

TRANSIT COOPERATIVE RESEARCH PROGRAM  
Sponsored by the Federal Transit Administration

# TCRP

## REPORT 165



# Transit Capacity and Quality of Service Manual



Third Edition



TRANSPORTATION RESEARCH BOARD  
OF THE NATIONAL ACADEMIES

## TCRP OVERSIGHT AND PROJECT SELECTION COMMITTEE\*

### CHAIR

**Keith Parker**  
*Metropolitan Atlanta Rapid Transit Authority*

### MEMBERS

**Michael Allegra**  
*Utah Transit Authority*  
**John Bartosiewicz**  
*McDonald Transit Associates*  
**Raul Bravo**  
*Raul V. Bravo & Associates*  
**Alice Cannon**  
*Jacksonville Transportation Authority*  
**John Catoe**  
*The Catoe Group*  
**Grace Crunican**  
*San Francisco Bay Area Rapid Transit District*  
**Carolyn Flowers**  
*Charlotte Area Transit System*  
**Angela Iannuzziello**  
*AECOM*  
**Paul Jablonski**  
*San Diego Metropolitan Transit System*  
**Ian Jarvis**  
*South Coast British Columbia Transportation Authority*  
**Ronald Kilcoyne**  
*Lane Transit District*  
**Ralph Larison**  
*HERZOG*  
**John Lewis**  
*LYNX-Central Florida RTA*  
**Sherry Little**  
*Spartan Solutions LLC*  
**Jonathan H. McDonald**  
*Atkins North America*  
**E. Susan Meyer**  
*Spokane Transit Authority*  
**Bradford Miller**  
*Pinellas Suncoast Transit Authority*  
**Peter Rogoff**  
*FTA*  
**Richard Sarles**  
*Washington Metropolitan Area Transit Authority*  
**James Stem**  
*United Transportation Union*  
**Gary Thomas**  
*Dallas Area Rapid Transit*  
**Matthew O. Tucker**  
*North County Transit District*  
**Phillip Washington**  
*Denver Regional Transit District*  
**Patricia Weaver**  
*University of Kansas*

### EX OFFICIO MEMBERS

**Michael P. Melaniphy**  
*APTA*  
**Robert E. Skinner, Jr.**  
*TRB*  
**Frederick G. (Bud) Wright**  
*AASHTO*  
**Victor Mendez**  
*FHWA*

### TDC EXECUTIVE DIRECTOR

**Louis Sanders**  
*APTA*

### SECRETARY

**Christopher W. Jenks**  
*TRB*

\*Membership as of July 2013.

## TRANSPORTATION RESEARCH BOARD 2013 EXECUTIVE COMMITTEE\*

### OFFICERS

CHAIR: **Deborah H. Butler**, *Executive Vice President, Planning, and CIO, Norfolk Southern Corporation, Norfolk, VA*  
VICE CHAIR: **Kirk T. Steudle**, *Director, Michigan DOT, Lansing*  
EXECUTIVE DIRECTOR: **Robert E. Skinner, Jr.**, *Transportation Research Board*

### MEMBERS

**Victoria A. Arroyo**, *Executive Director, Georgetown Climate Center, and Visiting Professor, Georgetown University Law Center, Washington, DC*  
**Scott E. Bennett**, *Director, Arkansas State Highway and Transportation Department, Little Rock*  
**William A. V. Clark**, *Professor of Geography (emeritus) and Professor of Statistics (emeritus), Department of Geography, University of California, Los Angeles*  
**James M. Crites**, *Executive Vice President of Operations, Dallas-Fort Worth International Airport, TX*  
**Malcolm Dougherty**, *Director, California Department of Transportation, Sacramento*  
**John S. Halikowski**, *Director, Arizona DOT, Phoenix*  
**Michael W. Hancock**, *Secretary, Kentucky Transportation Cabinet, Frankfort*  
**Susan Hanson**, *Distinguished University Professor Emerita, School of Geography, Clark University, Worcester, MA*  
**Steve Heminger**, *Executive Director, Metropolitan Transportation Commission, Oakland, CA*  
**Chris T. Hendrickson**, *Duquesne Light Professor of Engineering, Carnegie Mellon University, Pittsburgh, PA*  
**Jeffrey D. Holt**, *Managing Director, Bank of Montreal Capital Markets, and Chairman, Utah Transportation Commission, Huntsville, UT*  
**Gary P. LaGrange**, *President and CEO, Port of New Orleans, LA*  
**Michael P. Lewis**, *Director, Rhode Island DOT, Providence*  
**Joan McDonald**, *Commissioner, New York State DOT, Albany*  
**Donald A. Osterberg**, *Senior Vice President, Safety and Security, Schneider National, Inc., Green Bay, WI*  
**Steve Palmer**, *Vice President of Transportation, Lowe's Companies, Inc., Mooresville, NC*  
**Sandra Rosenbloom**, *Director, Innovation in Infrastructure, The Urban Institute, Washington, DC*  
**Henry G. (Gerry) Schwartz, Jr.**, *Chairman (retired), Jacobs/Sverdrup Civil, Inc., St. Louis, MO*  
**Kumares C. Sinha**, *Olson Distinguished Professor of Civil Engineering, Purdue University, West Lafayette, IN*  
**Daniel Sperling**, *Professor of Civil Engineering and Environmental Science and Policy; Director, Institute of Transportation Studies; University of California, Davis*  
**Gary C. Thomas**, *President and Executive Director, Dallas Area Rapid Transit, Dallas, TX*  
**Phillip A. Washington**, *General Manager, Regional Transportation District, Denver, CO*

### EX OFFICIO MEMBERS

**Rebecca M. Brewster**, *President and COO, American Transportation Research Institute, Marietta, GA*  
**Anne S. Ferro**, *Administrator, Federal Motor Carrier Safety Administration, U.S. DOT*  
**LeRoy Gishi**, *Chief, Division of Transportation, Bureau of Indian Affairs, U.S. Department of the Interior, Washington, DC*  
**John T. Gray II**, *Senior Vice President, Policy and Economics, Association of American Railroads, Washington, DC*  
**Michael P. Huerta**, *Administrator, Federal Aviation Administration, U.S. DOT*  
**David T. Matsuda**, *Administrator, Maritime Administration, U.S. DOT*  
**Michael P. Melaniphy**, *President and CEO, American Public Transportation Association, Washington, DC*  
**Victor M. Mendez**, *Administrator, Federal Highway Administration, U.S. DOT*  
**Robert J. Papp** (Adm., U.S. Coast Guard), *Commandant, U.S. Coast Guard, U.S. Department of Homeland Security*  
**Lucy Phillips Priddy**, *Research Civil Engineer, U.S. Army Corps of Engineers, Vicksburg, MS, and Chair, TRB Young Members Council, Washington, DC*  
**Cynthia L. Quarterman**, *Administrator, Pipeline and Hazardous Materials Safety Administration, U.S. DOT*  
**Peter M. Rogoff**, *Administrator, Federal Transit Administration, U.S. DOT*  
**David L. Strickland**, *Administrator, National Highway Traffic Safety Administration, U.S. DOT*  
**Joseph C. Szabo**, *Administrator, Federal Railroad Administration, U.S. DOT*  
**Polly Trottenberg**, *Under Secretary for Policy, U.S. DOT*  
**Robert L. Van Antwerp** (Lt. General, U.S. Army), *Chief of Engineers and Commanding General, U.S. Army Corps of Engineers, Washington, DC*  
**Barry R. Wallerstein**, *Executive Officer, South Coast Air Quality Management District, Diamond Bar, CA*  
**Gregory D. Winfree**, *Acting Administrator, Research and Innovative Technology Administration, U.S. DOT*  
**Frederick G. (Bud) Wright**, *Executive Director, American Association of State Highway and Transportation Officials, Washington, DC*

\*Membership as of April 2013.

---

---

**TCRP REPORT 165**

---

---

**Transit Capacity and  
Quality of Service Manual**

*Third Edition*

**KITTELSON & ASSOCIATES, INC.**  
Reston, VA

**PARSONS BRINCKERHOFF**  
Washington, DC

**KFH GROUP, INC.**  
Bethesda, MD

**TEXAS A&M TRANSPORTATION INSTITUTE**  
Houston, TX

**ARUP**  
San Francisco, CA

*Subscriber Categories*  
Public Transportation

---

Research sponsored by the Federal Transit Administration in cooperation with the Transit Development Corporation

---

**TRANSPORTATION RESEARCH BOARD**

WASHINGTON, D.C.  
2013  
[www.TRB.org](http://www.TRB.org)

## TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions*, published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

## TCRP REPORT 165

Project A-15C  
ISSN 1073-4872  
ISBN 978-0-309-28344-1  
Library of Congress Control Number 2013944215

© 2013 National Academy of Sciences. All rights reserved.

### COPYRIGHT INFORMATION

Authors herein are responsible for the authenticity of their materials and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used herein.

Cooperative Research Programs (CRP) grants permission to reproduce material in this publication for classroom and not-for-profit purposes. Permission is given with the understanding that none of the material will be used to imply TRB, AASHTO, FAA, FHWA, FMCSA, FTA, or Transit Development Corporation endorsement of a particular product, method, or practice. It is expected that those reproducing the material in this document for educational and not-for-profit uses will give appropriate acknowledgment of the source of any reprinted or reproduced material. For other uses of the material, request permission from CRP.

### NOTICE

The project that is the subject of this report was a part of the Transit Cooperative Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

The Transportation Research Board of the National Academies, the National Research Council, and the sponsors of the Transit Cooperative Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

*Published reports of the*

### TRANSIT COOPERATIVE RESEARCH PROGRAM

*are available from:*

Transportation Research Board  
Business Office  
500 Fifth Street, NW  
Washington, DC 20001

*and can be ordered through the Internet at*

<http://www.national-academies.org/trb/bookstore>

Printed in the United States of America

# THE NATIONAL ACADEMIES

*Advisers to the Nation on Science, Engineering, and Medicine*

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **[www.TRB.org](http://www.TRB.org)**

**[www.national-academies.org](http://www.national-academies.org)**

# COOPERATIVE RESEARCH PROGRAMS

## CRP STAFF FOR TCRP REPORT 165

**Christopher W. Jenks**, *Director, Cooperative Research Programs*  
**Crawford F. Jencks**, *Deputy Director, Cooperative Research Programs*  
**Dianne S. Schwager**, *Senior Program Officer*  
**Jeffrey L. Oser**, *Senior Program Assistant*  
**Eileen P. Delaney**, *Director of Publications*  
**Scott E. Hitchcock**, *Editor*

## TCRP PROJECT A-15C PANEL

### Field of Operations

**Thomas K. Harrington**, *Washington Metropolitan Area Transit Authority, Washington, DC (Chair)*  
**Steve Callas**, *Tri-County Metropolitan Transportation District, Portland, OR*  
**Paul F. Hanley**, *University of Iowa, Iowa City, IA*  
**Alfred H. Harf**, *Potomac and Rappahannock Transportation Commission, Woodbridge, VA*  
**Barbara K. Ostrom**, *AMEC E&I, Beltsville, MD*  
**Diane Quigley**, *Florida DOT, Tallahassee, FL*  
**Will Rodman**, *Nelson\Nygaard Consulting Associates, Boston, MA*  
**Steven Silkunas**, *Fernandina Beach, FL*  
**Carol G. Smith**, *Metropolitan Atlanta Rapid Transit Authority, Atlanta, GA*  
**Scott A. Wainwright**, *Chicago Transit Authority, Chicago, IL*  
**Tomika Monterville**, *FTA Liaison*  
**Chris Nutakor**, *FTA Liaison*  
**Helen Tann**, *FTA Liaison*  
**Arthur L. Guzzetti**, *APTA Liaison*  
**Richard A. Cunard**, *TRB Liaison*

## AUTHOR ACKNOWLEDGMENTS

The TCQSM, 3rd edition was developed by TCRP Project A-15C. Paul Ryus of Kittelson & Associates, Inc. (KAI) was the Principal Investigator. Co-investigators were Alan Danaher, Mark Walker, Foster Nichols, and William (Bill) Carter of Parsons Brinckerhoff, Inc. (PB); Elizabeth (Buffy) Ellis of KFH Group, Inc.; Linda Cherrington of Texas A&M Transportation Institute (TTI); and Anthony (Tony) Bruzzone of Arup.

Each edition of the TCQSM builds on the material developed for previous editions. The full set of contributors to the 1st and 2nd editions is too numerous to list here, but can be viewed in the acknowledgments sections of those editions. The original authors of material that has been retained between editions are acknowledged below.

The Introduction and Concepts chapters (Chapters 1–4) were written by Paul Ryus, with contributions from Buffy Ellis and Linda Cherrington (demand-response transit, Chapter 2), Daniel Fisher of Arup (value of time, Chapter 4), and Jamie Parks of KAI (bicycle access, Chapter 4). Some rail transit concepts material (Chapter 2) originally written for previous editions by Tom Parkinson has been retained, along with ferry transit concepts (Chapter 2) and park-and-ride material (Chapter 4) originally written by Miranda Blogg. Ferry vessel descriptions were updated based on comments provided by William Hockberger, a member of the TRB Committee on Ferry Transportation.

Chapter 5, Quality of Service Methods, was written by Paul Ryus (fixed-route transit and calculation examples), and Buffy Ellis and Linda Cherrington (demand-responsive transit). Material on quality of service applications is derived from a Florida Department of Transportation guide written by KAI. Some material on transit service coverage originally developed by Peter Haliburton for the 2nd edition has been retained.

Chapter 6, Bus Transit Capacity, was written by Paul Ryus, with contributions from Alan Danaher of PB (transit-preferential treatments) and Jamie Parks (calculation example). Appendix B (Dwell Time Data Collection Procedure) was originally authored by Lewis Nowlin for the 1st edition. The core bus capacity and speed methods were originally developed by Kevin St. Jacques and Herbert S. Levinson through TRCP Project A-7, “Operational Analysis of Bus Lanes on Arterials.”

Chapter 7, Demand-Responsive Transit, was developed for the 3rd edition by Buffy Ellis and Linda Cherrington.

Chapter 8, Rail Transit Capacity, was written by Foster Nichols, updating Tom Parkinson’s work from the 1st edition and adding the section on applications. Ian Hood of Arup and several members of TRB committees related to rail transit provided input during chapter development. The core rail capacity methods were originally developed by Tom Parkinson and Ian Fisher through TCRP Project A-8, “Rail Transit Capacity.”

Chapter 9, Ferry Transit Capacity, was written by Bill Carter and Ryan Avery of PB. Tony Bruzzone and several members of the TRB Committee on Ferry Transportation provided input during chapter development. The core ferry capacity method was originally developed by Miranda Blogg for the 2nd edition.

Chapter 10, Station Capacity, was written by Mark Walker. Contributions to the chapter were also made by James Anderson of PB, Daniel Fischer and Eric Rivers of Arup, and Jonathan Brooks of TTI. In addition, David Haase and Jeremy Parnes of New York City Transit contributed data and analysis referenced in the chapter. A major source for Chapter 10 was John Fruin’s *Pedestrian Planning and Design*.

Chapter 11, Glossary, was compiled from a number of sources for the 1st edition by Tom Parkinson. Definitions have been obtained from numerous sources with acknowledgment and thanks to the many individuals and committees involved—in particular, Benita H. Gray, editor of the 1989 TRB Urban Public Transportation Glossary, from which almost one-half of the entries originated. The TRB glossary is out of print. Other major sources are the APTA website glossary (April 1998); National Transportation Statistics Glossary; Washington State DOT Glossary; TCRP A-8 Rail Transit Capacity Glossary; APTA Glossary of Reliability, Availability, and Maintainability Technology for Rail Rapid Transit 1993; draft NCHRP 8-35 ITS Glossary (including material developed by the FHWA, FTA, and U.S. DOT Joint Program Office); ANSI B77.1 aerial ropeway definitions; and a 1985 U.S. Forest Service glossary on aerial tramways, ski lifts, and tows. The contributions of Ian Fisher in compiling and cross-referencing the glossary are acknowledged. Additional terms introduced in the 3rd edition have been added to the glossary.

Additional contributors to the development of the TCQSM 3rd edition include Kelly Blume (literature review), Kathryn Coffel and Jessica Horning (focus groups and survey), Jamie Parks and Alison Tanaka (spreadsheet tool development), Kyle Meyer (review website development), Matt Broughton (graphics assistance), and Jackie Olsommer and Dorret Oosterhoff (administrative assistance).

The project team would like to thank volunteers from TRB public transportation committees who provided comments on one or more individual chapters: John Allen, Tunde Balvanyos, Jeff Becker, Gregory Benz, Martha Bewick, Bob Bourne, John Crocker, Henning Eichler, William Hockberger, Alex Lu, Peter Martin, Paul O’Brien, Robin Russell, Roberta Weisbrod, and Charlene Wilder. The researchers would particularly like to thank Herbert Levinson, who reviewed and provided detailed comments on the entire draft manual. Finally, we would like to thank the 57 focus group participants and 131 survey respondents who took the time to share their feedback on the 2nd edition and thoughts on desired improvements for the 3rd edition.

Finally, the project team would like to thank the members of the TCRP Project A-15C panel, listed separately in this front section, whose thoughtful comments were greatly appreciated throughout the TCQSM development process.

## PHOTO CREDITS

*Alan Danaher*: Exhibit 10-22c; *Chris Stanley*: Exhibit 2-11d; *Dorret Oosterhoff*: Exhibit 2-8d; *Edmonton Transit System*: Exhibit 2-3d; *Federal Highway Administration/Parsons Brinckerhoff* “HOV Interactive 1.0”: Exhibits 6-26, 6-54i, 10-20d, 10-21b; *Houston TranStar*: Exhibit 6-25; *Jamie Parks*: cover—second from

top, left; *Justin Jahnke*: Exhibit 6-3; *Kelly Blume*: Exhibits 2-9c, 6-21b, 10-23a; *Kevin Lee*: Exhibit 2-4d; *Lee Rodegerdts*: Exhibits 2-18d, 2-19d, 6-50a, 10-12b, 10-19b, 10-22b; *Matt Johnson*: Exhibit 6-30a; *Minnesota Department of Transportation*: Exhibit 6-27; *North County Transit District (NCTD)*: Exhibit 2-7f; *Parsons Brinckerhoff*: Exhibit 8-11; *Patrick McMahon*: Exhibit 2-18b; *Paul Ryus*: Exhibits 2-3abcefg, 2-4bc, 2-5a, 2-6, 2-7abcde, 2-8abc, 2-9bd, 2-10, 2-11abc, 2-12, 2-13, 2-14abcd, 2-15, 2-16, 2-17, 2-18ac, 6-5, 6-20, 6-30b, 6-31ac, 6-32, 6-33, 6-40b, 6-44, 6-45, 6-46, 6-49, 6-50b, 6-51, 6-54abcdefghj, 6-64, 8-4, 8-18, 8-19, 8-20b, 8-21, 8-25, 8-26, 8-47, 9-2, 9-4, 9-6abef, 10-3abdef, 10-6, 10-7, 10-8, 10-9, 10-12a, 10-13, 10-14, 10-17, 10-18, 10-19a, 10-20abc, 10-21a, 10-22a, 10-23bcd, (cover: top, third and fourth from top); *Potomac and Rappahannock Transportation Commission (PRTC)*: Exhibit 2-5b; *Peter Koonce*: Exhibit 6-29a; *Rory Giles/Queensland University of Technology*: Exhibits 2-19a, 10-3c; *Sean Marshall*: Exhibit 6-31b; *Sound Transit*: Exhibits 2-19b, 6-21; *Stephen Rees*: Exhibit 2-4a; *Tom Parkinson*: Exhibits 2-9a, 8-20a; *TransLink*: Exhibit 9-6cd; and *WMTA Photo by Larry Levine*: cover—second from top, right.





# FOREWORD

By Dianne S. Schwager

Staff Officer

Transportation Research Board

*TCRP Report 165: Transit Capacity and Quality of Service Manual*, 3rd edition (TCQSM) is a reference document that provides current research-based guidance on transit capacity and quality of service issues and the factors influencing both. The manual contains background, statistics, and graphics on the various types of public transportation, and it provides a framework for measuring transit availability, comfort, and convenience from the passenger and transit provider points of view. The manual contains quantitative techniques for calculating the capacity and other operational characteristics of bus, rail, demand-responsive, and ferry transit services, as well as transit stops, stations, and terminals. Example calculations are included. The TCQSM and the accompanying CD-ROM are intended for use by a range of practitioners, including transit planners, transportation planners, traffic engineers, transit operations personnel, design engineers, management personnel, teachers, and university students.

---

## HISTORY OF THE TCQSM

The TCQSM, 3rd edition updates and improves the prior manuals. Much of the new content and revised presentation in the TCQSM, 3rd edition is a result of outreach in which users and potential users of TCQSM manual identified new or updated content that would make the manual more relevant to their work.

- **The 1st edition, *TCRP Web-Only Document 6*, was produced in 1999**, assembling for the first time in one place a set of methods for evaluating the capacity of bus and rail transit services and facilities, and introducing a framework for evaluating the quality of service from the passenger point of view. A portion of the material in this edition also formed the basis for the transit chapters in the *Highway Capacity Manual 2000*.
- **The 2nd edition, *TCRP Report 100*, was published in late 2003**. A major focus of this edition was on filling gaps in knowledge. This edition introduced material on ferry transit capacity, expanded coverage of demand-responsive transit (DRT) and Americans with Disabilities Act (ADA) issues, and added guidance on transit preferential treatments and park-and-ride access to transit. This edition tested and enhanced the TCQSM's transit quality of service framework.
- **The 3rd edition of the TCQSM** incorporates the results of new research on transit capacity and quality of service that has occurred in the ten years since the 2nd Edition was developed, including original research conducted as part of the production contract for the manual.

## ORGANIZATION OF THE TCQSM 3RD EDITION

The TCQSM 3rd edition consists of twelve chapters, divided into four main topic areas:

- **Introduction.** The introductory chapter provides a concise guide to the TCQSM. It describes how to use the manual; presents the manual's purpose, scope, and intended users; describes the contents of each chapter; highlights the changes made in the 3rd edition; and describes companion documents to the TCQSM.
- **Concepts Chapters.** The three concepts chapters present concepts, define important terms, and provide illustrations of the extent to which various factors inside and outside a transit agency's control influence transit capacity, speed, reliability, and quality of service.
- **Methods Chapters.** The six methods chapters provide a combination of mode-specific concepts information, computational methods for evaluating a variety of performance measures related to transit operations and quality of service, guidance on potential applications of the methods, and worked examples of performing calculations. These chapters address capacity for bus, DRT, rail transit, ferry transit, and stops and stations.
- **Reference Chapters and Supporting Material.** Two chapters at the end of the manual provide reference material supporting the rest of the manual, including a comprehensive transit glossary, a list of the variables used in the TCQSM's computational methods, and an index to the manual.

The CD-ROM that accompanies the TCQSM provides PDF versions of all the TCQSM chapters for use on tablets and computers; links to all of the TCRP reports referenced in the TCQSM; spreadsheets that help perform the calculations used in the bus, ferry, and rail transit capacity methods; and presentations that introduce the manual and its core material.



# CONTENTS

## **1-i Chapter 1 User's Guide**

- 1-1 1. INTRODUCTION
  - 1-1 How to Use the Manual
  - 1-5 How to Find Material of Interest
  - 1-6 Five Key Concepts
- 1-9 2. PURPOSE AND SCOPE
  - 1-9 Purpose and Objectives
  - 1-9 Scope
  - 1-9 Intended Users
  - 1-9 Potential Applications
  - 1-11 International Use
- 1-13 3. WHAT'S NEW IN THE THIRD EDITION
  - 1-13 Organizational Changes
  - 1-14 Content Changes
- 1-18 4. COMPANION DOCUMENTS
  - 1-18 Highway Capacity Manual
  - 1-18 Americans with Disabilities Act (ADA) Standards for Transportation Facilities
  - 1-18 National Fire Prevention Association (NFPA) 130 Standard
- 1-19 5. REFERENCES

## **2-i CHAPTER 2 Mode and Service Concepts**

- 2-1 1. INTRODUCTION
  - 2-1 How to Use This Chapter
  - 2-1 Other Resources
- 2-2 2. TRANSIT MODES
  - 2-2 Bus Transit
  - 2-6 Demand-Responsive Transit
  - 2-13 Vanpool
  - 2-13 Rail Transit
  - 2-27 Ferry Transit
- 2-31 3. OPERATING ENVIRONMENTS
  - 2-31 Mixed Traffic
  - 2-32 Semi-exclusive
  - 2-34 Exclusive
  - 2-35 Grade Separated
- 2-36 4. SERVICE PATTERNS
  - 2-36 Fixed Route
  - 2-42 Demand Responsive
- 2-48 5. REFERENCES

### **3-i CHAPTER 3 Operations Concepts**

3-1	1. INTRODUCTION
3-1	How to Use This Chapter
3-2	Other Resources
3-3	2. CAPACITY, SPEED, AND RELIABILITY
3-3	Overview
3-4	Capacity Concepts
3-10	Speed Concepts
3-13	Reliability Concepts
3-15	3. PASSENGER DEMAND CHARACTERISTICS
3-15	Transit Passenger Demand Patterns
3-18	Demand Related to Demographics
3-18	Demand Related to Land Use
3-21	Demand Related to Transportation Demand Management Strategies
3-23	4. DWELL TIME
3-23	Definition
3-23	Dwell Time Components
3-24	Dwell Time Variability
3-24	Illustrative Impacts of Dwell Time on Capacity
3-27	Illustrative Impacts of Dwell Time on Speed
3-28	5. OPERATING ENVIRONMENT
3-28	Guideway Type and Design
3-29	Traffic and Transit Vehicle Effects
3-30	Illustrative Impacts of Operating Environment on Capacity
3-35	Illustrative Impacts of Operating Environment on Speed
3-37	Impact of Operating Environment on Reliability
3-38	6. STOP AND STATION CHARACTERISTICS
3-38	Vehicle–Platform Interface
3-38	Vehicle Characteristics
3-39	Fare Collection
3-39	Stop Spacing
3-39	Illustrative Impacts of Stops and Stations on Capacity
3-41	Illustrative Impacts of Stops and Stations on Speed
3-44	7. REFERENCES

### **4-i CHAPTER 4 Quality of Service Concepts**

4-1	1. INTRODUCTION
4-1	Overview
4-2	Roles of Transit
4-4	Performance Points of View
4-7	2. QUALITY OF SERVICE FACTORS
4-7	Customer Satisfaction Research
4-9	Value of Time Research
4-15	3. QUALITY OF SERVICE FRAMEWORK
4-15	Transit Trip Decision-Making Process
4-17	Framework Outline
4-17	Transit Availability
4-32	Transit Comfort and Convenience
4-37	4. QUALITY OF SERVICE, RIDERSHIP, AND SERVICE COSTS
4-37	Quality of Service and Ridership
4-40	Quality of Service and Service Costs

4-42	5. REFERENCES
4-48	APPENDIX A: EXHIBITS IN METRIC UNITS

**5-i CHAPTER 5 Quality of Service Methods**

5-1	1. INTRODUCTION
5-1	How to Use This Chapter
5-2	Other Resources
5-3	2. FIXED-ROUTE QUALITY OF SERVICE
5-3	Overview
5-3	Measures of Availability
5-22	Measures of Comfort and Convenience
5-39	Multimodal Level of Service
5-47	3. DEMAND-RESPONSIVE QUALITY OF SERVICE
5-47	Overview
5-47	Availability Measures
5-56	Comfort and Convenience Measures
5-71	4. APPLICATIONS
5-71	Comprehensive Planning
5-71	Long-Range Transportation Planning
5-75	Statewide Transportation Planning
5-75	Comprehensive Operational Analysis
5-76	Transit Development Plans
5-77	Service Planning
5-77	Corridor Planning
5-78	Demand-Responsive Transit Operations
5-79	5. CALCULATION EXAMPLES
5-79	Calculation Example 1: Service Coverage Analysis (Planning Level)
5-85	Calculation Example 2: Service Coverage Analysis (Detailed)
5-89	Calculation Example 3: Reliability
5-93	Calculation Example 4: Multimodal Transit LOS
5-101	6. REFERENCES

**6-i CHAPTER 6 Bus Transit Capacity**

6-1	1. INTRODUCTION
6-2	How to Use This Chapter
6-2	Other Resources
6-3	2. FUNDAMENTALS
6-3	Sources of Bus Delay
6-15	Factors Determining Bus Capacity
6-20	Planning-Level Capacity Values
6-24	3. PREFERENTIAL TREATMENTS
6-24	Overview
6-26	Busways and Freeway Managed Lanes
6-31	Urban Street Bus Lanes
6-40	Transit Signal Priority (TSP)
6-46	Site-Specific Priority Treatments
6-51	Summary
6-53	4. OPERATIONAL TOOLS
6-53	Overview
6-53	Bus Stop Placement
6-55	Bus Stopping Patterns

6-57	Route Design
6-58	Yield-to-Bus Laws
6-59	Summary
6-60	5. BUS CAPACITY METHODOLOGY
6-60	Introduction
6-61	Step 1: Define the Facility
6-61	Step 2: Gather Input Data
6-63	Step 3: Set a Design Bus Stop Failure Rate
6-66	Step 4: Determine Dwell Time
6-70	Step 5: Determine Loading Area Capacity
6-77	Step 6: Determine Bus Stop Capacity
6-80	Step 7: Determine Facility Bus Capacity
6-84	Step 8: Determine Facility Person Capacity
6-86	6. BUS SPEED METHODOLOGY
6-87	Step 1: Define the Facility
6-87	Step 2: Gather Input Data
6-87	Step 3: Determine Section Maximum Capacity
6-87	Step 4: Determine Base Bus Running Time Rate
6-91	Step 5: Adjust for Skip-Stop Operation
6-92	Step 6: Adjust for Bus Congestion
6-93	Step 7: Determine Average Section Speed
6-94	Step 8: Determine Average Facility Speed
6-95	7. BUS RELIABILITY
6-95	Factors Influencing Bus Reliability
6-96	Scheduling and Holding Strategies
6-96	Relationships of Service Characteristics to Reliability
6-97	Applications of AVL Data
6-97	Forecasting Reliability
6-98	8. APPLICATIONS
6-98	Alternative Mode, Facility, and Service Comparisons
6-98	Fare Collection Technology Changes
6-99	Assessing the Impact of Transit Preferential Treatments
6-100	Diagnosing and Treating Capacity Issues
6-100	Sizing BRT Facilities for a Given Demand
6-102	9. CALCULATION EXAMPLE
6-102	The Situation
6-102	The Question
6-103	Bus Capacity
6-110	Bus Speed
6-112	Options Assessment
6-119	Comments
6-120	10. REFERENCES
6-125	APPENDIX A: EXHIBITS IN METRIC UNITS
6-126	APPENDIX B: DWELL TIME DATA COLLECTION
6-126	Introduction
6-126	Passenger Service Times
6-127	Dwell Times
6-129	APPENDIX C: BUS BUNCHING AND PERSON CAPACITY
6-130	Reference

<b>7-i</b>	<b>CHAPTER 7 Demand-Responsive Transit</b>
7-1	1. INTRODUCTION
7-1	How to Use This Chapter
7-1	Other Resources
7-3	2. DRT CAPACITY
7-3	Capacity Factors
7-6	Capacity Calculation Procedures
7-8	Importance of Ridership Demand for Estimating DRT Capacity
7-10	3. REFERENCES

<b>8-i</b>	<b>CHAPTER 8 Rail Transit Capacity</b>
8-1	1. INTRODUCTION
8-1	How to Use This Chapter
8-2	Other Resources
8-3	2. RAIL CAPACITY FUNDAMENTALS
8-3	Overview
8-3	Line Capacity
8-9	Person Capacity
8-13	Design Capacity
8-15	Speed
8-16	Positive Train Control
8-16	Reliability
8-18	3. TRAIN CONTROL AND SIGNALING
8-18	Overview
8-18	Fixed-Block Systems
8-19	Cab Signaling
8-19	Moving-Block Systems
8-20	Hybrid Systems
8-21	Automatic Train Operation
8-21	Automatic Train Supervision
8-21	On-Street Preferential Treatments
8-24	4. TRAIN OPERATIONS
8-24	Overview
8-24	Doorway Flow Rates
8-27	Operating Margins
8-31	Skip-Stop and Express Operation
8-31	Passenger-Actuated Doors
8-32	Train and Platform Screen Doors
8-32	Fare Payment
8-33	Station and Platform Design
8-34	Wheelchair Accommodations
8-40	System Design
8-44	5. RAIL SYSTEM CAPACITY METHODOLOGIES
8-44	Introduction
8-44	General Methodology
8-67	Commuter Rail Capacity
8-75	Automated Guideway Transit Capacity
8-77	Ropeway Capacity
8-81	6. APPLICATIONS
8-81	Designing for Future Growth
8-81	Planning-Level Analysis

8-89	Transit Operations Planning
8-91	Role of Simulation
8-99	Application of Simulation
8-102	Sketch-Planning Tools
8-105	Best Practices for the Use of Simulation Models and Sketch-Planning Tools
8-108	7. CALCULATION EXAMPLES
8-108	Calculation Example 1: High-Capacity Heavy Rail
8-111	Calculation Example 2: Heavy Rail Line with Junction
8-112	Calculation Example 3: Heavy Rail with Long Dwell
8-115	Calculation Example 4: Light Rail with Single-Track Section
8-117	Calculation Example 5: Commuter Rail with Limited Train Paths
8-118	Calculation Example 6: AGT with Short Trains
8-119	Calculation Example 7: AGT with Off-Line Stations
8-120	Calculation Example 8: Aerial Ropeway
8-124	8. REFERENCES
8-126	APPENDIX A: EXHIBITS IN METRIC UNITS

## **9-i CHAPTER 9 Ferry Transit Capacity**

9-1	1. INTRODUCTION
9-1	How to Use This Chapter
9-2	Other Resources
9-3	2. FERRY SERVICE AND FACILITIES
9-3	Ferry Service
9-5	Ferry Terminals
9-14	3. FERRY SCHEDULING AND SERVICE PLANNING
9-14	Port Dwell Time
9-16	Departure Clearance Time
9-16	Transit Time
9-17	Arrival Time
9-17	Operating Margin
9-18	Pedestrian Movements
9-18	Service Planning
9-21	4. VESSEL CAPACITY
9-22	Berth Capacity
9-27	Dock Capacity
9-28	5. PASSENGER AND AUTO CAPACITY
9-30	6. CALCULATION EXAMPLES
9-30	Calculation Example 1: Vessel Service Time (Passengers)
9-32	Calculation Example 2: Vessel Service Time (Automobiles)
9-33	Calculation Example 3: Berth Capacity
9-35	7. REFERENCES

## **10-i CHAPTER 10 Station Capacity**

10-1	1. INTRODUCTION
10-1	Chapter Overview
10-1	How to Use This Chapter
10-2	Other Resources
10-2	Station Design Capacity
10-2	Access for Persons with Disabilities



10-3	Emergency Evacuation
10-4	Security
10-5	2. STATION TYPES AND CONFIGURATIONS
10-5	Overview
10-5	Bus Stops
10-6	Transit Centers
10-7	Busway and BRT Stations
10-8	Light Rail and Streetcar Stations
10-8	Heavy Rail and AGT Stations
10-9	Commuter Rail Stations
10-10	Ferry Docks and Terminals
10-10	Intermodal Terminals
10-10	Passenger Amenities in Stations
10-13	3. PASSENGER CIRCULATION
10-13	Introduction
10-13	Pedestrian Level of Service
10-15	Station Access
10-20	Horizontal Circulation
10-24	Vertical Circulation
10-29	Platforms and Waiting Areas
10-31	4. VEHICLE CIRCULATION AND STORAGE
10-31	Transit Vehicles
10-34	Private Vehicles
10-38	5. STATION ELEMENTS AND THEIR CAPACITIES
10-38	Introduction
10-39	Station Access
10-43	Horizontal Circulation
10-48	Vertical Circulation
10-55	Platforms and Waiting Areas
10-58	Interactions Between Station Elements
10-58	Alternative Performance Measures for Sizing Station Circulation Elements
10-62	6. APPLICATIONS
10-62	Alternative Mode and Alignment Comparisons
10-63	Alternative Station Location and Features Comparisons
10-63	Remodeling an Existing Station
10-64	Addressing a Specific Capacity Issue in an Existing Station
10-64	Comprehensive Analysis of Passenger Circulation
10-67	Pedestrian Microsimulation
10-73	7. CALCULATION EXAMPLES
10-73	Calculation Example 1: Suburban Transit Center Design
10-76	Calculation Example 2: Stairway Sizing
10-79	Calculation Example 3: Platform Sizing
10-81	Calculation Example 4: Escalator Queuing Area
10-83	Calculation Example 5: Multiple Pedestrian Activities in a Facility
10-85	Calculation Example 6: Complex Multilevel Station
10-88	Calculation Example 7: Application of Pedestrian Microsimulation Software
10-91	8. REFERENCES
10-94	APPENDIX A: EXHIBITS IN METRIC UNITS

**11-i CHAPTER 11** Glossary and Symbols

11-1	1. GLOSSARY
11-1	A
11-4	B
11-8	C
11-14	D
11-16	E
11-17	F
11-20	G
11-21	H
11-22	I
11-23	J
11-24	K
11-24	L
11-27	M
11-29	N
11-30	O
11-32	P
11-36	Q
11-36	R
11-40	S
11-47	T
11-56	U
11-58	V
11-59	W
11-59	Y
11-60	Z
11-61	2. LIST OF SYMBOLS

**12-1 CHAPTER 12** Index

*Abbreviations and acronyms used without definitions in TRB publications:*

A4A	Airlines for America
AAAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI-NA	Airports Council International-North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation