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