Contents

Preface xi

1 Introduction to Regression Modeling of Survival Data 1
   1.1 Introduction, 1
   1.2 Typical Censoring Mechanisms, 3
   1.3 Example Data Sets, 9
       Exercises, 13

2 Descriptive Methods for Survival Data 16
   2.1 Introduction, 16
   2.2 Estimating the Survival Function, 17
   2.3 Using the Estimated Survival Function, 27
   2.4 Comparison of Survival Functions, 44
   2.5 Other Functions of Survival Time and Their Estimators, 59
       Exercises, 65

3. Regression Models for Survival Data 67
   3.1 Introduction, 67
   3.2 Semi-Parametric Regression Models, 69
   3.3 Fitting the Proportional Hazards Regression Model, 72
   3.4 Fitting the Proportional Hazards Model with Tied
       Survival Times, 85
   3.5 Estimating the Survival Function of the Proportional
       Hazards Regression Model, 87
       Exercises, 90
4. Interpretation of a Fitted Proportional Hazards Regression Model

4.1 Introduction, 92
4.2 Nominal Scale Covariate, 94
4.3 Continuous Scale Covariate, 106
4.4 Multiple-Covariate Models, 108
4.5 Interpreting and Using the Estimated Covariate-Adjusted Survival Function, 121
Exercises, 130

5. Model Development

5.1 Introduction, 132
5.2 Purposeful Selection of Covariates, 133
  5.2.1 Methods to examine the scale of continuous covariates in the log hazard, 136
  5.2.2 An example of purposeful selection of covariates, 141
5.3 Stepwise, Best-Subsets and Multivariable Fractional Polynomial Methods of Selecting Covariates, 153
  5.3.1 Stepwise selection of covariates, 154
  5.3.2 Best subsets selection of covariates, 159
  5.3.3 Selecting covariates and checking their scale using multivariable fractional polynomials, 162
5.4 Numerical Problems, 166
Exercises, 168

6. Assessment of Model Adequacy

6.1 Introduction, 169
6.2 Residuals, 170
6.3 Assessing the Proportional Hazards Assumption, 177
6.4 Identification of Influential and Poorly Fit Subjects, 184
6.5 Assessing Overall Goodness-of-Fit, 191
6.6 Interpreting and Presenting Results From the Final Model, 195
Exercises, 205

7. Extensions of the Proportional Hazards Model

7.1 Introduction, 207
7.2 The Stratified Proportional Hazards Model, 208
7.3 Time-Varying Covariates, 213
7.4 Truncated, Left Censored and Interval Censored Data, 228
Exercises, 241
8. Parametric Regression Models 244
   8.1 Introduction, 244
   8.2 The Exponential Regression Model, 246
   8.3 The Weibull Regression Model, 260
   8.4 The Log-Logistic Regression Model, 273
   8.5 Other Parametric Regression Models, 283
      Exercises, 283

9. Other Models and Topics 286
   9.1 Introduction, 286
   9.2 Recurrent Event Models, 287
   9.3 Frailty Models, 296
   9.4 Nested Case-Control Studies, 308
   9.5 Additive Models, 314
   9.6 Competing Risk Models, 329
   9.7 Sample Size and Power, 340
      Exercises, 351

Appendix 1  The Delta Method 355

Appendix 2  An Introduction to the Counting Process
            Approach to Survival Analysis 359

Appendix 3  Percentiles for Computation of the Hall
            and Wellner Confidence Band 364

References  365

Index  383