

# CONTENTS

## PREFACE vii

## Chapter 1 Introduction 1

- What Is Survival Analysis? 1
- What Is Survival Data? 2
- Why Use Survival Analysis? 4
- Approaches to Survival Analysis 5
- What You Need to Know 6
- Computing Notes 7

## Chapter 2 Basic Concepts of Survival Analysis 9

- Introduction 9
- Censoring 9
- Describing Survival Distributions 15
- Interpretations of the Hazard Function 18
- Some Simple Hazard Models 20
- The Origin of Time 23
- Data Structure 26

## Chapter 3 Estimating and Comparing Survival Curves with PROC LIFETEST 29

- Introduction 29
- The Kaplan-Meier Method 30
- Testing for Differences in Survivor Functions 38
- The Life-Table Method 49
- Life Tables from Grouped Data 55
- Testing for Effects of Covariates 59
- Log Survival and Smoothed Hazard Plots 64
- Conclusion 69



## Chapter 4 Estimating Parametric Regression Models with PROC LIFEREG 71

- Introduction 71
- The Accelerated Failure Time Model 72
- Alternative Distributions 77
- Categorical Variables and the CLASS Statement 87
- Maximum Likelihood Estimation 89
- Hypothesis Tests 95
- Goodness-of-Fit Tests with the Likelihood-Ratio Statistic 98
- Graphical Methods for Evaluating Model Fit 100
- Left Censoring and Interval Censoring 103
- Generating Predictions and Hazard Functions 108
- The Piecewise Exponential Model 112
- Bayesian Estimation and Testing 117
- Conclusion 124

## Chapter 5 Estimating Cox Regression Models with PROC PHREG 125

- Introduction 125
- The Proportional Hazards Model 126
- Partial Likelihood 128
- Tied Data 142
- Time-Dependent Covariates 153
- Cox Models with Nonproportional Hazards 172
- Interactions with Time as Time-Dependent Covariates 177
- Nonproportionality via Stratification 179
- Left Truncation and Late Entry into the Risk Set 183
- Estimating Survivor Functions 186
- Testing Linear Hypotheses with CONTRAST or TEST Statements 192
- Customized Hazard Ratios 195
- Bayesian Estimation and Testing 197
- Conclusion 200

## Chapter 6 Competing Risks 203

- Introduction 203
- Type-Specific Hazards 204
- Time in Power for Leaders of Countries: Example 207
- Estimates and Tests without Covariates 208



Covariate Effects via Cox Models	213
Accelerated Failure Time Models	220
Alternative Approaches to Multiple Event Types	227
Conclusion	232

## Chapter 7 Analysis of Tied or Discrete Data with PROC LOGISTIC 235

Introduction	235
The Logit Model for Discrete Time	236
The Complementary Log-Log Model for Continuous-Time Processes	240
Data with Time-Dependent Covariates	243
Issues and Extensions	246
Conclusion	255

## Chapter 8 Heterogeneity, Repeated Events, and Other Topics 257

Introduction	257
Unobserved Heterogeneity	257
Repeated Events	260
Generalized $R^2$	282
Sensitivity Analysis for Informative Censoring	283

## Chapter 9 A Guide for the Perplexed 289

How to Choose a Method	289
Conclusion	292

## Appendix 1 Macro Programs 293

Introduction	293
The LIFEHAZ Macro	293
The PREDICT Macro	296

## Appendix 2 Data Sets 299

Introduction	299
The MYEL Data Set: Myelomatosis Patients	299
The RECID Data Set: Arrest Times for Released Prisoners	300
The STAN Data Set: Stanford Heart Transplant Patients	301
The BREAST Data Set: Survival Data for Breast Cancer Patients	302
The JOBDUR Data Set: Durations of Jobs	302



The ALCO Data Set: Survival of Cirrhosis Patients	302
The LEADERS Data Set: Time in Power for Leaders of Countries	303
The RANK Data Set: Promotions in Rank for Biochemists	304
The JOBMULT Data Set: Repeated Job Changes	305

## References 307

## Index 313