



INSTITUTE OF TRANSPORTATION ENGINEERS



# TRAFFIC ENGINEERING

# HANDBOOK

SEVENTH EDITION 7

WILEY



# **TRAFFIC ENGINEERING HANDBOOK**



# TRAFFIC ENGINEERING HANDBOOK SEVENTH EDITION

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Institute of Transportation Engineers

Anurag Pande, Ph.D.

Brian Wolshon, Ph.D., P.E., PTOE  
*Co-editors*

WILEY

Cover image: Boston Complete Streets Guidelines, Boston Transportation Department;  
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Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Published simultaneously in Canada.

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Library of Congress Cataloging-in-Publication Data is available:

ISBN 978-1-118-76230-1 (hardback)  
978-1-118-76228-8 (epdf)  
978-1-118-76226-4 (epub)

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

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# The Institute of Transportation Engineers, Traffic Engineering Handbook, 7th Edition

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## I. EDITORIAL PREFACE

As the transportation profession continues to broaden in scope as issues emerge and technologies advance, the Institute of Transportation Engineers has sought to keep pace through the evolution of the *Traffic Engineering Handbook* (TEH). The content of this latest edition reflects updates to the most prominent sources of transportation practice, including the *Highway Capacity Manual* (HCM), *Manual on Uniform Traffic Control Devices* (MUTCD), *A Policy on Geometric Design of Highways and Streets* (the Green Book), *Highway Safety Manual* (HSM), and many others. This version of the *Handbook* also marks a significant departure from all prior versions of this publication.

Beyond the standard updates to reflect evolving changes in practice, this new edition of the *Handbook* also reflects the shifting philosophy of traffic engineering practice in which transportation professionals no longer serve as merely planners, designers, and operators of transportation systems. Rather, they are integral components of more comprehensive societal roles of community builders, influencers of social and economic change, and investors of public resources.

Just as transportation systems must be adapted to meet the changing expectations and needs of users and increasing costs and threats to the environment, the *Traffic Engineering Handbook* cannot be static. In this seventh edition, the handbook reflects an effort to reduce traditional modal stove-piping and promote a more inclusive approach to the planning, design, and operation of transportation systems. The goal of this shift is to serve the needs of all users and design context-sensitive transportation facilities, all with an eye toward developing more integrated, sustainable, and resilient transportation solutions to address modern problems and needs.

The expectation is for this edition to equip traffic engineers for the key roles that they will play in the evolution of communities into hubs of economic and social activity. The streets of the twenty-first century must meet the complex needs of society in a safe, efficient, and cost-effective manner. The organization of this *Handbook* is reflective of this complexity through a functionally driven multimodal approach to content categorization. In the development of this *Handbook*, the editors, along with ITE staff and teams of practicing professionals throughout North America, have worked to integrate the needs of all modes and all transportation system users through a holistic approach rather than just an afterthought. We hope that readers will also recognize, appreciate, and benefit from these changes.

Anurag Pande, Ph.D. and Brian Wolshon, Ph.D., P.E., PTOE  
*Editors*



# Acknowledgments

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Many individuals contributed to this seventh edition of the *Traffic Engineering Handbook*, including the authors, advisory panel members, reviewers, *LeadershipITE* (Class of 2014), and ITE staff. Many thanks for all of their efforts.

The advisory panel was comprised of a diverse group of transportation professionals with recognized expertise and active involvement in traffic engineering issues and practices. The panel members, listed below, worked with ITE staff and the handbook's co-editors, in the development of the scope of work and in defining a new approach for this handbook. These individuals served as mentors to each of the chapter authors as they developed the technical content for their chapters. They also participated in a series of critical reviews providing key feedback at various stages in the development process.

James Copeland	Peter Koonce	Timothy Haagsma
Joanna Kervin	Richard (Rick) Werts	Zaki Mustafa
John LaPlante	Steve Brown	
Keith Hines	Thomas Hicks	

The following subject-matter experts served as volunteer reviewers of the draft handbook chapters:

Alan Hampshire	Emmanuel Anastasiadis	Julie Whitcher
Albert Letzkus	Fred Hanscom	Karl Rothermel
Angelo Rao	Gary Schatz	Kevin Phillips
Arun Bhowmick	George Butzer	Kordel Braley
Bart Thrasher	George Dore	Laurie Radow
Ben Powell	Herbert Levinson	Louis Rubenstein
Borg Chan	Huaguo Hugo Zhou	Lucinda Gibson
Brad Strader	Ilya Sher	Mary Miranda (Randy) Wade
Charles (Charlie) Trask III	Jamie Parks	Michael Moule
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Chris Cunningham	Jerry Ogden	Mike King
Christopher Milner	Jess Billmeyer	Muhammad Arif
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Donald (Don) Monahan	John Davis	Paul Villaluz
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Eagan Foster	Julie Conn	Phani Rama Jammalamadaka
Eli Veith	Julie Kroll	Praveen Pasumarthy

Randy McCourt	Scott Batson	Sue Chrysler
Richard (Rich) Coakley	Scott Wainwright	Theodore Petritsch
Richard Nassi	Shared Uprety	Vishal Kakkad
Robert Brooks	Shourie Kondagari	Walter Kraft
Robert Wunderlich	Stephan Parker	William Sproule
Rock Miller	Steve Pyburn	Zaher Khatib
Roxann Hayes	Steven Latoski	
Saeed Asadi Bagloee	Sudhir Murthy	

Several graduates from the *Leadership/ITE*, Class of 2014, reviewed the second draft of the handbook to ensure that the content recognizes the need to approach planning, design and operations from a holistic perspective recognizing all modes and all users and included the following:

Amir Rizavi	Irini Akhnoukh	Kati Tamashiro
Andy Kaplan	J. Andrew (Andy) Swisher	Martin Gugel
Carrie Falkenrath	K. Scott Walker	Michael Hofener
Danielle Scharf	Katherine Kortum	Susan Paulus

In addition to the reviewers recognized above, we would also like to recognize the following two individuals who served as overall reviewers. This role entailed reviewing the handbook in its entirety to ensure that the new organization provided adequate content coverage and technical accuracy, as well as, consistency.

Beverly Kuhn  
John LaPlante

ITE staff also provided valuable input to development process. Thomas W. Brahms provided overall guidance and vision for the handbook. Lisa Fontana Tierney managed the development process and helped keep the project on schedule. Courtney L. Day harmonized the flow of drafts between the authors, the volunteer reviewers and the editors and coordinated the final production stages with the publisher.

Anurag Pande, Ph.D.  
Brian Wolshon, Ph.D., P.E., PTOE  
*Co-editors*

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# Introduction to the *Traffic Engineering Handbook* and Its Role in Evolving Practice

Anurag Pande, Ph.D., and Brian Wolshon, Ph.D., P.E., PTOE

## I. BACKGROUND

**T**raffic engineering is the subdiscipline of transportation engineering that addresses the planning, design, and operation of streets and highways, their networks, adjacent lands, and interaction with other modes of transportation (air, water, and rail) and their terminals. Over many decades, the Institute of Transportation Engineers (ITE) has provided traffic engineering professionals with a comprehensive resource of fundamental traffic engineering concepts, as well as state-of-the-art practices, through the *Traffic Engineering Handbook* (*TEH* or *Handbook*). The *Handbook's* prior editions have been widely used by public agencies, consultants, and educational institutions as a basic day-to-day reference source on the proven techniques of the practice. The primary audience for this publication is practicing professionals responsible for the safe and efficient operation of the roadway transportation networks. The secondary audience includes academia in general and educators in particular. The *Handbook* can also be used as a reference by the general public and policymakers, but it is not written primarily for that audience.

The practice of traffic engineering continues to evolve even as fundamental concepts remain largely unchanged. At the time of publication of the first ITE *Traffic Engineering Handbook* in 1941, the focus of the traffic engineering profession was largely on providing and expanding road capacity—through the construction of new roads and the widening of existing ones. However, increasing congestion, even as the highway network continued to grow in subsequent decades, led to the realization that adding capacity, while useful for a period of time, was not the only solution to the congestion problem. As a result, the management of traffic demand also became part of the traffic engineering profession as a way to address congestion. The concept of demand management has now evolved into another fundamental tool used in the transportation paradigm by providing travel choices using multiple different modes (Schreffler et al., 2012).

Currently, traffic engineers are required to think differently than in the past to provide a range of design and control options that facilitate the safe and efficient movements of all users, in all modes, while providing context-sensitive solutions. In the case of urban streets, for example, traffic engineers need to consider alternative traffic designs that lead to slower travel speeds to create a safer environment for all users, encourage economic activity in downtown areas, and contribute to revitalized city centers that facilitate urban economic growth.

## II. THE VISION FOR THIS EDITION

As one of the definitive technical resources in traffic engineering for nearly 70 years and 6 prior editions, the ITE *Traffic Engineering Handbook* has served as a concise yet comprehensive source for the fundamental principles, proven techniques, and practical applications in the field. Through periodic revisions and updates, the *TEH* has remained current with emerging knowledge and advancements in practice by including topics such as transportation communications, traffic calming, and access management, among many others. In the seventh edition ITE has once again evolved this publication by incorporating the latest traffic engineering principles and techniques, while integrating the changing needs and thinking within the practice. This edition also makes a significant departure from prior editions in terms of its structure, organization, and presentation of the content.

Among the most significant of these changes is the move away from traditional automobile-centric approaches to traffic engineering. In this edition, traffic engineering principles are presented as tools to meet broader societal needs to facilitate the safe and efficient movement of all road users. The authors have sought to incorporate in this publication the needs of the full range of users (pedestrians, bicyclists, automobile/public-transit users of all ages and abilities, and emergency- and commercial-vehicle operators) that rely on the surface transportation system, while keeping it true to its roots as the “go-to” resource on the fundamental principles and applications of traffic planning, operations, control, design, and analysis. This shift is in recognition of the fact that traditional, narrowly focused solutions have, at times, been inadequate to address the needs of all users.

This edition of the *Handbook* also integrates contemporary approaches to traffic engineering and planning to include context-sensitive solutions, resiliency, environmental sensitivity, system reliability, and sustainability. By emphasizing the application of performance-based design and analysis philosophies and promoting a comprehensive design approach, it tries to eliminate the long-standing sequestrations that exist in the specialized fields within traffic engineering. Performance-based design seeks to design, analyze, and build transportation systems that are economical and adaptable to the changing demands, user preferences, and conditions placed upon them. Under this approach, planners and engineers attempt to quantify performance before, during, and after construction so that decisions can be made based on a number of quantifiable cost-and-benefit performance measures instead of solely on the cost of construction. Similarly, benefits have, in the past, been measured narrowly in terms of level of service and reduced crash frequency/rate, when in reality there are many other measures that can be applied. It has been suggested that, in addition to their roles as quantitative analysts of traffic performance, traffic engineers of the future can use these approaches to serve as “financial advisors” for strategic investment of public funds for the improvement of mobility and creation of more sustainable, resilient, and livable communities.

### III. ORGANIZATION OF THE HANDBOOK

To reflect evolving views of traffic engineering and the variety of approaches, ITE has significantly changed the organization and presentation of the traditional technical content for this publication. This edition of the *Handbook* is divided into four *functional content* areas that group chapters by related topics based on traffic engineering roles and tasks. *Functional content* areas deliver traditional technical material, a mainstay of prior editions, within inclusive, integrated, and overlapping topical areas. These areas are aimed at encouraging a concurrent, multimodal, and multiuse approach to planning, design, operation, and management of roads and streets. The organization of each chapter within a functional content area follows a similar pattern of coverage. First and foremost, each chapter covers the basics, which include the fundamental elements of the subject area along with relevant references (e.g., *Highway Capacity Manual (HCM)*, “A Policy on Geometric Design of Highways and Streets” (*AASHTO Green Book*), *Highway Safety Manual (HSM)*, the *Manual on Uniform Traffic Control Devices (MUTCD)*, and *Public Rights-of-Way Accessibility Guidelines (PROWAG)*, among others. Then, the application of these concepts is described, including how these individual elements fit together within a holistic approach to design and analysis that can be sequenced for implementation.

The goal of this format is to better connect the roadway with the surrounding land-use environment, considering all user categories and other relevant elements. This is a departure from the traditional layered approach, which typically considers vehicular traffic first and then considers user groups such as pedestrians and persons with disabilities. The intent is that providing a harmonization of the material will build an awareness of and appreciation for the integration and interaction of one specific topic with another.

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Even as the new functional content areas of this edition deliver traditional technical material, a mainstay of prior editions, the organization of the *Handbook* represents a significant departure from the traditional layered approach to traffic engineering.

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In the first functional content area, the editors provide a foundational mathematical and scientific basis for key fundamentals of the traffic engineering profession. The chapters in this content area include concepts from probability and statistics, engineering economics (Chapter 2), and human factors (Chapter 3). Next, ideas and processes for conducting traffic engineering studies are included in Chapter 4. Concepts of multimodal level of service (LOS; Chapter 5),



as well as forecasting of travel demand (Chapter 6), are also part of this content area. Examples of how these concepts are applied in professional practice are provided in the individual chapters.

In the remaining three functional content areas, the *Handbook* groups traffic engineering practice into categories of roadway functional operation to serve the needs of readers in terms of facility location, users, and the expected operational environment. These three content areas include:

*Design and Operation of Uninterrupted Flow Facilities (freeways, multilane highways, and two-lane rural roadways)*—covering the fundamentals of uninterrupted traffic flow, along with design and operations of uninterrupted flow facilities in urban and rural areas.

*Design and Operation of Complete Streets in Town Centers and Neighborhoods*—incorporating the multimodal LOS concepts for the design and operation of complete streets. This functional area also incorporates issues related to the management of access, traffic calming, and parking on urban and suburban streets.

*Special Operational Considerations*—this topical area includes coverage of issues related to planning, design, control, management, and operations for planned special events, transportation-incident conditions, and emergencies. Areas of discussion include managed lanes, work zones, planned-event traffic management, evacuations, and disaster recovery.

Under this format, there are no exclusive chapters that address concepts such as ITS (intelligent-transportation systems), safety, traffic signals, and communication strategies. To further aid the reader in locating relevant content, we note chapters that cover some of these important topical areas here:

- **ITS:** Adaptive components of transportation systems are part and parcel of the modern traffic engineer's arsenal. ITE, in collaboration with the U.S. Department of Transportation (USDOT) Research and Innovative Technology Administration (RITA) Intelligent Transportation Systems (ITS) Joint Program Office (JPO) and ITS America, produced the *ITS ePrimer* ([www.pcb.its.dot.gov/ePrimer.aspx](http://www.pcb.its.dot.gov/ePrimer.aspx)), which describes these systems in great depth in the form of up-to-date web-based modules (*Knowledge Exchange: ePrimer*). In the *Handbook*, the ITS components are discussed in Chapter 8, Chapter 9, Chapter 10, Chapter 13, and Chapter 15 in the context of problems they are designed to solve. These provide appropriate background and context to support application of the *ePrimer*.
- **Safety:** The concept of safety in the *HSM* is described as nominal and substantive safety. Nominal safety is achieved by making sure that all the components of design and traffic control meet the criteria prescribed in the governing manuals. The idea of nominal safety in terms of the human factors associated with these standards is described in Chapter 3. This foundation is then reinforced within the context of design functions in later chapters of this book. *Substantive safety* is described by the measure of safety expressed in the form of expected number of crashes on a facility. The statistical concepts related to substantive-safety measurement are first presented in Chapter 2. Chapter 4 describes the relevant procedures in detail, which are then applied in the context of rural uninterrupted flow in Chapter 8. Specific safety issues are also discussed in the context of urban uninterrupted flow (Chapter 9), urban streets/intersections (Chapter 10), and access management (Chapter 12).
- **Traffic signals:** In the previous edition of the *Handbook*, the subject of traffic signals was covered in a single chapter. Signals are traffic control devices, and their application is context-sensitive. In this edition, the signals to implement ramp metering are covered in Chapter 9, because their application concerns urban uninterrupted flow. In contrast, the basics of signal control are discussed in Chapter 10 as part of the basics of interrupted flow within a multimodal environment. Finally, Chapter 11 adds to the discussion by highlighting traffic-signal applications within the context of complete streets.
- **Communication strategies:** Communicating with the public through various channels is a crucial aspect of a traffic engineer's function. Instead of addressing this need in an isolated chapter, we address community engagement in varying levels of detail in the context of mitigating traffic impacts (Chapter 6), phasing in complete streets with multimodal traffic streams (Chapter 11), access management (Chapter 12), traffic calming (Chapter 14), work zone scheduling (Chapter 15), and emergency- and event-traffic management (Chapter 16).

To guide readers familiar with previous editions of the *Handbook* through the content reorganization, Table 1-1 maps the content of the previous edition to the functional content areas and chapters of this edition. Content from some

Table 1-1. Content Mapping from <i>TEH</i> 6th Edition		
Chapter ( <i>TEH</i> 6th Edition)	Functional Content Area(s) ( <i>TEH</i> 7th Edition)	Chapter(s) ( <i>TEH</i> 7th Edition)
Chapter 2: Road Users	Background and Fundamentals	Chapter 3: Road Users
Chapter 3: Vehicles	Background and Fundamentals Uninterrupted-Flow Facilities	Chapter 3: Road Users Chapter 7: Traffic Flow Characteristics for Uninterrupted-Flow Facilities Chapter 8: Design and Operations of Road Segments and Interchanges in Rural Areas
Chapter 4: Traffic and Flow Characteristics	Uninterrupted-Flow Facilities Design and Operation of Complete Streets in Town Centers and Neighborhoods	Chapter 7: Traffic Flow Characteristics for Uninterrupted-Flow Facilities Chapter 10: Design and Control for Interrupted Traffic Flow through Intersections
Chapter 5: Safety*	Background and Fundamentals Uninterrupted-Flow Facilities Design and Operation of Complete Streets in Town Centers and Neighborhoods	Chapter 2: Probability and Statistical Analyses Techniques for Traffic Engineering Performance Measurement Chapter 4: Traffic Engineering Studies Chapter 8: Design and Operations of Road Segments and Interchanges in Rural Areas Chapter 9: Planning, Design, and Operations of Road Segments and Interchanges in Urban Areas Chapter 10: Design and Control for Interrupted Traffic Flow through Intersections Chapter 11: Design and Operation of Complete Streets and Intersections Chapter 12: Access Management Chapter 14: Traffic Calming
Chapter 6: Probability and Statistics	Background and Fundamentals	Chapter 2: Probability and Statistical Analyses Techniques for Traffic Engineering Performance Measurement
Chapter 7: Geometric Design for Traffic*	Uninterrupted-Flow Facilities Design and Operation of Complete Streets in Town Centers and Neighborhoods	Chapter 8: Design and Operations of Road Segments and Interchanges in Rural Areas Chapter 9: Planning, Design, and Operations of Road Segments and Interchanges in Urban Areas Chapter 10: Design and Control for Interrupted Traffic Flow through Intersections Chapter 11: Design and Operation of Complete Streets and Intersections
Chapter 8: Traffic Engineering Studies	Background and Fundamentals	Chapter 4: Traffic Engineering Studies
Chapter 9: Planning for Operations	Background and Fundamentals	Chapter 6: Forecasting Travel Demand

Table 1-1. (Continued)		
Chapter ( <i>TEH</i> 6th Edition)	Functional Content Area(s) ( <i>TEH</i> 7th Edition)	Chapter(s) ( <i>TEH</i> 7th Edition)
Chapter 10: Managing Traffic Demand to Address Congestion: Providing Travelers with Choices	Background and Fundamentals	Chapter 6: Forecasting Travel Demand
Chapter 11: Signs and Pavement Markings*	Uninterrupted-Flow Facilities Design and Operation of Complete Streets in Town Centers and Neighborhoods Special Operational Considerations	Chapter 8: Design and Operations of Road Segments and Interchanges in Rural Areas Chapter 9: Planning, Design, and Operations of Road Segments and Interchanges in Urban Areas Chapter 10: Design and Control for Interrupted Traffic Flow through Intersections Chapter 11: Design and Operations of Complete Streets and Intersections Chapter 13: Parking Chapter 14: Traffic Calming Chapter 15: Work Zone Maintenance of Traffic and Construction Staging
Chapter 12: Traffic Control Signals*	Uninterrupted-Flow Facilities Design and Operation of Complete Streets in Town Centers and Neighborhoods	Chapter 9: Planning, Design, and Operations of Road Segments and Interchanges in Urban Areas Chapter 10: Design and Control for Interrupted Traffic Flow through Intersections Chapter 11: Design and Operation of Complete Streets and Intersections
Chapter 13: Access Management	Design and Operation of Complete Streets in Town Centers and Neighborhoods	Chapter 12: Access Management
Chapter 14: Parking	Design and Operation of Complete Streets in Town Centers and Neighborhoods	Chapter 13: Parking
Chapter 15: Traffic Calming	Design and Operation of Complete Streets in Town Centers and Neighborhoods	Chapter 14: Traffic Calming
Chapter 16: Effective Communication for Transportation Projects*	Background and Fundamentals Design and Operation of Complete Streets in Town Centers and Neighborhoods Special Operational Considerations	Chapter 6: Forecasting Travel Demand Chapter 11: Design and Operation of Complete Streets and Intersections Chapter 14: Traffic Calming Chapter 15: Work Zone Maintenance of Traffic and Construction Staging Chapter 16: Traffic Management for Planned, Unplanned, and Emergency Events

(continued)

Table 1-1. (Continued)		
Chapter (TEH 6th Edition)	Functional Content Area(s) (TEH 7th Edition)	Chapter(s) (TEH 7th Edition)
Chapter 17: Traffic Regulation and Control*	Uninterrupted-Flow Facilities Design and Operation of Complete Streets in Town Centers and Neighborhoods Special Operational Considerations	Chapter 8: Design and Operations of Road Segments and Interchanges in Rural Areas Chapter 9: Planning, Design, and Operations of Road Segments and Interchanges in Urban Areas Chapter 10: Design and Control for Interrupted Traffic Flow through Intersections Chapter 11: Design and Operation of Complete Streets and Intersections Chapter 12: Access Management Chapter 13: Parking Chapter 14: Traffic Calming Chapter 15: Work Zone Maintenance of Traffic and Construction Staging
Chapter 18: Maintenance-of-Traffic Design and Construction Staging	Special Operational Considerations	Chapter 15: Work Zone Maintenance of Traffic and Construction Staging

\*Content from the chapter in the previous edition is now distributed over multiple chapters to ensure that the relevant concepts are presented within the right context.

of the chapters from the sixth edition (e.g., Chapter 4, “Traffic and Flow Characteristics”) still map to individual chapters in the current edition, whereas content from several individual chapters from the sixth edition (e.g., Chapter 5, “Safety” and Chapter 12, “Traffic Control Signals”) is now distributed over multiple chapters.

Beyond mapping the content of the sixth edition, we have also covered several new areas of emerging interest to traffic engineers: namely, traffic management during planned and unplanned emergency events and, of course, multimodal LOS. Conversely, it should also be noted that not all content from the sixth edition has made it into the seventh edition. For example, in addressing the concepts of interrupted flow, the readers are now referred to the *Traffic Control Devices Handbook* (Seyfried, 2013) for a discussion of traffic control equipment standards and maintenance. Perhaps most important to note is that the breadth of the topics within the field is so vast that it is not realistically possible to capture the full breadth of all topics within a single book. Nevertheless, within that reality, the level of coverage here provides valuable background and foundational information to support judgments and decision making, as well as to guide readers to resources and publications that contain more specific details on topics of interest.

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The new approach to the *Traffic Engineering Handbook* may present challenges for educators who use this publication in the classroom. However, it is expected that the academic community will be able to use these changes to take a holistic approach to traffic engineering and use it to educate students to become traffic engineering practitioners of the twenty-first century.

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In its entirety, it is expected that this edition of the *Handbook* will provide readers with broader and more comprehensive perspectives and approaches to traffic engineering. This publication is meant to serve the needs of the practitioner community, with knowledge generally applicable to any location, road type, and user group, as well as the students and researchers of the academic community who are seeking to learn about and build upon the foundational concepts of the traffic engineering profession. While this approach may present some initial challenges for educators who use this publication in the classroom, it is expected that the academic community will use this challenge as an

opportunity to take a holistic approach to traffic engineering in educating their students to become holistic traffic engineering practitioners of the twenty-first century.

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