Traffic Engineering

Fifth Edition

Roger P. Roess, Ph.D.
Professor Emeritus
New York University Tandon School of Engineering

Elena S. Prassas, Ph.D.
Associate Professor of Transportation Engineering
New York University Tandon School of Engineering

William R. McShane, Ph.D., PE, PTOE
Professor Emeritus
New York University Tandon School of Engineering
Chairman Emeritus, KLD Engineering, P.C.
President/CEO, KLD Associates, Inc.

Pearson
330 Hudson Street, NY NY 10013
Contents

Preface ix

Part I Basic Concepts and Characteristics 1

1 Introduction 2
  1.1 Traffic Engineering as a Profession 2
  1.2 Transportation Systems and Their Function 5
  1.3 History of U.S. Highway Legislation 9
  1.4 Elements of Traffic Engineering 13
  1.5 Modern Problems for the Traffic Engineer 14
  1.6 Standard References for the Traffic Engineer 15
  1.7 Metric versus U.S. Units 16
  1.8 Closing Comments 16
  References 16

2 Transportation Modes and Characteristics 17
  2.1 Classifying Transportation Modes 17
  2.2 The Transportation Infrastructure and Its Use 18
  2.3 Modal Attributes 19
  2.4 The Capacity of Transportation Modes 22
  2.5 Multimodal Focus 25
  References 25
  Problems 26

3 Road-User, Vehicle, and Roadway Characteristics 27
  3.1 Dealing with Diversity 27
  3.2 Road Users and Their Characteristics 28
  3.3 Vehicle Characteristics 37
  3.4 Roadway Characteristics 47
  3.5 Traffic Control Systems and Characteristics 51
  3.6 Closing Comments 51
  References 51
  Problems 52

4 Communicating with Drivers: Traffic Control Devices 53
  4.1 The Manual on Uniform Traffic Control Devices 53
  4.2 Traffic Markings 57
  4.3 Traffic Signs 63
  4.4 Traffic Signals 75
  4.5 Special Types of Control 81
  4.6 Closing Comments 81
  References 82
  Problems 82

5 Traffic Stream Characteristics 83
  5.1 Types of Facilities 83
  5.2 Traffic Stream Parameters 84
  5.3 Relationships among Flow Rate, Speed, and Density 92
  5.4 A Brief History of Mathematical Models of Freeway Flow—Traffic Flow Theory 94
  5.5 Characteristics of Interrupted Flow 100
  5.6 Closing Comments 100
  References 100
  Problems 100
6 The Concepts of Demand, Volume, and Capacity 102
   6.1 When Capacity Constrains Demand 102
   6.2 Relationships among Demand, Volume (or Rate of Flow), and Capacity 103
   6.3 The Formation of Queues and Their Impacts 107
   6.4 Bottlenecks, Hidden Bottlenecks, and Demand Starvation 109
   6.5 Capacity versus Queue Discharge 110
   6.6 Closing Comments 112
   Problems 112

7 Level of Service and the Highway Capacity Manual: History and Fundamental Concepts 114
   7.1 Uninterrupted and Interrupted Flow Facilities 115
   7.2 A Brief Chronology of the Highway Capacity Manual 115
   7.3 The Concept of Capacity 118
   7.4 The Concept of Level of Service 119
   7.5 Service Volumes and Service Flow Rates 123
   7.6 The v/c Ratio and Its Use in Capacity Analysis 124
   7.7 Closing Comments 125
   References 125
   Problems 125

8 Intelligent Transportation Systems 126
   8.1 An Overview 127
   8.2 ITS Standards 128
   8.3 ITS Systems Engineering Process 129
   8.4 ITS-Related Commercial Routing and Delivery 131
   8.5 Sensing Traffic by Virtual and Other Detectors 131
   8.6 Connected Vehicle Pilot Studies 132
   8.7 Variable Pricing 134
   8.8 Closing Comments 135
   References 135
   Problems 135

Part II Traffic Studies and Programs 137

9 Traffic Data Collection and Reduction Methodologies 138
   9.1 Sources of Data 139
   9.2 The Connected Vehicle 144
   9.3 Applications of Traffic Data 144
   9.4 Types of Studies 145
   9.5 Manual Data Collection Methodologies 146
   9.6 Semi-Automated Studies Using Pneumatic Road Tubes and Similar Devices 150
   9.7 Permanent Detectors and Their Use 151
   9.8 Closing Comments 152
   References 152
   Problems 152

10 Traffic Volume Studies and Characteristics 155
   10.1 Volume Characteristics 155
   10.2 Intersection Volume Studies 163
   10.3 Limited Network Volume Studies 165
   10.4 Statewide Counting Programs 172
   10.5 Specialized Counting Studies 177
   10.6 Closing Comments 184
   References 184
   Problems 184

11 Speed, Travel Time, and Delay Studies 186
   11.1 Introduction 186
   11.2 Spot Speed Studies 187
   11.3 Travel-Time Studies 205
   11.4 Intersection Delay Studies 211
   11.5 Closing Comments 216
   References 216
   Problems 216

12 Highway Traffic Safety: An Overview 218
   12.1 Introduction 218
   12.2 Current and Emerging Priorities 220
   12.3 The Highway Safety Manual 227
   12.4 Historical Crash Data and Regression to the Mean 238
   12.5 Effective Crash Countermeasures 238
   12.6 Approaches to Highway Safety 240
19.5 Compound Signal Phasing 429
19.6 Sample Signal Timing Problems 430
References 442
Problems 443

20 Fundamentals of Signal Timing and Design: Actuated Signals 447
20.1 Types of Actuated Control 448
20.2 Detectors and Detection 449
20.3 Actuated Control Features and Operation 450
20.4 Actuated Signal Timing and Design 453
20.5 Sample Problems in Actuated Signal Design and Timing 458
References 464
Problems 464

21 Signal Coordination for Arterials and Networks 467
21.1 A Key Requirement: A Common Cycle Length 467
21.2 The Time-Space Diagram 467
21.3 Ideal Offsets 469
21.4 Signal Progression on One-Way Streets 469
21.5 Signal Progression for Two-Way Streets and Networks 475
21.6 Types of Progression 481
21.7 Software for Signal Progression Design 485
21.8 Coordination of Signals for Oversaturated Networks 486
References 495
Problems 495

22 Capacity and Level of Service Analysis: Signalized Intersections—The HCM Method 499

Part I: Analysis of Pre-timed Signalized Intersections 500
22.1 Fundamental Concepts 500
22.2 Model Structure for Pre-timed Signals 505
22.3 Computational Steps in the Model 505
22.4 Interpreting the Results of Signalized Intersection Analysis 528
22.5 Methodological Complexities 529

Part II: Analysis of Actuated Signals 536
22.6 Measuring Prevailing Saturation Flow Rates 537
22.7 Measuring Base Saturation Flow Rates 537
22.8 Measuring Start-Up Lost Time 537
22.9 Calibrating Adjustment Factors 539
22.10 Normalizing Signalized Intersection Analysis 541

Part III: Calibration Issues 536
References 542
Problems 542

Part IV: Closing Comments 542
References 542
Problems 542

23 Planning-Level Analysis of Signalized Intersections 545
23.1 The TRB Circular 212 Methodology 545
23.2 The 2016 HCM Planning Methodology 546
23.3 Closing Comments 556
References 556
Problems 557

24 Urban Streets and Arterials: Complete Streets and Level of Service 559
24.1 Designing Urban Streets 560
24.2 Level of Service Analysis of a Multimodal Street Segment 563
24.3 Facility Level of Service Analysis 570
24.4 Closing Comments 570
References 570
Problems 571

25 Unsignalized Intersections and Roundabouts 572

Part I: Two Way Stop-Controlled Intersections 573
25.1 TWSC Intersection Operation: A Fundamental Modeling Approach 573
25.2 Computational Steps in TWSC Intersection Analysis 574
25.3 Interpreting Results 584

Part II: All-Way STOP-Controlled Intersections 589
25.4 Computational Steps 591
25.5 Comment 598
CONTENTS

Part III: Roundabouts  602
25.6 Types of Roundabouts and General Characteristics  603
25.7 Signing and Marking for Roundabouts  603
25.8 Capacity and Level of Service Analysis of Roundabouts  608
25.9 Closing Comments  615
References 615
Problems  616

26 Interchanges and Alternative Intersections  618
26.1 Interchanges  619
26.2 Alternative Intersections  625
26.3 Level of Service Analysis  630
26.4 Closing Comments  638
References  639
Problems  639

Part IV Uninterrupted Flow Facilities: Design, Control, and Level of Service  643

27 An Overview of Geometric Design of Roadways  644
27.1 Introduction to Highway Design Elements  644
27.2 Horizontal Alignment of Highways  646
27.3 Vertical Alignment of Highways  659
27.4 Cross-Sectional Elements of Highways  665
27.5 Closing Comments  669
References  669
Problems  669

28 Capacity and Level of Service Analysis: Basic Freeway and Multilane Highway Segments  671
28.1 Facility Types Included  671
28.2 Segment Types on Freeways and Some Multilane Highways  672
28.3 Generic Speed-Flow Characteristics on Freeways and Multilane Highways  672
28.4 Levels of Service for Freeways and Multilane Highways  674
28.5 Base Speed-Flow Curves  676
28.6 Applications of Base Curves to Capacity and LOS Analysis of Freeways and Multilane Highways  687
28.7 The Heavy Vehicle Adjustment Factor and Related Issues  689
28.8 Sample Problems  694
28.9 Closing Comments  700
References 700
Problems  701

29 Capacity and Level of Service Analysis: Weaving Segments on Freeways and Multilane Highways  703
29.1 Level of Service Criteria for Weaving Segments  704
29.2 Converting Demand Volumes to Flow Rates in pc/h  705
29.3 A Brief History of the Development of Weaving Segment Methodologies  705
29.4 Component Flows in a Weaving Area  706
29.5 Critical Geometric Variables Describing a Weaving Segment  707
29.6 Computational Procedures for Weaving Area Analysis  711
29.7 Sample Problems in Weaving Segment Analysis  720
References 725
Problems  726

30 Capacity and Level of Service Analysis: Merge and Diverge Segments on Freeways and Multilane Highways  728
30.1 Level-of-Service Criteria  729
30.2 Converting Demand Volumes  729
30.3 Fundamental Variables Involved in Merge and Diverge Segment Analysis  730
30.4 Computational Procedures for Merge and Diverge Segments  731
30.5 Special Applications in Merge and Diverge Analysis  741
30.6 Closing Comments  745
30.7 Sample Problems in Merging and Diverging Analysis  745
References 751
Problems  751
31 Operation and Analysis of Freeways and Highways 753

31.1 Traffic Markings on Freeways and Rural Highways 753
31.2 Signing for Freeways and Rural Highways 758
31.3 Establishing and Posting of Speed Limits on Rural Roads 771

31.4 Managed Lanes on Freeways 772
31.5 Active Transportation and Demand Management Strategies 774
31.6 Analysis of Freeway Facilities 774
References 776
Problems 777

Index 778
Preface

The transportation system is the nation’s lifeblood circulation system. Our complex system of roads and highways, railroads, airports and airlines, waterways, and urban transit systems provides for the movement of people and goods to and from the most remote outposts of the nation. It is the transportation network which allows for the concentrated production of food, goods, energy, and other material in an economically optimal manner, knowing that the systems needed to collect raw materials, and distribute final products throughout the nation are in place.

Traffic engineering deals with several critical elements of the transportation system: our streets and highways, and the transportation services they support. Because the transportation system is such a critical part of our infrastructure, the traffic engineer is involved in a wide range of issues, often in a very public setting, and must bring a broad range of skills to the table. Traffic engineers must have an appreciation for and understanding of planning, design, management, construction, operation, control, and system optimization. All of these functions involve traffic engineers at some level.

This text focuses on the key engineering skills required to practice traffic engineering in a broad setting. This is the fifth edition of the textbook, and it includes the latest standards and criteria of the Manual on Uniform Traffic Control Devices (2009, as updated through May 2012), the Policy on Geometric Design of Highways and Streets (2011), the Highway Capacity Manual (2016), the Highway Safety Manual (2010, with 2014 Supplement), and other critical documents. While this edition uses the latest versions of basic references, students must be aware that all of these are periodically updated, and (at some point), versions not available at this writing will become available, and should be used.

The text is organized into four major functional parts:

Part I – Basic Concepts and Characteristics
Part II – Traffic Studies and Programs
Part III – Interrupted Flow Facilities: Design, Control, and Level of Service
Part IV – Uninterrupted Flow Facilities: Design, Control, and Level of Service

The text is appropriate for an undergraduate survey course in traffic engineering, or for more detailed graduate (or undergraduate) courses focusing on specific aspects of the profession. A survey course might include all of Part I, a selection of chapters from Part II, and a few chapters focusing on signal design and/or capacity and level of service analysis. Over the years, the authors have used the text for graduate courses on Traffic Studies and Characteristics, Traffic Control and Operations, and Highway Capacity and Level of Service Analysis. Special courses on highway traffic safety and geometric design have also used this text.

Some chapters, particularly Traffic Impact and Mitigation Studies, are organized around case studies. These should only be used in a more advanced course with an instructor who is familiar with the many tools referenced.

What’s New in This Edition

This edition of the textbook adds a significant amount of material, including, but not limited to:

1. More than 50% of the homework problems (and an available solutions manual) are new for most chapters.
2. New material on unsignalized intersections, roundabouts, alternative intersections, interchanges, operation and analysis of facilities, and more.

3. Material on signalized intersections, signal design and timing, and signal hardware has been updated and extended.

4. Material from the latest editions of key traffic engineering references is included, as noted previously.

5. Links to a number of new Web sites which students and instructors will find valuable.

There are some additional revisions. There is no overview chapter on statistics; undergraduate engineering degrees now require coursework in statistics. We have included supporting material on statistical analyses within the applications in which they are used. An overview chapter can’t cover everything, and it should be expected that modern engineering students have been exposed to this material. The text still provides details on a number of capacity and level of service applications. The 2016 HCM, however, has over 3,000 pages of printed and electronic material, and many complicated analyses can only be presented in outline or overview form. There is material from the Highway Safety Manual, but complete analysis material is included for only one type of application. Again, there is simply too much material to include more than an example of its procedures and applications.

We hope that students and instructors will continue to find this text useful in learning about the profession of traffic engineering, and about many of its key components. As in the past, comments are always welcome.

ROGER P. ROESS
ELENA S. PRASSAS
WILLIAM R. MCShANE
Configure traffic engineering properties for IS-IS. IS-IS always performs shortest-path-first (SPF) calculations to determine next hops. For prefixes reachable through a particular next hop, IS-IS places that next hop for that prefix in the inet.0 routing table. The inet.3 table, which is present on the ingress router, contains the host address of each MPLS label-switched path (LSP) egress router. BGP uses this routing table to resolve next-hop addresses.
Traffic engineering of IP networks is an important problem in operational IP networks. While protocols such as OSPF and IS-IS define how routers communicate among themselves to update information such as link weights, they are also silent on how to pick good link weights. Thus, mechanisms are needed to determine good link weights. To do so, a critical component is to recognize that this leads to first identifying how to estimate traffic in the network, as well as what performance measures might be of interest in IP networks.

Transport Planning and Traffic Engineering. Edited by CA O’Flaherty. Contributing authors. MGH ...Â Internet Traffic Engineering 1 Guest Editorial; Terje Jensen Section I: Introduction/Overview 3 Side_1_360 Chapter 1 Introduction to Highway Engineering and Traffic Analysis. 350 PagesÂ·2014Â·15.25 MBÂ·1,408 Downloads. Chapter 5 presents the fundamentals of traffic flow and queuing theory, which provide the basic Traffic & Highway Engineering , Fouth Edition. /interface traffic-eng monitor 0. tunnel-id: 12 primary-path-state: established. primary-path: dyn secondary-path-state: not-necessary.Â Whenever the link comes back, TE tunnel will use the same path even it is not the best path (unless reoptimize-interval is configured). To fix it we can manually reoptimize the tunnel path. /interface traffic-eng reoptimize 0. /interface traffic-eng monitor 0. tunnel-id: 12 primary-path-state: established. primary-path: dyn secondary-path-state: not-necessary.