheses	160
9.2	PARTIAL AND SEQUENTIAL SUMS OF SQUARES	162
9.3	TESTING MODEL FIT USING A LIKELIHOOD RATIO TEST	166
9.4	SAS EXAMPLE FOR MULTIPLE REGRESSION	168
9.5	POWER OF MULTIPLE REGRESSION	170
9.5.1	SAS Example for Calculating Power	171
9.6	PROBLEMS WITH REGRESSION	172
9.6.1	Analysis of Residuals	173
9.6.2	Extreme Observations	174
9.6.3	Multicollinearity	177
9.6.4	SAS Example for Detecting Problems with Regression	178
9.7	CHOOSING THE BEST MODEL	181
9.7.1	SAS Example for Model Selection	183
CHAPTER 10	CURVILINEAR REGRESSION	185
10.1	POLYNOMIAL REGRESSION	185
10.1.1	SAS Example for Quadratic Regression	189
10.2	NONLINEAR REGRESSION	190
10.2.1	SAS Example for Nonlinear Regression	192
10.3	SEGMENTED REGRESSION	194
10.3.1	SAS Examples for Segmented Regression	198
10.3.1.1	<i>SAS Example for Segmented Regression with Two Simple Regressions</i>	198
10.3.1.2	<i>SAS Example for Segmented Regression with Plateau</i>	200
CHAPTER 11	ONE-WAY ANALYSIS OF VARIANCE	204
11.1	THE FIXED EFFECTS ONE-WAY MODEL	206
11.1.1	Partitioning Total Variability	208
11.1.2	Hypothesis Test - <i>F</i> Test	210
11.1.3	Estimation of Group Means	214
11.1.4	Maximum Likelihood Estimation	214
11.1.5	Likelihood Ratio Test	215
11.1.6	Multiple Comparisons among Group Means	217
11.1.6.1	<i>Least Significance Difference (LSD)</i>	217
11.1.6.2	<i>Tukey Test</i>	218
11.1.6.3	<i>Contrasts</i>	220
11.1.6.4	<i>Orthogonal contrasts</i>	221
11.1.6.5	<i>Scheffe Test</i>	223
11.1.7	Test of Homogeneity of Variance	225
11.1.8	SAS Example for the Fixed Effects One-way Model	226
11.1.9	Power of the Fixed Effects One-way Model	228
11.1.9.1	<i>SAS Example for Calculating Power</i>	230
11.2	THE RANDOM EFFECTS ONE-WAY MODEL	231
11.2.1	Hypothesis Test	233

11.2.2	Prediction of Group Means	234
11.2.3	Variance Component Estimation.....	235
11.2.4	Intraclass Correlation	237
11.2.5	Maximum Likelihood Estimation	238
11.2.6	Restricted Maximum Likelihood Estimation	240
11.2.7	SAS Example for the Random Effects One-way Model	241
11.3	MATRIX APPROACH TO THE ONE-WAY ANALYSIS OF VARIANCE MODEL	243
11.3.1	The Fixed Effects Model.....	243
11.3.1.1	Linear Model.....	243
11.3.1.2	Estimating Parameters.....	245
11.3.1.3	Maximum Likelihood Estimation	249
11.3.1.4	Regression Model for the One-way Analysis of Variance.....	250
11.3.2	The Random Effects Model	253
11.3.2.1	Linear Model.....	253
11.3.2.2	Prediction of Random Effects.....	254
11.3.2.3	Maximum Likelihood Estimation	256
11.3.2.4	Restricted Maximum Likelihood Estimation	257
11.4	MIXED MODELS	257
11.4.1.1	Prediction of Random Effects.....	258
11.4.1.2	Maximum Likelihood Estimation	259
11.4.1.3	Restricted Maximum Likelihood Estimation	260
	EXERCISES	262
	CHAPTER 12 CONCEPTS OF EXPERIMENTAL DESIGN	263
12.1	EXPERIMENTAL UNITS AND REPLICATIONS	264
12.2	EXPERIMENTAL ERROR.....	265
12.3	PRECISION OF EXPERIMENTAL DESIGN	266
12.4	CONTROLLING EXPERIMENTAL ERROR.....	268
12.5	REQUIRED NUMBER OF REPLICATIONS	269
12.5.1	SAS Example for the Number of Replications	270
	CHAPTER 13 BLOCKING	272
13.1	RANDOMIZED COMPLETE BLOCK DESIGN.....	272
13.1.1	Partitioning Total Variability	274
13.1.2	Hypotheses Test - <i>F</i> test.....	275
13.1.3	SAS Example for Block Design.....	279
13.2	RANDOMIZED BLOCK DESIGN – TWO OR MORE UNITS PER TREATMENT AND BLOCK	280
13.2.1	Partitioning Total Variability and Test of Hypotheses.....	281
13.2.2	SAS Example for Two or More Experimental Unit per Block x Treatment.....	287
13.3	POWER OF TEST	291
13.3.1	SAS Example for Calculating Power	291
	EXERCISES	293
	CHAPTER 14 CHANGE-OVER DESIGNS.....	294
14.1	SIMPLE CHANGE-OVER DESIGN	294
14.2	CHANGE-OVER DESIGNS WITH THE EFFECTS OF PERIODS.....	297

14.2.1 SAS Example for Change-over Designs with the Effects of Periods.....	299
14.3 LATIN SQUARE.....	301
14.3.1 SAS Example for Latin Square	305
14.4 CHANGE-OVER DESIGN SET AS SEVERAL LATIN SQUARES.....	307
14.4.1 SAS Example for Several Latin Squares.....	309
EXERCISES	311
 CHAPTER 15 FACTORIAL EXPERIMENTS.....	 313
15.1 THE TWO FACTOR FACTORIAL EXPERIMENT.....	313
15.2 SAS EXAMPLE FOR FACTORIAL EXPERIMENT	320
EXERCISE	322
 CHAPTER 16 HIERARCHICAL OR NESTED DESIGN	 323
16.1 HIERARCHICAL DESIGN WITH TWO FACTORS.....	323
16.2 SAS EXAMPLE FOR HIERARCHICAL DESIGN	328
 CHAPTER 17 MORE ABOUT BLOCKING.....	 331
17.1 BLOCKING WITH PENS, CORRALS AND PADDOCKS	331
17.1.1 SAS Example for Designs with Pens and Paddocks	334
17.2 DOUBLE BLOCKING.....	338
 CHAPTER 18 SPLIT-PLOT DESIGN	 342
18.1 SPLIT-PLOT DESIGN – MAIN PLOTS IN RANDOMIZED BLOCKS.....	342
18.1.1 SAS Example: Main Plots in Randomized Blocks.....	346
18.2 SPLIT-PLOT DESIGN – MAIN PLOTS IN A COMPLETELY RANDOMIZED DESIGN	348
18.2.1 SAS Example: Main Plots in a Completely Randomized Design	351
EXERCISE	354
 CHAPTER 19 ANALYSIS OF COVARIANCE	 355
19.1 COMPLETELY RANDOMIZED DESIGN WITH A COVARIATE.....	355
19.1.1 SAS Example for a Completely Randomized Design with a Covariate.....	356
19.2 TESTING THE DIFFERENCE BETWEEN REGRESSION SLOPES	358
19.2.1 SAS Example for Testing the Difference between Regression Slopes	363
 CHAPTER 20 REPEATED MEASURES	 365
20.1 HOMOGENEOUS VARIANCES AND COVARIANCES AMONG REPEATED MEASURES	365
20.1.1 SAS Example for Homogeneous Variances and Covariances	368
20.2 HETEROGENEOUS VARIANCES AND COVARIANCES AMONG REPEATED MEASURES	372
20.2.1 SAS Examples for Heterogeneous Variances and Covariances.....	373
20.3 RANDOM COEFFICIENT REGRESSION	376
20.3.1 SAS Examples for Random Coefficient Regression.....	377
20.3.1.1 Homogeneous Variance-Covariance Parameters across Treatments	377
20.3.1.2 Heterogeneous Variance-Covariance Parameters across Treatments	379

CHAPTER 21 ANALYSIS OF NUMERICAL TREATMENT LEVELS	384
21.1 LACK OF FIT	384
21.1.1 SAS Example for Lack of Fit	387
21.2 POLYNOMIAL ORTHOGONAL CONTRASTS	389
21.2.1 SAS Example for Polynomial Contrasts	391
CHAPTER 22 DISCRETE DEPENDENT VARIABLES	394
22.1 LOGIT MODELS, LOGISTIC REGRESSION	395
22.1.1 Testing Hypotheses	397
22.1.2 SAS Examples for Logistic Models	402
22.2 PROBIT MODEL	407
22.2.1 SAS Example for a Probit model	409
22.3 LOG-LINEAR MODELS	412
22.3.1 SAS Example for a Log-Linear Model	415
SOLUTIONS OF EXERCISES	419
APPENDIX A: VECTORS AND MATRICES	421
TYPES AND PROPERTIES OF MATRICES	421
MATRIX AND VECTOR OPERATIONS	422
APPENDIX B: STATISTICAL TABLES	426
AREA UNDER THE STANDARD NORMAL CURVE, $Z > Z_\alpha$	426
CRITICAL VALUES OF STUDENT T DISTRIBUTIONS, $T > T_\alpha$	427
CRITICAL VALUES OF χ^2 -SQUARE DISTRIBUTIONS, $\chi^2 > \chi^2_\alpha$	429
CRITICAL VALUES OF F DISTRIBUTIONS, $F > F_\alpha$ $\alpha = 0.05$	431
CRITICAL VALUE OF F DISTRIBUTIONS, $F > F_\alpha$ $\alpha = 0.01$	433
CRITICAL VALUES OF THE STUDENTIZED RANGE, $Q(A, V)$	435
REFERENCES	436
SUBJECT INDEX	439