

# Contents

## Preface xiii

## 1 Introduction to Traffic Engineering 1

- 1.1 Traffic Engineering as a Profession 1
  - 1.1.1 Safety: The Primary Objective 1
  - 1.1.2 Other Objectives 2
  - 1.1.3 Responsibility, Ethics, and Liability in Traffic Engineering 2
- 1.2 Transportation Systems and their Function 3
  - 1.2.1 The Nature of Transportation Demand 4
  - 1.2.2 Concepts of Mobility and Accessibility 5
  - 1.2.3 People, Goods, and Vehicles 6
  - 1.2.4 Transportation Modes 7
- 1.3 Highway Legislation and History in the United States 7
  - 1.3.1 The National Pike and the States' Rights Issue 7
  - 1.3.2 Key Legislative Milestones 10
  - 1.3.3 The National System of Interstate and Defense Highways 11
- 1.4 Elements of Traffic Engineering 13
- 1.5 Modern Problems for the Traffic Engineer 14
- 1.6 Standard References for the Traffic Engineer 14
- 1.7 Metric versus U.S. Units 15
- 1.8 Closing Comments 15

## Part 1 Components of the Traffic System and their Characteristics 16

## 2 Road User and Vehicle Characteristics 17

- 2.1 Overview of Traffic Stream Components 17

- 2.1.1 Dealing with Diversity 17
  - 2.1.2 Addressing Diversity Through Uniformity 18
  - 2.2 Road Users 18
    - 2.2.1 Visual Characteristics of Drivers 19
    - 2.2.2 Important Visual Deficits 21
    - 2.2.3 Perception-Reaction Time 21
    - 2.2.4 Pedestrian Characteristics 23
    - 2.2.5 Impacts of Drugs and Alcohol on Road Users 25
    - 2.2.6 Impacts of Aging on Road Users 26
    - 2.2.7 Psychological, Personality, and Related Factors 26
  - 2.3 Vehicles 27
    - 2.3.1 Concept of the Design Vehicle 27
    - 2.3.2 Turning Characteristics of Vehicles 28
    - 2.3.3 Braking Characteristics 31
    - 2.3.4 Acceleration Characteristics 32
  - 2.4 Total Stopping Distance and Applications 33
    - 2.4.1 Safe Stopping Sight Distance 33
    - 2.4.2 Decision Sight Distance 34
    - 2.4.3 Other Sight Distance Applications 34
    - 2.4.4 Change (Yellow) and Clearance (All Red) Intervals for a Traffic Signal 35
  - 2.5 Closing Comments 36
- References 36  
Problems 37

## 3 Roadways and Their Geometric Characteristics 38

- 3.1 Highway Functions and Classification 38
  - 3.1.1 Trip Functions 38

3.1.2	Highway Classification	39	4.1.5	Communicating with the Driver	75
3.1.3	Preserving the Function of a Facility	40	4.2	Traffic Markings	76
3.2	Highway Design Elements	42	4.2.1	Colors and Patterns	76
3.2.1	Introduction to Horizontal Alignment	42	4.2.2	Longitudinal Markings	77
3.2.2	Introduction to Vertical Alignment	43	4.2.3	Transverse Markings	78
3.2.3	Introduction to Cross-Sectional Elements	43	4.2.4	Object Markers	80
3.2.4	Surveying and Stationing	43	4.2.5	Delineators	81
3.3	Horizontal Alignment of Highways	44	4.3	Traffic Signs	83
3.3.1	Geometric Characteristics of Horizontal Curves	44	4.3.1	Regulatory Signs	83
3.3.2	Spiral Transition Curves	52	4.3.2	Warning Signs	87
3.3.3	Sight Distance on Horizontal Curves	55	4.3.3	Guide Signs	88
3.3.4	Compound Horizontal Curves	57	4.4	Traffic Signals	94
3.3.5	Reverse Horizontal Curves	57	4.4.1	Traffic Control Signals	94
3.4	Vertical Alignment of Highways	58	4.4.2	Pedestrian Signals	100
3.4.1	Grades	58	4.4.3	Other Traffic Signals	100
3.4.2	Geometric Characteristics of Vertical Curves	61	4.4.4	Traffic Signal Controllers	101
3.4.3	Sight Distance on Vertical Curves	63	4.5	Special Types of Control	103
3.4.4	Other Minimum Controls on Length of Vertical Curves	64	4.6	Summary and Conclusion	103
3.4.5	Some Design Guidelines for Vertical Curves	65	References	104	
3.5	Cross-Section Elements of Highways	65	Problems	104	
3.5.1	Travel Lanes and Pavement	65	<b>5</b>	<b>Traffic Stream Characteristics</b>	<b>105</b>
3.5.2	Shoulders	66	5.1	Types of Facilities	106
3.5.3	Side-Slopes for Cuts and Embankments	67	5.2	Traffic Stream Parameters	106
3.5.4	Guardrail	67	5.2.1	Volume and Rate of Flow	106
3.6	Closing Comments	69	5.2.2	Speed and Travel Time	111
References	69		5.2.3	Density and Occupancy	112
Problems	70		5.2.4	Spacing and Headway: Microscopic Parameters	114
<b>4</b>	<b>Introduction to Traffic Control Devices</b>	<b>71</b>	5.3	Relationships among Flow Rate, Speed, and Density	115
4.1	The Manual on Uniform Traffic Control Devices	71	References	118	
4.1.1	History and Background	72	Problems	118	
4.1.2	General Principles of the MUTCD	72	<b>6</b>	<b>Intelligent Transportation Systems</b>	<b>120</b>
4.1.3	Contents of the MUTCD	73	6.1	The Range of ITS Applications	121
4.1.4	Legal Aspects of the MUTCD	74	6.2	Network Optimization	122
			6.3	Sensing Traffic using Virtual Detectors	122
			6.4	In-Vehicle Routing, and Personal Route Information	123
			6.5	The Smart Car	124
			6.6	Commercial Routing and Delivery	124
			6.7	Electronic Toll Collection	125
			6.8	The Smart Card	125
			6.9	Congestion Pricing	126
			6.10	Dynamic Assignment	126

- 6.11 Traffic Enforcement 127
- 6.12 Bus Transit and Paratransit 127
- 6.13 Emerging Issues 127
- 6.14 Summary 128
- References 128
- Problems 129

## Part 2 Traffic Studies and Programs 130

### 7 Statistical Applications in Traffic Engineering 131

- 7.1 An Overview of Probability Functions and Statistics 132
  - 7.1.1 Discrete versus Continuous Functions 132
  - 7.1.2 Randomness and Distributions Describing Randomness 132
  - 7.1.3 Organizing Data 132
  - 7.1.4 Common Statistical Estimators 133
- 7.2 The Normal Distribution and Its Applications 135
  - 7.2.1 The Standard Normal Distribution 135
  - 7.2.2 Important Characteristics of the Normal Distribution Function 138
- 7.3 Confidence Bounds 138
- 7.4 Sample Size Computations 139
- 7.5 Addition of Random Variables 139
  - 7.5.1 The Central Limit Theorem 140
- 7.6 The Binomial Distribution Related to the Bernoulli and Normal Distributions 141
  - 7.6.1 Bernoulli and the Binomial Distribution 141
  - 7.6.2 Asking People Questions: Survey Results 143
  - 7.6.3 The Binomial and the Normal Distributions 143
- 7.7 The Poisson Distribution 143
- 7.8 Hypothesis Testing 144
  - 7.8.1 Before-and-After Tests with Two Distinct Choices 145
  - 7.8.2 Before-and-After Tests with Generalized Alternative Hypothesis 147
  - 7.8.3 Other Useful Statistical Tests 149
- 7.9 Summary and Closing Comments 156

- References 156
- Problems 156

### 8 Volume Studies and Characteristics 159

- 8.1 Introduction to Traffic Studies 159
  - 8.1.1 Modern Technology 160
  - 8.1.2 Types of Studies 160
- 8.2 Volume Characteristics 161
  - 8.2.1 Volume, Demand, and Capacity 162
  - 8.2.2 Volume Patterns and Characteristics 166
- 8.3 Field Techniques for Volume Studies 172
  - 8.3.1 Manual Count Techniques 173
  - 8.3.2 Portable Count Techniques 176
  - 8.3.3 Permanent Counts 177
- 8.4 Intersection Volume Studies 178
  - 8.4.1 Arrival versus Departure Volumes: A Key Issue for Intersection Studies 178
  - 8.4.2 Special Considerations for Signalized Intersections 179
  - 8.4.3 Presentation of Intersection Volume Data 179
- 8.5 Limited Network Volume Studies 180
  - 8.5.1 Control Counts 182
  - 8.5.2 Coverage Counts 182
  - 8.5.3 An Illustrative Study 182
  - 8.5.4 Estimating Vehicle Miles Traveled (VMT) on a Network 186
  - 8.5.5 Display of Network Volume Results 186
- 8.6 Statewide Counting Programs 186
  - 8.6.1 Calibrating Daily Variation Factors 189
  - 8.6.2 Calibrating Monthly Variation Factors 189
  - 8.6.3 Grouping Data from Control Count Locations 191
  - 8.6.4 Using the Results 192
  - 8.6.5 Estimating Annual Vehicle-Miles Traveled 192
- 8.7 Specialized Counting Studies 193
  - 8.7.1 Origin and Destination Counts 193
  - 8.7.2 Cordon Counts 196
  - 8.7.3 Screen-Line Counts 198
- 8.8 Closing Comments 200
- References 200
- Problems 200

## 9 Speed, Travel Time, and Delay Studies 203

- 9.1 Introduction 203
- 9.2 Spot Speed Studies 204
  - 9.2.1 Speed Definitions of Interest 204
  - 9.2.2 Uses of Spot Speed Data 205
  - 9.2.3 Measurement Techniques 205
  - 9.2.4 Reduction and Analysis of Spot Speed Data 208
  - 9.2.5 Proper Location for Speed Studies 221
- 9.3 Travel-Time Studies 222
  - 9.3.1 Field Study Techniques 222
  - 9.3.2 Travel Time Data Along an Arterial: An Example of the Statistics of Travel Times 223
  - 9.3.3 Overriding Default Values: Another Example of Statistical Analysis of Travel-Time Data 225
  - 9.3.4 Travel-Time Displays 227
- 9.4 Intersection Delay Studies 228
- 9.5 Closing Comments 233
- References 233
- Problems 233

## 10 Accidents: Studies, Statistics, and Programs 236

- 10.1 Introduction 236
- 10.2 Approaches to Highway Safety 238
  - 10.2.1 Exposure Control 238
  - 10.2.2 Accident Risk Control/Accident Prevention 239
  - 10.2.3 Behavior Modification 239
  - 10.2.4 Injury Control 240
  - 10.2.5 Post-Injury Management 240
  - 10.2.6 Planning Actions to Implement Policy Strategies 240
  - 10.2.7 National Policy Initiatives 242
- 10.3 Accident Data Collection and Record Systems 242
  - 10.3.1 Accident Reporting 242
  - 10.3.2 Manual Filing Systems 243
  - 10.3.3 Computer Record Systems 244
- 10.4 Accident Statistics 246
  - 10.4.1 Types of Statistics 246
  - 10.4.2 Accident Rates 247
  - 10.4.3 Statistical Displays and their Use 248
  - 10.4.4 Identifying High-Accident Locations 249

- 10.4.5 Before-and-After Accident Analysis 251
- 10.5 Site Analysis 253
  - 10.5.1 Collision Diagrams 253
  - 10.5.2 Condition Diagrams 255
  - 10.5.3 Interpretation of Condition and Collision Diagrams 255
- 10.6 Development of Countermeasures 257
- 10.7 Closing Comments 257
- References 257
- Problems 261

## 11 Parking: Studies, Characteristics, Facilities, and Programs 263

- 11.1 Introduction 263
- 11.2 Parking Generation and Supply Needs 264
  - 11.2.1 Parking Generation 264
  - 11.2.2 Zoning Regulations 267
- 11.3 Parking Studies and Characteristics 270
  - 11.3.1 Proximity: How Far Will Parkers Walk? 270
  - 11.3.2 Parking Inventories 270
  - 11.3.3 Accumulation and Duration 272
  - 11.3.4 Other Types of Parking Studies 276
- 11.4 Design Aspects of Parking Facilities 277
  - 11.4.1 Some Basic Parking Dimensions 278
  - 11.4.2 Parking Modules 279
  - 11.4.3 Separating Small and Large Vehicle Areas 280
  - 11.4.4 Parking Garages 283
- 11.5 Parking Programs 283
- 11.6 Closing Comments 286
- References 286
- Problems 286

## Part 3 Applications to Freeway and Rural Highway Systems 289

### 12 Capacity and Level-of-Service Analysis for Freeways and Multilane Highways 290

- 12.1 Introduction to Capacity and Level-of-Service Concepts 290
  - 12.1.1 The Capacity Concept 291
  - 12.1.2 The Level-of-Service Concept 292
  - 12.1.3 The  $w/c$  Ratio and Its Use in Capacity Analysis 294
- 12.2 Freeways and Multilane Highways 295
  - 12.2.1 Facility Types 295

- 12.2.2 Basic Freeway and Multilane Highway Characteristics 295
  - 12.3 Analysis Methodologies for Basic Freeway Sections and Multilane Highways 299
    - 12.3.1 Types of Analysis 301
    - 12.3.2 Determining the Free-Flow Speed 303
    - 12.3.3 Determining the Heavy-Vehicle Factor 308
    - 12.3.4 Determining the Driver Population Factor 315
  - 12.4 Sample Applications 315
  - 12.5 Calibration Issues 322
    - 12.5.1 Calibrating Base Speed-Flow Curves 322
    - 12.5.2 Calibrating Passenger Car Equivalents 328
    - 12.5.3 Calibrating the Driver Population Factor 331
    - 12.5.4 Adjustment Factors to Free-Flow Speed 331
  - 12.6 Software 332
  - References 332
  - Problems 333
- 13 Weaving, Merging, and Diverging Movements on Freeways and Multilane Highways 335**
- 13.1 Turbulence Areas on Freeways and Multilane Highways 335
  - 13.2 Level-of-Service Criteria 337
  - 13.3 A Common Point: Converting Demand Volumes 338
  - 13.4 Analysis of Weaving Areas 338
    - 13.4.1 Flows in a Weaving Area 339
    - 13.4.2 Critical Geometric Variables 340
    - 13.4.3 Computational Procedures for Weaving Area Analysis 345
    - 13.4.4 Multiple Weaving Areas 350
    - 13.4.5 Weaving on Collector-Distributor Roadways and Other Types of Facilities 350
  - 13.5 Analysis of Merge and Diverge Areas 351
    - 13.5.1 Structure of the Methodology for Analysis of Merge and Diverge Areas 351
    - 13.5.2 Estimating Demand Flow Rates in Lanes 1 and 2 352
    - 13.5.3 Capacity Considerations 357
  - 13.5.4 Determining Density and Level-of-Service in the Ramp Influence Area 358
  - 13.5.5 Determining Expected Speed Measures 358
  - 13.5.6 Special Cases 359
  - 13.6 Sample Problems in Weaving, Merging, and Diverging Analysis 360
  - 13.7 Analysis of Freeway Facilities 370
    - 13.7.1 Segmenting the Freeway 370
    - 13.7.2 Analysis Models 371
  - References 371
  - Problems 372
- 14 Two-Lane, Two-way Rural Highways 389**
- 14.1 Introduction 589
  - 14.2 Design Standards 390
  - 14.3 Passing Sight Distance on Rural Two-Lane Highways 393
  - 14.4 Capacity and Level-of-Service Analysis of Two-Lane Rural Highways 394
    - 14.4.1 Capacity 395
    - 14.4.2 Level-of-Service 396
    - 14.4.3 Types of Analysis 397
    - 14.4.4 Free-Flow Speed 397
    - 14.4.5 Estimating Demand Flow Rate 399
    - 14.4.6 Estimating Average Travel Speed 405
    - 14.4.7 Determining Percent Time Spent Following 409
    - 14.4.8 Impacts of Passing Lanes 418
    - 14.4.9 Impact of Climbing Lanes 421
  - 14.5 Summary 421
  - References 422
  - Problems 422
- 15 Signing and Marking for Freeways and Rural Highways 424**
- 15.1 Traffic Markings on Freeways and Rural Highways 424
    - 15.1.1 Freeway Markings 424
    - 15.1.2 Rural Highway Markings 424
    - 15.1.3 Ramp Junction Markings 427
  - 15.2 Establishing and Posting of Speed Limits 428
  - 15.3 Guide Signing of Freeways and Rural Highways 431
    - 15.3.1 Reference Posts 431
    - 15.3.2 Numbered Highway Systems 431

- 15.3.3 Exit Numbering Systems 432
  - 15.3.4 Route Sign Assemblies 433
  - 15.3.5 Freeway and Expressway Guide Signing 436
  - 15.3.6 Guide Signing for Conventional Roads 441
  - 15.4 Other Signs on Freeways and Rural Highways 441
  - References 442
  - Problems 442
- Part 4 Applications to Urban and Suburban Street Systems 444**
- 16 Introduction to Intersection Control 445**
- 16.1 The Hierarchy of Intersection Control 445
  - 16.2 Level I Control: Basic Rules of the Road 446
  - 16.3 Level II Control: YIELD and STOP Control 449
    - 16.3.1 Two-way STOP Control 449
    - 16.3.2 YIELD Control 451
    - 16.3.3 Multiway STOP Control 452
  - 16.4 Level III Control: Traffic Control Signals 452
    - 16.4.1 Advantages of Traffic Signal Control 453
    - 16.4.2 Disadvantages of Traffic Signal Control 454
    - 16.4.3 Warrants for Traffic Signals 454
    - 16.4.4 Summary 462
    - 16.4.5 A Sample Problem in Application of Signal Warrants 463
  - 16.5 Closing Comments 466
  - References 466
  - Problems 466
- 17 Basic Principles of Intersection Signalization 470**
- 17.1 Terms and Definitions 470
    - 17.1.1 Components of a Signal Cycle 471
    - 17.1.2 Types of Signal Operation 471
    - 17.1.3 Treatment of Left Turns 472
  - 17.2 Discharge Headways, Saturation Flow, Lost Times, and Capacity 473
    - 17.2.1 Saturation Headway and Saturation Flow Rate 473
    - 17.2.2 Start-up Lost Time 474
    - 17.2.3 Clearance Lost Time 475
    - 17.2.4 Total Lost Time and the Concept of Effective Green Time 475
    - 17.2.5 Capacity of an Intersection Lane or Lane Group 475
    - 17.2.6 Notable Studies on Saturation Headways, Flow Rates, and Lost Times 476
  - 17.3 The Critical-Lane and Time-Budget Concepts 477
    - 17.3.1 The Maximum Sum of Critical-Lane Volumes: One View of Signalized Intersection Capacity 479
    - 17.3.2 Finding an Appropriate Cycle Length 480
  - 17.4 The Concept of Left-Turn Equivalency 483
  - 17.5 Delay as a Measure of Effectiveness 485
    - 17.5.1 Types of Delay 486
    - 17.5.2 Basic Theoretical Models of Delay 487
    - 17.5.3 Inconsistencies in Random and Overflow Delay 493
    - 17.5.4 Delay Models in the HCM 2000 494
    - 17.5.5 Examples in Delay Estimation 495
  - 17.6 Overview 496
  - References 497
  - Problems 497
- 18 Fundamentals of Signal Timing and Design 500**
- 18.1 Development of Signal Phase Plans 501
    - 18.1.1 Treatment of Left Turns 501
    - 18.1.2 General Considerations in Signal Phasing 503
    - 18.1.3 Phase and Ring Diagrams 503
    - 18.1.4 Common Phase Plans and Their Use 504
    - 18.1.5 Summary and Conclusion 515
  - 18.2 Determining Vehicular Signal Requirements 515
    - 18.2.1 Change and Clearance Intervals 515
    - 18.2.2 Determining Lost Times 517
    - 18.2.3 Determining the Sum of Critical-Lane Volumes 518
    - 18.2.4 Determining the Desired Cycle Length 520
    - 18.2.5 Splitting the Green 521
  - 18.3 Determining Pedestrian Signal Requirements 522

- 18.4 Sample Signal Timing Applications 524  
References 536  
Problems 537
- 19 Elements of Intersection Design and Layout 540**
- 19.1 Intersection Design Objectives and Considerations 540  
19.2 A Basic Starting Point: Sizing the Intersection 541  
19.2.1 Unsignalized Intersections 541  
19.2.2 Signalized Intersections 543  
19.3 Intersection Channelization 544  
19.3.1 General Principles 544  
19.3.2 Some Examples 544  
19.3.3 Channelizing Right Turns 546  
19.4 Special Situations at Intersections 548  
19.4.1 Intersections at Skewed Angles 548  
19.4.2 T-Intersections: Opportunities for Creativity 550  
19.4.3 Offset Intersections 551  
19.4.4 Special Treatments for Heavy Left-Turn Movements 555  
19.5 Street Hardware for Signalized Intersections 558  
19.6 Closing Comments 563  
References 563  
Problems 564
- 20 Actuated Signal Control and Detection 565**
- 20.1 Types of Actuated Control 566  
20.2 Detectors and Detection 567  
20.3 Actuated Control Features and Operation 568  
20.3.1 Actuated Controller Features 569  
20.3.2 Actuated Controller Operation 570  
20.4 Actuated Signal Timing and Design 572  
20.4.1 Phase Plans 572  
20.4.2 Minimum Green Times 572  
20.4.3 Unit or Vehicle Extension 572  
20.4.4 Detector Location Strategies 573  
20.4.5 Yellow and All-Red Intervals 574  
20.4.6 Maximum Green Times and the Critical Cycle 575  
20.4.7 Pedestrian Requirements for Actuated Signals 576
- 20.5 Examples in Actuated Signal Design and Timing 576  
References 582  
Problems 582
- 21 Analysis of Signalized Intersections 585**
- 21.1 Introduction 585  
21.2 Conceptual Framework for the HCM 2000 Methodology 586  
21.2.1 The Critical-Lane Group Concept 586  
21.2.2 The  $v/s$  Ratio as a Measure of Demand 586  
21.2.3 Capacity and Saturation Flow Rate Concepts 587  
21.2.4 Level-of-Service Concepts and Criteria 590  
21.2.5 Effective Green Times and Lost Times 590  
21.3 The Basic Model 591  
21.3.1 Model Structure 591  
21.3.2 Analysis Time Periods 593  
21.3.3 The Input Module 593  
21.3.4 The Volume Adjustment Module 597  
21.3.5 The Saturation Flow Rate Module 599  
21.3.6 Capacity Analysis Module 606  
21.3.7 Level-of-Service Module 606  
21.3.8 Interpreting the Results of Signalized Intersection Analysis 611  
21.4 Some "Simple" Sample Problems 612  
21.4.1 Sample Problem 1: Intersection of Two One-Way Streets 612  
21.4.2 Sample Problem 2: A Multiphase Signal with No Permitted Left Turns 617  
21.4.3 Sample Problem 3: Dealing with Initial Queues 626  
21.5 Complexities 628  
21.5.1 Left-Turn Adjustment Factor for Permitted Left Turns 628  
21.5.2 Modeling Compound Phasing 634  
21.5.3 Altering Signal Timings Based on  $v/s$  Ratios 637  
21.5.4 Analysis of Actuated Signals 639  
21.6 Calibration Issues 639  
21.6.1 Measuring Prevailing Saturation Flow Rates 639  
21.6.2 Measuring Base Saturation Flow Rates 640

- 21.6.3 Measuring Start-up Lost Time 640
- 21.6.4 An Example of Measuring Saturation Flow Rates and Start-up Lost Times 640
- 21.6.5 Calibrating Adjustment Factors 642
- 21.6.6 Normalizing Signalized Intersection Analysis 643
- 21.7 Summary 644
- References 644
- Problems 645
- 22 Applications of Signalized Intersection Analysis 650**
  - 22.1 Software Packages 650
  - 22.2 A Sample Problem 651
    - 22.2.1 Base Case: Existing Conditions 651
    - 22.2.2 New Scenario: Additional Traffic Due to Development 651
    - 22.2.3 Adjusting the Signal Timing 653
    - 22.2.4 Investigating the Cycle Length 655
    - 22.2.5 Another Option: Protected-Plus-Permitted Phasing 658
    - 22.2.6 Other Options? 659
  - 22.3 Additional Sensitivities 659
    - 22.3.1 Cycle Length versus Delay 661
    - 22.3.2 Delay versus  $w/c$  Ratio 662
    - 22.3.3 Demand versus Delay 663
    - 22.3.4 Summary 664
  - 22.4 Closing Comments 664
  - Problem 664
- 23 Analysis of Unsignalized Intersections 666**
  - 23.1 Analysis of Two-way STOP-Controlled Intersections 666
    - 23.1.1 Determining Conflicting Volume 667
    - 23.1.2 Critical Gaps and Follow-Up Times 669
    - 23.1.3 Determining Potential Capacity 671
    - 23.1.4 Accounting for Impedance Effects-Movement Capacity 671
    - 23.1.5 Determining Shared-Lane Capacity 673
    - 23.1.6 Adjusting for Upstream Signals and Platoon Flow 674
    - 23.1.7 Two-Stage Gap Acceptance 674
    - 23.1.8 Analysis of Flared Approaches 675
    - 23.1.9 Determining Control Delay 676
    - 23.1.10 Estimating Queue Length 677
    - 23.1.11 Sample Problem in TWSC Intersection Analysis 677
  - 23.2 Analysis of Roundabouts 680
  - 23.3 Analysis of All-Way STOP-Controlled Intersections (AWSC) 682
  - References 682
  - Problems 682
- 24 Signal Coordination for Arterials and Networks 684**
  - 24.1 Basic Principles of Signal Coordination 684
    - 24.1.1 A Key Requirement: Common Cycle Length 684
    - 24.1.2 The Time-Space Diagram and Ideal Offsets 684
  - 24.2 Signal Progression on One-Way Streets 686
    - 24.2.1 Determining Ideal Offsets 686
    - 24.2.2 Potential Problems 688
  - 24.3 Bandwidth Concepts 689
    - 24.3.1 Bandwidth Efficiency 690
    - 24.3.2 Bandwidth Capacity 690
  - 24.4 The Effect of Queued Vehicles at Signals 691
  - 24.5 Signal Progression for Two-way Streets and Networks 693
    - 24.5.1 Offsets on a Two-way Street 693
    - 24.5.2 Network Closure 695
    - 24.5.3 Finding Compromise Solutions 697
  - 24.6 Common Types of Progression 699
    - 24.6.1 Progression Terminology 699
    - 24.6.2 The Alternating Progression 700
    - 24.6.3 The Double-Alternating Progression 701
    - 24.6.4 The Simultaneous Progression 702
    - 24.6.5 Insights Regarding the Importance of Signal Spacing and Cycle Length 702
  - 24.7 Coordination of Signals for Oversaturated Networks 704
    - 24.7.1 System Objectives for Oversaturated Conditions 704
    - 24.7.2 Signal Remedies 705
  - 24.8 Computer-Controlled Traffic Systems 710
    - 24.8.1 System Characteristics 710
    - 24.8.2 Collection and Use of Data 711



24.8.3	An Overview of Modern Systems	713	26.3	Preserving the Function of an Arterial	743
24.8.4	Adaptive Signal Control	717	26.3.1	Design Treatments	744
24.9	Closing Comments	717	26.3.2	Reallocation of Arterial Space	745
References		718	26.3.3	Other Aspects of Operation	745
Problems		719	26.4	Access Management	746
<b>25</b>	<b>Analysis of Arterial Performance</b>	<b>726</b>	26.4.1	Goods Activity on Arterials	750
25.1	Determining Arterial Class	727	26.5	Signal Policies	752
25.2	Basic Performance Concepts	728	26.5.1	Transitions from One Plan to Another	752
25.2.1	Arterial Speed Concepts	728	26.5.2	Coordinating Multiphase Signals	753
25.2.2	Determination of Arterial Speed	730	26.5.3	Multiple and Sub-Multiple Cycle Lengths	754
25.3	Sensitivities	734	26.5.4	The Diamond Interchange	755
25.3.1	The Impact of Signal Spacing on Arterial Performance	734	26.6	Summary	756
25.3.2	The Impact of Progression Quality on Arterial Speed	735	References		757
25.3.3	Impact of Cycle Length on Arterial Speed	735	Problems		758
25.4	Through Vehicles on the Arterial	736	<b>27</b>	<b>Traffic Planning and Operations for Urban Street Networks</b>	<b>759</b>
25.5	Arterial vs. Intersection LOS	736	27.1	Goals and Objectives	759
25.6	Design Implications	737	27.2	Functional Issues	760
25.7	Summary	737	27.3	Control of Left-Turn Conflicts	760
References		737	27.4	One-Way Street Systems	761
Problems		737	27.5	Special-Use Lanes	762
<b>26</b>	<b>Arterial Planning and Design</b>	<b>740</b>	27.6	Managing the Curb	764
26.1	Arterial Planning Issues and Approaches	740	27.7	Traffic Calming	765
26.2	Multimodal Performance Assessment	741	27.7.1	Traffic Calming Approaches	768
26.2.1	Bicycle Level-of-Service	741	27.7.2	Impacts and Effectiveness of Traffic Calming Measures	772
26.2.2	Pedestrian Level-of-Service	741	27.8	Closing Comments	776
26.2.3	Bus Level-of-Service	742	References		776
			Problems		777
			<b>Index</b>		<b>779</b>