TRANSIT COOPERATIVE RESEARCH PROGRAM
Sponsored by the Federal Transit Administration

TCRP
REPORT 100

2nd Edition

Transit Capacity and Quality of Service
MANUAL

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TCRP OVERSIGHT AND PROJECT SELECTION COMMITTEE
(as of October 2003)

CHAIR
J. BARRY BARKER
Transit Authority of River City

MEMBERS
DANNY ALVAREZ
Miami-Dade Transit Agency
KAREN ANTION
Karen Antion Consulting
GORDON AOYAGI
Montgomery County Government
RONALD L. BARNES
Central Ohio Transit Authority
LINDA J. BOHLINGER
HNTB Corp.
ANDREW BONDS, JR.
Parsons Transportation Group, Inc.
JENNIFER L. DORN
FTA
NATHANIEL P. FORD, SR.
Metropolitan Atlanta RTA
CONSTANCE GARBER
York County Community Action Corp.
FRED M. GILLIAM
Capital Metropolitan Transportation Authority
KIM R. GREEN
GFI GENFARE
SHARON GREENE
Sharon Greene & Associates
ROBERT H. IRWIN
British Columbia Transit
CELIA G. KUPERSMITH
Golden Gate Bridge, Highway and Transportation District
PAUL J. LARROUSSE
National Transit Institute
DAVID A. LEE
Connecticut Transit
CLARENCE W. MARSELLA
Denver Regional Transportation District
FAYE L. M. MOORE
Southeastern Pennsylvania Transportation Authority
STEPHANIE L. PINSON
Gilbert Tweed Associates, Inc.
ROBERT H. PRINCE, JR.
DMJM+HARRIS
JEFFREY M. ROSENBERG
Amalgamated Transit Union
RICHARD J. SIMONETTA
pbConsult
PAUL P. SKOUTELAS
Port Authority of Allegheny County
LINDA S. WATSON
Corpus Christi RTA

EX OFFICIO MEMBERS
WILLIAM W. MILLAR
APTA
MARY E. PETERS
FHWA
JOHN C. HORSLEY
AASHTO
ROBERT E. SKINNER, JR.
TRB

TDC EXECUTIVE DIRECTOR
LOUIS F. SANDERS
APTA

SECRETARY
ROBERT J. REILLY
TRB

TRANSPORTATION RESEARCH BOARD EXECUTIVE COMMITTEE 2003 (Membership as of October 2003)

OFFICERS

Chair: *Genevieve Giuliano, Director, Metrans Transportation Center, and Professor, School of Policy, Planning, and Development, USC, Los Angeles*
Vice Chair: *Michael S. Townes, President and CEO, Hampton Roads Transit, Hampton, VA*
Executive Director: *Robert E. Skinner, Jr., Transportation Research Board*

MEMBERS

MICHAEL W. BEHRENS, *Executive Director, Texas DOT*
JOSEPH H. BOARDMAN, *Commissioner, New York State DOT*
SARAH C. CAMPBELL, *President, TransManagement, Inc., Washington, DC*
E. DEAN CARLSON, *President, Carlson Associates, Topeka, KS*
JOANNE F. CASEY, *President and CEO, Intermodal Association of North America*
JAMES C. CODELL III, *Secretary, Kentucky Transportation Cabinet*
JOHN L. CRAIG, *Director, Nebraska Department of Roads*
BERNARD S. GROSECLOSE, JR., *President and CEO, South Carolina State Ports Authority*
SUSAN HANSON, *Landry University Prof. of Geography, Graduate School of Geography, Clark University*
LESTER A. HOEL, *L. A. Lacy Distinguished Professor of Engineering, Depart. of Civil Engineering, University of Virginia*
HENRY L. HUNGERBEELER, *Director, Missouri DOT*
ADIB K. KANAFANI, *Cahill Prof. and Chair, Dept. of Civil and Environmental Engineering, University of California at Berkeley*
RONALD F. KIRBY, *Director of Transportation Planning, Metropolitan Washington Council of Governments*
HERBERT S. LEVINSON, *Principal, Herbert S. Levinson Transportation Consultant, New Haven, CT*
MICHAEL D. MEYER, *Professor, School of Civil and Environmental Engineering, Georgia Institute of Technology*
JEFF P. MORALES, *Director of Transportation, California DOT*
KAM MOVASSAGHI, *Secretary of Transportation, Louisiana Department of Transportation and Development*
CAROL A. MURRAY, *Commissioner, New Hampshire DOT*
DAVID PLAVIN, *President, Airports Council International, Washington, DC*
JOHN REBENSDORF, *Vice Pres., Network and Service Planning, Union Pacific Railroad Co., Omaha, NE*
CATHERINE L. ROSS, *Harry West Chair of Quality Growth and Regional Development, College of Architecture, Georgia Institute of Technology*
JOHN M. SAMUELS, *Sr. Vice Pres., Operations, Planning and Support, Norfolk Southern Corporation, Norfolk, VA*
PAUL P. SKOUTELAS, *CEO, Port Authority of Allegheny County, Pittsburgh, PA*
MARTIN WACHS, *Director, Institute of Transportation Studies, University of California at Berkeley*
MICHAEL W. WICKHAM, *Chairman, Roadway Corporation, Akron, OH*

EX OFFICIO MEMBERS

MARION C. BLAKEY, *Federal Aviation Administrator, U.S.DOT*
SAMUEL G. BONASSO, *Acting Administrator, Research and Special Programs Administration, U.S.DOT*
REBECCA M. BREWSTER, *President and COO, American Transportation Research Institute, Smyrna, GA*
GEORGE BUGLIARELLO, *Foreign Secretary, National Academy of Engineering*
THOMAS H. COLLINS (Adm., U.S. Coast Guard), *Commandant, U.S. Coast Guard*
JENNIFER L. DORN, *Federal Transit Administrator, U.S.DOT*
ROBERT B. FLOWERS (Lt. Gen., U.S. Army), *Chief of Engineers and Commander, U.S. Army Corps of Engineers*
EDWARD R. HAMBERGER, *President and CEO, Association of American Railroads*
JOHN C. HORSLEY, *Exec. Dir., American Association of State Highway and Transportation Officials*
ROGER L. KING, *Chief Applications Technologist, National Aeronautics and Space Administration*
ROBERT S. KIRK, *Director, Office of Advanced Automotive Technologies, U.S. DOE*
RICK KOWALEWSKI, *Acting Director, Bureau of Transportation Statistics, U.S.DOT*
WILLIAM W. MILLAR, *President, American Public Transportation Association*
MARY E. PETERS, *Federal Highway Administrator, U.S.DOT*
SUZANNE RUDZINSKI, *Director, Transportation and Regional Programs, U.S. EPA*
JEFFREY W. RUNGE, *National Highway Traffic Safety Administrator, U.S.DOT*
ALLAN RUTTER, *Federal Railroad Administrator, U.S.DOT*
ANNETTE M. SANDBERG, *Federal Motor Carrier Safety Administrator, U.S.DOT*
WILLIAM G. SCHUBERT, *Maritime Administrator, U.S.DOT*

TRANSIT COOPERATIVE RESEARCH PROGRAM

Transportation Research Board Executive Committee Subcommittee for TCRP

GENEVIEVE GIULIANO, *University of Southern California, Los Angeles* (Chair)
E. DEAN CARLSON, *Carlson Associates, Topeka, KS*
JENNIFER L. DORN, *Federal Transit Administration, U.S.DOT*
LESTER A. HOEL, *University of Virginia*
WILLIAM W. MILLAR, *American Public Transportation Association*
ROBERT E. SKINNER, JR., *Transportation Research Board*
PAUL P. SKOUTELAS, *Port Authority of Allegheny County, Pittsburgh, PA*
MICHAEL S. TOWNES, *Hampton Roads Transit, Hampton, VA*

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
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
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 100

Transit Capacity and Quality of Service Manual

2nd Edition

KITTELSON & ASSOCIATES, INC.
Orlando, FL

KFH GROUP, INC.
Bethesda, MD

PARSONS BRINCKERHOFF QUADE & DOUGLASS, INC.
New York, NY

DR. KATHERINE HUNTER-ZAWORSKI
Corvallis, OR

SUBJECT AREAS
Planning and Administration • Public Transit • Rail • Marine Transportation

Research Sponsored by the Federal Transit Administration in Cooperation with the Transit Development Corporation

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2003
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 100

Project A-15A   FY'99
ISSN 1073-4872
ISBN 0-309-08776-7
Library of Congress Control Number 2003113861

Price $45.00

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. Such approval reflects the Governing Board's judgment that the project concerned is appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Special Notice

The Transportation Research Board of The National Academies, the National Research Council, the Transit Development Corporation, and the Federal Transit Administration (sponsor 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 clarity and completeness of the project reporting.

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. Bruce M. Alberts 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. William A. Wulf 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 the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is a division of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation through research. In an objective and interdisciplinary setting, the Board facilitates the sharing of information on transportation practice and policy by researchers and practitioners; stimulates research and offers research management services that promote technical excellence; provides expert advice on transportation policy and programs; and disseminates research results broadly and encourages their implementation. The Board's varied activities annually engage more than 4,000 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**

www.national-academies.org

CONTENTS

Part 1: Introduction and Concepts

Part 2: Transit in North America

Part 3: Quality of Service

Part 4: Bus Transit Capacity

Part 5: Rail Transit Capacity

Part 6: Ferry Capacity

Part 7: Stop, Station, and Terminal Capacity

Part 8: Glossary

Part 9: Index

FOREWORD TO THE SECOND EDITION

The *Transit Capacity and Quality of Service Manual* (TCQSM) is intended to be a fundamental reference document for public transit practitioners and policy makers. The manual contains background, statistics, and graphics on the various types of public transportation, and it provides a framework for measuring transit availability and quality of service from the passenger point of view. The manual contains quantitative techniques for calculating the capacity of bus, rail, and ferry transit services, and transit stops, stations, and terminals. Example problems are included.

Material from this document that is relevant to traffic engineering is also included in Chapters 14, "Transit Concepts," and Chapter 27, "Transit," of the *Highway Capacity Manual 2000,* which is available from TRB in printed and CD-ROM versions.

Until the publication of *TCRP Web Document 6: Transit Capacity and Quality of Service Manual,* First Edition, the transportation profession lacked a consolidated set of transit capacity and quality of service definitions, principles, practices, and procedures for planning, designing, and operating vehicles and facilities. This is in contrast to the highway mode, where the *Highway Capacity Manual* (HCM) defines quality of service and presents fundamental information and computational techniques related to quality of service and capacity of highway facilities. The HCM also provides a focal point and structure for advancing the state of knowledge. It is anticipated that the TCQSM will provide similar benefits.

"Transit capacity" is a multifaceted concept that deals with the movement of people and vehicles; depends on the size of the transit vehicles and how often they operate; and reflects the interaction between passenger traffic and vehicle flow. "Quality of service" is an even more complex concept that must reflect a transit user's perspective and must measure how a transit route, service, facility, or system is operating under various demand, supply, and control conditions.

The First Edition of the TCQSM was developed under TCRP Project A-15, conducted by a team led by Kittelson & Associates, Inc. This project (a) included market research on what potential users would like to see in a TCQSM, (b) assembled and edited existing information on transit capacity, and (c) provided results of original research on measuring transit quality of service. The First Edition, released in 1999, introduced an "A" to "F" classification framework for measuring transit availability and comfort/convenience at transit stops, along transit routes, and for transit systems as a whole.

A team led by Kittelson & Associates, Inc. addressed gaps in the First Edition by executing the following tasks:

- Arranging for transit agencies, metropolitan planning organizations, and others to apply and evaluate, in their own environments, the quality of service concepts and thresholds. In addition, comments from others who independently applied the quality of service framework were solicited and reviewed.
- Soliciting and analyzing comments on the First Edition, through an Internet site and other forums, and coordinating with the TRB Task Force on Transit Capacity and Quality of Service (A1E53).
- Supplementing the material in the First Edition to more thoroughly address quality of service and capacity implications of service for persons with disabilities.

- Identifying updated passenger service time information available from the literature and from industry sources.
- Reviewing the weaknesses of the "transit-supportive-area-served" measure of service coverage, and suggesting improvements to the measure.
- Creating an alphabetized index of the First Edition.

Based on the results of these tasks, a plan was developed for additional research needed to address identified gaps and to produce this Second Edition. This plan included the following tasks:

- Identifying the effects of transit preferential treatments on bus operations.
- Developing a pedestrian accessibility factor to be incorporated into the service-coverage measure.
- Developing passenger service times for low-floor light-rail vehicles and buses accepting multiple fare media.
- Performing an assessment of the standards by which on-time performance achievements are measured by transit agencies.
- Quantifying the contribution of park-and-ride lots to transit access.

Several significant structural changes have been made to the TCQSM between the First and Second Editions. Most notably, the part on quality of service has been moved in front of the capacity parts to reflect user interest in this section and the importance of quality of service to successful transit services. Demand-responsive transit quality of service has been given a chapter of its own, with measures entirely separate from fixed-route transit.

"Planning Applications" chapters have been added to the bus- and rail-transit capacity chapters, and an entirely new part on ferry capacity has been added.

Other major changes include expanded sections on transit-priority treatments, bus rapid transit, and commuter-rail capacity; and a new section on ropeway (e.g., aerial tramway, funicular, and cable-hauled people-mover) capacity. Also, the stop, station, and terminal capacity part has been expanded to address system interactions of different station elements and the sizing of station facilities to accommodate certain "event" conditions.

TRB has established a Committee on Transit Capacity and Quality of Service that will be responsible for guiding the long-term development and evolution of this manual.

AUTHOR ACKNOWLEDGMENTS

The Second Edition of the TCQSM was developed under TCRP Project A-15A. The TCRP Project A-15A team consisted of Kittelson & Associates, Inc. (prime contractor), assisted by KFH Group, Inc., Parsons Brinckerhoff Quade & Douglas, Inc., and Dr. Katherine Hunter-Zaworski.

Alan Danaher, P.E., PTOE, AICP, Senior Principal, Kittelson & Associates, Inc., was the principal investigator. Co-investigators were Paul Ryus, P.E., Associate Engineer, Kittelson & Associates, Inc.; Elizabeth (Buffy) Ellis, AICP, Senior Transportation Planner, KFH Group, Inc.; Mark C. Walker, Senior Planner, Parsons Brinckerhoff Quade & Douglas, Inc.; and Dr. Katherine Hunter-Zaworski, Assistant Professor, Oregon State University.

Part 1, Introduction and Concepts, was developed for the Second Edition by Alan Danaher.

Part 2, Transit in North America, was originally written for the First Edition by Tom Parkinson, P. Eng., President, Transport Consulting Limited, and was edited and expanded for the Second Edition by Paul Ryus. Updated transit statistics were compiled by Helen Donoway, Jessica Wineberg, and Kelly Blume of Kittelson & Associates, Inc.

Part 3, Quality of Service, was originally written for the First Edition by Paul Ryus, with contributions from Tom Parkinson, and was updated by Paul Ryus for the Second Edition. Buffy Ellis led the development of Chapter 4 on demand-responsive transit quality of service. Peter Haliburton, Pr. Eng. of Kittelson & Associates, Inc., led the development of the detailed service coverage factors, and Miranda Blogg, Ph.D., of Kittelson & Associates, Inc., led the development of the park-and-ride service coverage material.

Part 4, Bus Transit Capacity, was originally written for the First Edition by Paul Ryus and updated by him for the Second Edition. The material in the First Edition was developed from a number of sources, particularly Chapter 12 (Transit) of the 1985, 1994, and 1997 editions of the *Highway Capacity Manual,* authored by Herbert S. Levinson. Timothy Lomax and Bill Eisele of the Texas Transportation Institute contributed to Chapter 4 (Busways and Freeway HOV Lanes). Chapter 5 (Arterial Street Bus Lanes) is a condensed version of research developed by Kevin St. Jacques of Wilbur Smith Associates, Inc., and Herbert S. Levinson that is presented in *TCRP Report 26* and *TCRP Research Results Digest 38*. Appendix B (Dwell Time Data Collection Procedure) was authored by Lewis Nowlin, Assistant Research Scientist, Texas Transportation Institute. Peter Haliburton also contributed material to the First Edition. Peter Koonce, P.E., Kittelson & Associates, Inc., added material on transit preferential treatments for the Second Edition, and Judith Gray and Kelly Blume, Kittelson & Associates, Inc., updated passenger service time information.

Part 5, Rail Transit Capacity, was originally written for the First Edition by Tom Parkinson, with the assistance of Ian Fisher, based on their prior work presented in *TCRP Report 13*. Paul Ryus edited the material for the Second Edition, expanded the Commuter Rail Capacity chapter, and added the Ropeway Capacity chapter.

Part 6, Ferry Capacity, was developed for the Second Edition by Miranda Blogg.

Part 7, Stop, Station, and Terminal Capacity, was originally written for the First Edition by Alan Danaher and updated by Mark C. Walker for the Second Edition. A major source for Part 7 was *Pedestrian Planning and Design,* by John Fruin. Lewis Nowlin and Daniel Fambro of Texas A&M University also contributed to this part in the First Edition.

Part 8, Glossary, was compiled from a number of sources for the First 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 APTA web site 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. Kelly Blume updated the glossary for the Second Edition.

Part 9, Index, was developed for the Second Edition by Kelly Blume.

Katherine Hunter-Zaworski provided input throughout the TCQSM on addressing capacity and quality of service issues for persons with disabilities and on Americans with Disabilities Act (ADA) regulations.

Wayne Kittelson, P.E., Senior Principal, Kittelson & Associates, Inc., reviewed the First and Second Editions; John Zegeer, P.E., Principal, Kittelson & Associates, Inc., also reviewed the First Edition.

The project team would particularly like to thank the agencies and staff who volunteered to apply and comment on the First Edition's quality of service framework. Their assistance and input was invaluable in helping to shape the version of the framework appearing in the Second Edition. Participants included

- *Chicago:* Regional Transportation Authority—Mary Lupa; Chicago Transit Authority—Kenneth E. Dallmeyer and Catherine V. Quinn; Metra—Dana Long, A. Christopher Wilson, and Gary Foyle; PACE—Brad Thompson and Dick Brazda; and Chicago Area Transportation Study—Mark Thomas.
- *Albuquerque:* SunTran—Bill Slauson.
- *Gainesville, Florida:* City of Gainesville—Linda Dixon; Regional Transit System—Jesus Gomez and Maria Savoia; North Central Florida Regional Planning Council—Marlie Sanderson, Gerry Dedenbach, and Lynn Franson-Godfrey; and University of Florida—Linda Crider.
- *Northwest Missouri:* OATS—Mike Landy and Linda Yaeger.

In addition, several organizations independently applied the quality of service framework and provided feedback to the project team. These included Tara Bartee and Ike Ubaka of the Florida Department of Transportation Public Transit Office, who sponsored statewide evaluations; Victoria Perk of the Center for Urban Transportation Research, who conducted follow-up analyses and interviews associated with the Florida statewide evaluation; Lucie Ayer, AICP and Beth Malaby, AICP of the Hillsborough County Metropolitan Planning Organization and Diana Carsey of Hartline, who applied the framework in Tampa; and Brett Wallace, Wilbur Smith Associates, Inc., who applied the framework in Birmingham, Alabama.

Thomas W. Kowalski, President/CEO of Urban Transportation Associates, Inc., and Steve Callas of TriMet provided automatic vehicle location data used to test the reliability service measures.

The New York MTA Office of the Inspector General provided suggestions incorporated into the Second Edition: Iris Berman provided input used to update the passenger loading service measure and Gary Henderson provided input on the effects of bus bunching on capacity. Lawrence F. Hughes, AICP, of Varsity Transit, provided feedback used to update the passenger loading and headway adherence service measures.

The Institute of Transportation Engineers student chapters at Morgan State University, the University of South Florida, and the University of Maryland collected data in Baltimore, Tampa, and Washington, D.C., respectively, to update bus fare collection service times. Fare collection service time data were collected in Portland, Oregon, by Dave Vest, Erin Ray, Elisa Leverton, Mollie Uselman, and Monica Leal. The American Society of Civil Engineers student chapter at the University of Portland collected data to update low-floor light-rail boarding and alighting times.

Ralph Bentley of Kittelson & Associates, Inc., developed much of the graphic art used in the TCQSM and Ben Worsley developed the CD-ROM's introductory page.

Finally, the project team would like to express its appreciation for the dedicated work of the TCRP Project A-15/A-15A panel. The majority of the panel members, who are listed elsewhere in this front section, have been involved with the development and oversight of both editions of the TCQSM throughout a 6-year period. The panel provided many thoughtful comments that have helped shape the current form of the manual. The guidance provided by the TCRP Program Officers for the First and Second Editions, Stephen J. Andrle and S.A. Parker, respectively, is also greatly appreciated.

All web addresses provided in the TCQSM were current at the time this report was produced, but are subject to change.

Internet addresses are subject to change.

COOPERATIVE RESEARCH PROGRAMS STAFF FOR TCRP REPORT 100

ROBERT J. REILLY, *Director, Cooperative Research Programs*
CHRISTOPHER W. JENKS, *TCRP Manager*
S.A. PARKER, *Senior Program Officer*
EILEEN P. DELANEY, *Managing Editor*
KAMI CABRAL, *Associate Editor*

TCRP PROJECT A-15A PANEL

MICHAEL S. TOWNES, *Peninsula Transportation District Commission* (Chair)
TARA BARTEE, *Florida DOT*
ALFRED H. HARF, *Potomac and Rappahannock Transportation Commission*
WOLFGANG S. HOMBURGER, *Consultant*
HERBERT S. LEVINSON, *Herbert S. Levinson Transportation Consultants*
FRANKLIN L. SPIELBERG, *SG Associates, Inc.*
JACK M. REILLY, *Capital District Transportation Authority*
STAN TEPLY, *University of Alberta*
JOEL WASHINGTON, *FTA Liaison Representative*
RICHARD A. CUNARD, *TRB Liaison Representative*

PHOTO CREDITS

BC Ferries: Exhibit 6-1b

Kelly Blume: Exhibits 2-30c, 3-7c, 5-69c

Alan Danaher: Exhibit 7-30c

Jeff Dunning: Exhibit 2-12g

Edmonton Transit System: Exhibit 2-12b

Federal Highway Administration/Parsons Brinckerhoff "HOV Interactive 1.0": Exhibits 2-8, 2-9b, 4-20, 4-21bc, 4-46, 4-48e, 7-13c, 7-29b

http://ops.fhwa.dot.gov/Travel/traffic/hov/

Federal Transit Administration: Exhibit 4-24a

Ian Fisher: Exhibit 2-13b

Rory Giles/Queensland University of Technology: Exhibits 4-44, 4-45b, 7-28c

Peter Haliburton: Exhibit 2-7c

Justin Jahnke: Exhibit 4-45a

Nathan Kendall/Squaw Valley Ski Corp.: Exhibit 2-36d

Peter Koonce: Exhibits 4-23a, 4-28c, 4-29b

Patrick Monsere: Exhibit 2-36c

Tom Parkinson: Exhibits 2-7a, 2-30a, 5-18, 5-32a, 5-79

Lee Rodegerdts: Exhibits 2-12f, 2-34bd, 2-38b, 2-39h, 5-39b, 5-67b, 5-70b, 7-10b, 7-15b, 7-26e, 7-30b

Paul Ryus: Exhibits 2-7b, 2-9acd, 2-10, 2-12acdeh, 2-13a, 2-19, 2-23, 2-27, 2-30bd, 2-33, 2-34acf, 2-36ab, 2-38a, 2-39acdefg, 2-41, 3-7abd, 4-4, 4-19, 4-23b, 4-24b, 4-28b, 4-29c, 4-30bc, 4-31, 4-32, 4-48abcdf, 4-49, 4-61, 5-3, 5-30, 5-31, 5-32b, 5-33, 5-37, 5-38, 5-39a, 5-67a, 5-68, 5-69abd, 5-70a, 5-73, 6-1acd, 6-3, 6-5, 6-7, 6-9abef, 7-10a, 7-13abd, 7-15a, 7-18, 7-19, 7-21, 7-22, 7-23, 7-25, 7-26abcdf, 7-28abdef, 7-29a, 7-30a

Chris Stanley: Exhibit 2-34e

TransLink: Exhibits 2-7d, 2-39b, 6-9cd

NJ Transit cover photo courtesy of *Rail Magazine*, bogren@ctaa.org

This page is intentionally blank.

PART 1
INTRODUCTION AND CONCEPTS

CONTENTS

LIST OF EXHIBITS

CHAPTER 1. INTRODUCTION

PURPOSE OF THE MANUAL

The *Transit Capacity and Quality of Service Manual* (TCQSM) provides transportation practitioners with a consistent set of techniques for evaluating the quality of service and capacity of transit services, facilities, and systems. The TCQSM does not set policies regarding a desirable or appropriate quality of service or capacity related to such transit elements. The manual's objectives include providing a logical set of methods for assessing transit services, facilities, and systems; assuring that practitioners have access to the latest research results; and presenting example problems illustrating the application of different procedures. The TCQSM is the primary source document incorporating research findings on transit capacity and quality of service. A companion document, the *Highway Capacity Manual 2000*, presents methods for evaluating the quality of service of roadway, pedestrian, and bicycle facilities.

SCOPE OF THE MANUAL

This manual is divided into nine parts:

- Part 1, *Introduction and Concepts,* summarizes the content and intended application of the manual and presents an overview of transit quality of service and capacity concepts.
- Part 2, *Transit in North America,* presents an overview of the various transit modes, services, and facilities provided in the United States and Canada.
- Part 3, *Quality of Service,* describes the factors that influence passengers' perceptions of their quality of travel on transit and provides quantitative methods for evaluating these factors.
- Part 4, *Bus Transit Capacity,* provides procedures for evaluating bus loading area (berth), stop, and facility (including busway, freeway high occupancy vehicle lane, arterial street bus lane, and mixed traffic lane) capacity.
- Part 5, *Rail Transit Capacity,* provides both generalized and more detailed procedures for evaluating the capacity of heavy rail (rapid) transit, light rail, commuter rail, automated guideway transit, and ropeways.
- Part 6, *Ferry Capacity,* addresses the capacity of passenger and auto ferries, focusing particularly on potential constraints at the dock.
- Part 7, *Stop, Station, and Terminal Capacity,* provides procedures to evaluate the capacity of and design passenger comfort level for various elements of bus stops, transit centers, transit stations, intermodal terminals, and similar facilities.
- Part 8, *Glossary,* presents a comprehensive glossary of terms used in the transit industry.
- Part 9, *Index,* provides an overall index to the TCQSM.

Quality of service focuses on the passenger point of view.

Capacity addresses the number of people and/or transit vehicles that can be served consistently in a given amount of time.

USE OF THE MANUAL

The TCQSM is 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. To use the manual effectively and to apply its methodologies, some technical background is desirable, typically university-level training or technical work in a public agency or consulting firm.

The material from this document that is relevant to traffic engineers is also included in Chapter 14, "Transit Concepts," and Chapter 27, "Transit," of the *Highway Capacity Manual 2000,* which is available from TRB in printed and CD-ROM versions.

The quality of service section of the manual is intended to provide a comprehensive look at transit quality of service from a passenger's point-of-view, and a set of performance measures are provided. These measures can be applied to assess existing and projected quality of service as an aid in identifying transit service, facility, and system performance and improvement needs.

Level of service used to quantify quality of service.

The TCQSM uses the concept of *level of service* (LOS) to quantify quality of service. LOS is used for two main reasons: to ease the explanation of transit service quality concepts to laypeople and for consistency with how other modes already measure quality of service. Fixed-route transit LOS is based on an "A" (highest quality) through "F" (lowest quality) system similar to, but not exactly the same as, letter grades in school. Because of fundamental differences both between fixed-route and demand-responsive services, and among different types of demand-responsive service, a 1 through 8 scale is used to describe demand-responsive LOS.

The TCQSM provides guidance and not standards.

LOS standards are not identified in this manual, because individual agencies develop these related to their individual system and area characteristics. The TCQSM is not intended to set a national standard regarding the amount or level of service that should be provided for a given situation. In recognition of the fact that LOS may not be appropriate for all applications, the TCQSM also discusses alternative ways of measuring transit quality of service.

The capacity sections of the manual provide both planning and more detailed operations analysis procedures for assessing capacity for bus, rail, and ferry transit modes, and transit stops, stations, and terminals. A building-block approach to capacity analysis is presented, initially addressing the capacity characteristics of individual transit stops and station components, and then expansion of the concepts to address the capacity of broader transit services, facilities, and systems. The estimation of transit ridership in sizing transit services and facilities is not addressed in the manual.

The TCQSM does not address ridership estimation.

MEASUREMENT UNITS

This edition of the TCQSM has been published in dual units, U.S. customary and metric. U.S. customary units are presented as the primary units, with metric units as supplemental units.

NORTH AMERICAN AND INTERNATIONAL APPLICATIONS

Unless otherwise specified, "North America" in the TCQSM refers to the United States and Canada.

In producing the TCQSM with metric units, TRB has taken a step toward making these methods and procedures more applicable to international work. However, the user of the manual is cautioned that the majority of the research base, the default values, and the typical applications are from North America, particularly the United States. Although there is considerable value in the general methods presented, their use outside of North America will likely require calibrating the procedures to local conditions, particularly in regard to user expectations of service quality. International users should also recognize major differences in the composition of traffic in on-street, mixed-traffic transit operations, and in typical geometrics and passenger processing measures.

TCQSM MEDIA

The TCQSM is provided in two forms: a printed document and an electronic version available on an accompanying CD-ROM or by downloading from the TCRP online publications website. The electronic version is hyperlinked, allowing users to jump immediately to related material within the manual. In addition, the references section of each part of the manual contains links to other related documents available on the Internet at the time the TCQSM was published.

Internet links are subject to change.

Calculation Software

The accompanying CD-ROM provides Microsoft® Excel spreadsheets that assist with the rail transit capacity procedures. In addition, spreadsheets have been provided that were used to develop the planning graphs presented in Part 4, Bus Transit Capacity. **Neither TRB nor the project team that developed the TCQSM provides support for these spreadsheets.**

For the other sections of the TCQSM, no software is provided to replicate the quality of service or capacity procedures; however, in most cases, the procedures can be worked out by hand or with the assistance of a spreadsheet. Over time, vendors may develop software packages to implement the TCQSM procedures, but TRB does not produce, review, or endorse any such software.

Other Reference Material on the CD-ROM

The accompanying CD-ROM also contains a library of related TCRP documents on transit capacity and quality of service. The introductory screen on the CD lists all of the documents that are included.

TYPOGRAPHIC CONVENTIONS

The following conventions are used in this manual:

Margin notes look like this.

- Margin notes are used to highlight certain points and to facilitate finding specific topics within a particular section.
- Blue underlined text indicates hyperlinks in the electronic version of the TCQSM.
- References are indicated by the letter "R" and a number, like this.(R1) Clicking on these numbers in the electronic version of the TCQSM takes the reader to the appropriate reference. Once there, clicking on the hyperlink provided below the reference (if available) opens a copy of that document, assuming that the document is still located on the Internet and in the same location as when the TCQSM was developed. Each part is treated as a separate document; therefore, the references cited in the text refer to the reference list at the end of each part. For example, (R1) in Part 2 refers to the references at the end of Part 2 and (R1) in Part 5 refers to the references at the end of Part 5.

Equation numbers, exhibit numbers, and appendices in text refer to the specific part they are used in (e.g., Exhibit 3-1). Clicking on an equation number or exhibit number reference in the electronic version of the TCQSM takes the reader to that equation or exhibit.

WHAT'S NEW IN THE SECOND EDITION

This Second Edition of the TCQSM represents a reorganization and expansion of material presented in the First Edition. A total of nine parts have been prepared, with a total of 43 chapters. The changes to the TCQSM are summarized below.

Part 1: Introduction and Concepts

Part 1 has been reorganized to include an overview of the content and application of the TCQSM. In addition, the overview of transit quality of service and capacity concepts has been expanded.

Part 2: Transit in North America

Part 2 has been formatted to focus on North American transit applications, with the quality of service and capacity concept discussions moved to Part 1. Transit mode statistics have been updated whenever data were available, including using the most recent National Transit Database information.

Part 3: Quality of Service

Quality of service has been moved in front of capacity in the Second Edition of the TCQSM to reflect user interest in this concept and the importance of quality of service related to all transit services. Part 3 includes an expanded quality of service discussion that provides a new framework for demand-responsive transit. This new framework—which describes quality of service on a "1" through "8" scale—was developed to better reflect the fundamental differences between the fixed-route and demand-responsive transit modes. The fixed-route quality of service framework presented in the First Edition has been retained, but enhancements and/or adjustments have been made to most of the measures.

Part 4: Bus Transit Capacity

Two significant additions to the Bus Transit Capacity part have been made. The first is a new "Planning Applications" chapter that, through the use of default values and graphs, allows users to quickly evaluate capacity issues related to broader planning applications. The second is the incorporation of research from TCRP Project A-7A that refines the arterial street bus lane speed estimation techniques.

Other enhancements to Part 4 include expanded sections on transit signal priority and bus rapid transit, given the increased application of these treatments to facilitate bus operations. The transit priority treatment discussion includes a presentation of the effects of different treatments on travel time and delay to both transit and general traffic.

Part 5: Rail Transit Capacity

Part 5 provides rail transit capacity analysis procedures. In addition to a new "Planning Applications" chapter, this entire part was rewritten to better flow with the rest of the TCQSM, as this part in the First Edition was developed by extracting material directly from the previous *TCRP Report 13*(R5) document on rail transit capacity.

Other enhancements in this part include a new section on ropeway capacity. Ropeways are defined as including aerial tramways, funiculars, and cable-hauled people movers. The commuter rail capacity section has also been expanded. Finally, the heavy rail, light rail, and commuter rail route statistics for lines in North America were updated to reflect the latest route development and ridership statistics, based on a survey of agencies providing these services.

Part 6: Ferry Capacity

For the first time, passenger and auto ferry capacity is addressed in the TCQSM. This part initially discusses different types of ferry services, vehicles, and docking/terminal facilities. This is followed by an assessment of how berth and dock capacity impact vessel capacity and how overall passenger and auto capacity on ferry routes may be calculated. As with other parts of the manual, example problems illustrating the ferry capacity analysis procedures are included.

Part 7: Stop, Station, and Terminal Capacity

Part 7 now focuses on an expanded discussion of stop, station, and terminal capacity, the title reflecting consideration of analysis procedures related to different types of transit facilities. Major enhancements to this part include a broader discussion of the relationship of different passenger processing elements in larger stations and terminals in impacting overall facility capacity, and discussions about sizing station facilities to address passenger demands, ADA requirements, and emergency evacuation requirements.

Part 8: Glossary

Part 8 includes an expanded glossary of terms from that presented in the First Edition, with more than 2,000 terms defined.

Part 9: Index

Part 9 includes a comprehensive alphabetical index of terms used in the manual.

FUTURE UPDATES

In future years, other updates of the TCQSM will likely occur as research is conducted and new concepts and analytical procedures to assess transit capacity and quality of service are developed. The new TRB Committee on Transit Capacity and Quality of Service will take a leadership role in identifying research priorities and in helping shape further updates of the manual and the application of the document by the user community.

The committee welcomes user feedback on the TCQSM and has established a web site to solicit comments and suggestions that will be used to guide future editions of the manual.

http://webboard.trb.org/~tcqsm

This page is intentionally blank.

CHAPTER 2. QUALITY OF SERVICE CONCEPTS

INTRODUCTION

Quality of service is defined as follows:

Quality of service defined.

> "The overall measured or perceived performance of transit service from the passenger's point of view."

While transit capacity issues are mainly concentrated in larger cities, transit quality of service is important to all communities. Transit quality of service measures reflect two important aspects of transit service: (1) the degree to which transit service is *available* to given locations and (2) the *comfort and convenience* of the service provided to passengers. Quality of service measures differ from both traditional highway service quality measures, which are more vehicle-oriented than person-oriented, and from the numerous utilization and economic performance measures routinely collected by the transit industry, which tend to reflect the transit operator's point-of-view.

TRANSIT PERFORMANCE MEASUREMENT

Performance measurement points of view.

Many of the performance measures used in the transit industry—particularly those collected for the National Transit Database—reflect the business aspects of running a transit agency. The measures traditionally used by transportation engineers and planners for roadway design and planning, such as those given in the *Highway Capacity Manual,* reflect conditions experienced by vehicles using those roadways, but not necessarily the conditions experienced by persons in those vehicles, particularly when those vehicles are transit vehicles carrying a number of passengers. An emerging area of transit performance measurement is the impact that transit has on the community it serves, in terms of jobs created or supported, property value increases resulting from investments in transit service, reductions in pollution or congestion, and so on.

The TCQSM focuses on measures that reflect the quality of the service provided to transit passengers. These measures reflect the kinds of decisions potential passengers make, consciously or not, when deciding whether to use transit or another mode, usually the private automobile. *TCRP Report 88* defines five categories of measures that wholly or partially reflect the passenger's point-of-view:(R4)

- *Availability*: how easily passengers can access and use transit service;
- *Service Monitoring*: measures of passengers' day-to-day experiences using transit;
- *Travel Time*: how long it takes to make a trip;
- *Safety and Security*: real and perceived chances of being involved in an accident (safety) or being the victim of a crime (security) while using transit; and
- *Maintenance and Construction*: impacts of maintenance program quality and construction activity on passenger trips.

Of these categories, *availability* is the most important, because it determines whether or not transit is even a potential mode choice, regardless of the quality of the trip. Unlike the automobile mode, which has near-universal access to locations, and (for those who have access to an automobile) provides the ability to be used for trips at any desired time, transit service is limited to specific areas and specific times. Further, transit service is usually not available to one's door, so a potential transit passenger must find a way to get to a location served by transit.

Comfort and convenience includes measures from all of the remaining categories, but concentrates on measures in two categories—service monitoring and travel time—that research indicates are both highly important to passengers and relatively easily quantified. Safety and security, while very important to customers, is based as much on perception as on actual circumstances, and thus is difficult to quantify or to predict the effects of actions designed to improve safety or security. The quality of an agency's maintenance program impacts passengers as an aspect of service reliability when vehicle breakdowns or a shortage of replacement vehicles leads to missed service.

TRANSIT AVAILABILITY

There are a number of conditions that affect transit availability, all of which need to be met for transit to be an option for a particular trip:

- *Transit must be provided near one's trip origin.* If demand-responsive service is not provided to one's door, a transit stop must be located within walking distance and the pedestrian environment in the area should not discourage walking (e.g., due to a lack of sidewalks, steep grades, or wide or busy streets). Persons with disabilities require a continuous ADA-accessible path to the transit stop. One may also be able to ride a bicycle to a transit stop if bicycle storage facilities are available at the stop or if bicycles can be carried on transit vehicles. Similarly, one may be able to drive to a park-and-ride lot if such a lot is provided along the way and space is available in the lot.
- *Transit must be provided near one's destination.* The same kinds of factors discussed for the trip origin apply to the trip destination as well, except that bicycles or automobiles left behind at the boarding transit stop will not be available to passengers at their destination.
- *Transit must be provided at or near the times required.* In most cases, service must be available for both halves of a round trip—from one's origin to one's destination, as well as for the return trip. If passengers perceive a risk of missing the final return trip of the day, or if transit is available for only one of the two halves of passengers' round trips, transit is less likely to be an option for those passengers.
- *Passengers must be able to find information on when and where transit service is provided and how to use transit.* If passengers are unable to find out where to go to board transit, where they need to transfer, how much the fare will be, and so forth, transit will not be an option.
- *Sufficient capacity must be provided.* If a transit vehicle must pass up passengers waiting at a stop because the vehicle is already full, transit service was not available at that time to the passengers waiting at the stop.

If all of these conditions are met, transit is an *option* for a particular trip. Whether or not a passenger will decide to use transit will depend on the *comfort and convenience* of the service relative to competing modes.

TRANSIT COMFORT AND CONVENIENCE

Unlike transit availability, the kinds of questions weighed by potential passengers when assessing the comfort and convenience of transit service are often not all-or-nothing. Each person assesses particular comfort and convenience factors differently, depending on his or her own needs and situation. A passenger's decision to use transit rather than a competing mode (when transit is an option) will depend on how well transit service quality compares with that of competing modes.

Some of the more important factors that affect transit comfort and convenience are the following:

- *Passenger loads* aboard transit vehicles. It is more uncomfortable to stand for long periods of time and the time spent standing may not be able to be used for more productive or relaxing purposes, such as reading.
- The kinds of *passenger amenities* provided at transit stops.
- The *reliability* of transit service. Are passengers assured of getting to their destinations at the promised time or must they allow extra time for frequently irregular service?
- Door-to-door *travel times*, by themselves, and in relation to other modes.
- The out-of-pocket *cost* of using transit, relative to other modes.
- Passengers' perceptions of *safety and security* at transit stops, on board vehicles, and walking to and from transit stops.
- Whether *transfers* are required to complete a trip.
- The *appearance and comfort* of transit facilities.

QUALITY OF SERVICE FRAMEWORK

The key measures in the areas of transit availability and transit comfort and convenience that are important to passengers and can be relatively easily quantified are presented in the form of *quality of service frameworks.* These frameworks—one for fixed-route service and one for demand-responsive service—each provide service measures of availability and service measures of comfort and convenience.

Quality of service is quantified by six *levels of service* for each service measure. For fixed-route transit, LOS ranges from "A" (best) through "F" (worst). For demand-responsive transit, LOS ranges from "1" (best) through "8" (worst). Depending on the application, these service measures can be used individually to assess transit quality of service for a transit stop, route segment, or system, or they can be combined into a transit "report card" to provide a broader perspective. The availability measures, along with the travel time measures, are particularly suited to short- and long-term planning efforts, while the remaining comfort and convenience measures in each framework are well suited for ongoing service delivery monitoring.

As not every factor that affects transit quality of service can be accounted for by these service measures, it is important for planners and analysts not to lose sight of the broader issues that influence transit quality of service by concentrating solely on calculations of LOS. Part 3 of the TCQSM discusses other factors that should also be considered for measurement, depending on local needs and goals.

Exhibit 1-1 presents the quality of service framework for fixed-route transit, while Exhibit 1-2 presents the framework for demand-responsive transit.

Exhibit 1-1
Quality of Service Framework: Fixed-Route Transit

	Service Measures		
	Transit Stop	**Route Segment**	**System**
Availability	Frequency	Hours of Service	Service Coverage
Comfort & Convenience	Passenger Load	Reliability	Transit-Auto Travel Time

Exhibit 1-2
Quality of Service Framework: Demand-Responsive Transit

	Service Measures		
Availability	Response Time	Span of Service	
Comfort & Convenience	On-Time Performance	Trips Not Served	DRT-Auto Travel Time

QUALITY OF SERVICE RELATIONSHIPS

Capacity and Speed

Measures that an agency takes to improve quality of service may have both positive and negative effects on capacity and speed, and vice versa. This section looks at some measures often considered as part of bus rapid transit projects to examine their impacts on quality of service, capacity, and speed.

Increased Stop Spacing

Increasing the distance between stops (by consolidating stops or providing limited-stop or express service in combination with local service) speeds up service, as buses have to stop fewer times. However, passengers are distributed among fewer stops, so more passengers board at each stop. More boarding passengers result in longer dwell times and reduced bus capacity and speed, but also allow for a greater level of stop amenities. Quality of service is positively impacted by the net increase in travel speeds and the improved stop amenities, but negatively impacted by the longer distances some passengers must travel to walk to a stop.

Low-Floor Buses

Passenger boarding times are faster with low-floor buses, as no steps need to be climbed, which leads to shorter dwell times. Shorter dwell times result in faster travel times and greater stop and facility capacities. However, low-floor buses have fewer seats than equivalent high-floor buses, resulting in potentially lower person capacities. Quality of service is positively impacted by the faster travel times and ease of boarding, but is negatively impacted by the greater probability of having to stand, compared to a high-floor bus.

Traffic Signal Priority

Priority measures reduce delays for buses at traffic signals. Fewer delays translate into higher speeds, and the longer green times for buses increase the roadway’s bus capacity. Finally, the improved travel times and reliability that result from traffic signal priority have positive impacts on quality of service.

Proof-of-Payment Fare Collection

Proof-of-payment fare collection shortens the per-passenger boarding time, as no farebox is needed, and greatly shortens the overall boarding time required, as passengers are able to board through all doors. The decreased dwell time results in faster speeds and greater bus capacities, while the improved speeds have a positive impact on quality of service.

Increased Service Frequency

Service frequency improvements will spread existing passengers over a greater number of buses, reducing the dwell time associated with the existing passengers. This time savings will be partially or, in some cases, wholly offset by the additional dwell time required to serve new passengers attracted to the more frequent service. The overall result will range from no net impact on speed to an increase in speed. However, if the facility used by the additional buses is operating toward the upper limit of its capacity, the increased bus congestion may result in lower speeds.

Increased frequency will significantly increase the person capacity of the route. However, at higher frequencies (typically, headways of 10 minutes or less), bus bunching is more likely to occur, resulting in some of the added capacity being unutilized.

Quality of service is impacted positively by the improved frequencies and potentially lower per-bus loading. It may be impacted negatively if service reliability suffers due to bus bunching (which would also result in some buses being particularly crowded), or if travel times suffer due to increased bus congestion.

Ridership

Improvements in quality of service can result in increases in ridership, which in many cases, can result in an improvement in an agency's financial performance. It should be noted that, if ridership increases sufficiently, additional service must be added and additional costs might be incurred. Also, the opposite is often true in ADA paratransit service,(R4) where most trips are made with only one passenger: increased ridership results in increased agency costs, without the economies of scale that apply to fixed-route service.

The impacts of quality of service on ridership are usually estimated using one of two methods. *Discrete choice models* estimate the probability that a traveler will use a particular mode choice (e.g., transit) from a variety of mode choice options available. Given a known number of travelers in an area, the number of people using each mode can thus be estimated. *Elasticity* relates the observed percent change in ridership to the percent change in some other factor (e.g., fares, headways, etc.)

A presentation of detailed procedures for estimating ridership is beyond the scope of this manual, and readers are referred to textbooks on discrete choice models and to *TCRP Web Document 12*(R7) (which has been re-published as *TCRP Report 95*) for further information. However, some general guidelines on the impacts of quality of service changes on ridership are presented below, based on information from *TCRP Web Document 12*.

Response to Service Frequency Changes

Ridership is more responsive to changes in service frequencies when the existing service is infrequent (30-minute headways or longer), in middle- and upper-income areas, and when the distances traveled are short enough that walking is an option. Ridership is less responsive when service was already relatively frequent, in lower-income areas, and when most trips are long. All other factors being equal, climate (which affects passenger comfort while waiting for service), the condition of the local economy, the overall agency image, and the ways the new service is marketed will also affect the amount of the response.

Observed elasticities generally range from 0.0 (no change in ridership) to +1.0 (i.e., a 1% increase in frequency results in a 1% increase in ridership), with an average elasticity in the range of +0.3 to +0.5. More recent observations have grouped around either +0.3 (mainly central city urban systems) or +1.0 (suburban systems with positive images undergoing planned, comprehensive service increases). Limited research suggests that improvements in hours of service can be as important as improvements in service frequency.

Commuter rail elasticities related to service frequency are generally higher than those for buses, in part because commuter rail frequencies tend to be relatively low. Observed *headway* elasticities range from –0.7 to –0.9 for headways greater than 50 minutes (i.e., a 1% increase in headway results in a 0.7 to 0.9% *decrease* in ridership), and from –0.4 to –0.6 at shorter headways. In contrast, light rail and heavy rail elasticities related to service frequency are typically less than those for buses because these rail modes already operate at relatively high frequencies.

Response to Reliability Changes

Reports of passenger responses to decreases in reliability are mostly anecdotal, indicating that ridership is lost when service is perceived to be unreliable. Part of this response can be attributed to additional wait time incurred when transit vehicles leave early or are late (or never arrive at all), and part can be attributed to passenger uncertainty, anxiety, and annoyance. London Transport has estimated that elasticities due to unplanned service losses (e.g., scheduled vehicle-miles not operated) are 33% larger than elasticities related to planned service cuts.(R12) An analysis of automatic vehicle location (AVL) and automated passenger counter (APC) data in Portland, Oregon found that a 10% reduction in headway delay variation (the average absolute value of the difference between the actual and scheduled headway) on radial bus routes during the a.m. peak hour led to an increase of 0.17 passengers per trip per timepoint.(R3)

Response to Service Coverage Changes

Average elasticities of service expansions of existing systems (measured in terms of bus-miles or bus-hours) range from +0.6 to +1.0, with the higher values occurring in areas where the existing service level is below average, such as in small cities and suburbs, and during off-peak hours. (Note that existing ridership is often low in these situations, and that the same number of new passengers will result in a greater percentage increase in ridership when starting from a low ridership level than from a higher ridership level.) Packages of improvements, combining better routes and schedules, with new buses and/or reduced fares have been found to do particularly well in attracting new ridership.

Studies of service expansions since the 1960s—whether by extending existing routes, or by adding reverse-commute or suburb-to-suburb routes—indicate a success rate (i.e., the service was retained after the experimental period) at or slightly higher than 50 percent. New bus routes take 1 to 3 years to reach their full patronage potential, while entirely new bus systems may take even longer. New residential and multi-purpose feeders to line-haul bus and commuter rail services tend to attract 100 to 600 daily trips after 2 to 3 years, while single-employer shuttles are in the range of 25 to 600 daily trips.

Response to Fare Changes

Peak-period riders, persons traveling to and from work, and captive riders are significantly less responsive to fare changes than others. Passengers in larger cities are less sensitive to fare increases than are passengers in smaller cities. Perhaps similarly, ridership is less sensitive in areas where transit is in a competitive price and service position relative to the automobile. Elasticities do not appear to be different for large fare changes compared with small changes, nor for fare increases versus fare decreases.

The average elasticity of bus fare changes is –0.40 (i.e., a 1% fare increase results in a 0.4% decrease in ridership). The elasticity of rapid transit fare changes is about half as great, averaging –0.17 to –0.18. Off-peak ridership sensitivity is generally twice as sensitive as peak ridership, as new or infrequent riders are attracted to transit as a result of fare decreases. Peak-period riders, with the exception of senior citizens, tend not to shift travel to off-peak periods in response to off-peak fare reductions. The average senior citizen fare elasticity is –0.21.

With the exception of downtown free-ride zones, eliminating fares systemwide results in no greater increase in ridership than would be predicted from a 100% fare reduction. Downtown free-ride zones and free shuttles are attractive for lunchtime trips and often attract trips previously made by walking.

CHAPTER 3. CAPACITY CONCEPTS

INTRODUCTION

Transit agencies may consider themselves fortunate when they have capacity problems—it indicates a strong demand for their service. However, for the majority of small and mid-size transit systems, capacity constraints are usually not an issue—sufficient demand exists to provide service only once or twice per hour on most routes and more frequently on the busiest routes. However, even smaller systems may experience capacity issues in downtown areas where a number of routes may converge.

Why, then, should transit agencies and transportation planners be concerned with transit capacity? There are a number of reasons:

Factors influencing capacity also influence speed and reliability.

- *Improving speed and reliability.* The same factors that influence transit capacity also influence speed and reliability. Faster, more reliable service is an important quality of service issue for passengers. From an agency perspective, speed improvements reduce the time required for a vehicle to travel a route, while reliability improvements may allow reductions in the recovery time provided in the schedule at the end of each run.[1] In the best-case scenario for an agency, the combined reduction in running and recovery time would be greater than or equal to one headway, allowing a vehicle to be assigned to other service. More typically, the time saved postpones the need to add more service in order to maintain a particular headway due to congestion.
- *Managing passenger loads.* Capacity plays a role in determining how many cars or trains are needed to provide a desired quality of service in terms of passenger loading.
- *Forecasting the effects of changes in fare collection procedures, vehicle types, or other agency decisions.* Dwell time, the time a vehicle spends stopped to load and unload passengers, is often the key determinant of speed and capacity. Changes that impact passenger service times may create unanticipated impacts on running times, passenger loads, or vehicle bunching, which may entail additional costs to correct. Changes in vehicle types (e.g., switching from standard to articulated buses, or high-floor to low-floor buses) may also have dwell time and passenger capacity impacts.
- *Planning for the future.* Planning studies may suggest more than one possible mode or service type to meet a particular travel demand. Knowledge of the speed and capacity provided by each option is essential for making an informed decision. New light rail systems are sometimes developed with built-in capacity constraints to help reduce initial costs. Knowing how much of a constraint will exist is important for comparing short-term savings with long-term costs.

---

[1] The scheduled time between when a transit vehicle ends one run and departs for the next run is typically divided into two parts, *layover time* and *recovery time.* Layover time is a set amount of time, usually stipulated in the union contract, to provide a break for the operator. Recovery time is at least partially an allowance for run time variations to make sure that an operator can get a full break and still depart for the next run on time. (It may also represent additional time needed to provide clock headways—consistent departure times each hour—or for the operator to perform other duties at the end of the run.) When the variation in running times is less, due to improved reliability, it may be possible to reduce recovery time. *TCRP Report 30*(R6) provides more information on transit scheduling.

- *Analyzing the operation of major bus streets in large cities and the areas around transit centers in all sizes of communities.* Small cities that operate a small number of buses will often have all of the buses meet at a central location. Because delays in bus arrivals will often result in delays to the other bus departures (to avoid missing transfers), efficient bus access to and from the transit center is important. Larger cities will often have a number of routes converge on a small number of downtown streets, and the capacity procedures can be used to analyze the operation of those streets.
- *Special event service.* Transit agencies are often called on to provide service to community festivals, county fairs, sporting events, and the like, often providing service to the event site from remote parking areas. The procedures in this manual can be used to help size passenger waiting areas at the event site and to help determine the appropriateness of temporary transit preferential treatments (e.g., temporary bus lanes).
- *Transportation system management.* Transit vehicles typically carry more passengers than automobiles do. As a result, an increase in transit vehicle capacity has the potential to increase the *person* capacity of a facility more than an increase in automobile vehicle capacity does.(R9)

Analysts who are familiar with the *Highway Capacity Manual* will find that transit capacity is different than highway capacity: it deals with the movement of *both* people and vehicles; depends on the size of the transit vehicles and how often they operate; and reflects the interaction between passenger traffic concentrations and vehicle flow. Transit capacity depends on the operating policy of the transit agency, which normally specifies service frequencies, allowable passenger loading, and the type of vehicle used to carry passengers. Accordingly, the traditional concepts applied to highway capacity must be adapted and broadened.(R9)

The remainder of this chapter introduces the basic capacity concepts common to all public transit modes. Parts 4 through 7 of the TCQSM apply these concepts to the development of mode-specific capacity and speed procedures. Many of these concepts also have quality of service impacts, which are discussed in Part 3.

CAPACITY DEFINED

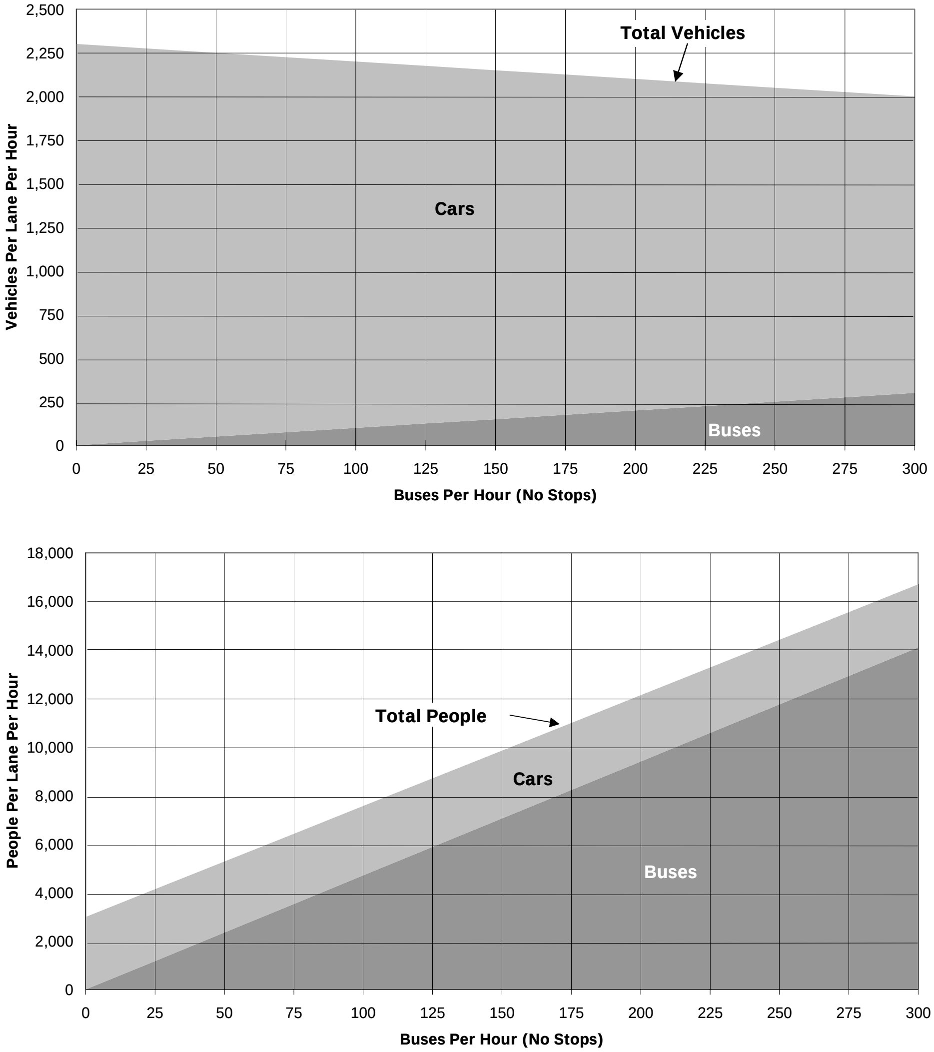
Capacity Relationships

Public transit service focuses on moving people from one place to another. In contrast to the automobile mode, where a large number of vehicles are used to transport a somewhat larger number of people, transit service works by using a relatively small number of vehicles to transport large numbers of people. As a result, transit capacity is focused more on the number of people that can be served in a given amount of time (*person capacity*), rather than the number of transit vehicles (*vehicle capacity*). However, determining the maximum number of vehicles that can be served in a given amount of time is often a necessary first step in determining the maximum number of people that can be served.

Exhibit 1-3 illustrates the relationship between vehicle and person capacity, using a freeway lane as an example. The number of buses operated is set by the service provider. The number of cars that can operate in the lane used by buses reflects the passenger vehicle capacity of the freeway lane after deducting the vehicle equivalencies of the buses. The total person capacity thus represents the number of people that can be carried by the specified number of buses and the remaining passenger vehicles.

For the purposes of this example, the capacity of the freeway lanes is assumed to be 2,300 passenger vehicles per hour per lane (without buses), one bus is assumed to be the equivalent of 2 passenger vehicles, buses are assumed not to stop along the freeway, and buses and passenger vehicles are assumed to have average occupancies of 47 and 1.3, respectively, corresponding to typical major-city vehicle occupancies. It can be seen that, as the number of buses using a freeway lane increases to 300, the person capacity of that lane increases from about 3,000 to more than 16,800, while the vehicle capacity drops only from 2,300 to 2,000 (1,700 passenger vehicles plus 300 buses). Note that this figure only refers to capacity, not to demand or actual use.

Exhibit 1-3
Examples of Freeway Vehicle and Person Capacity(R9)



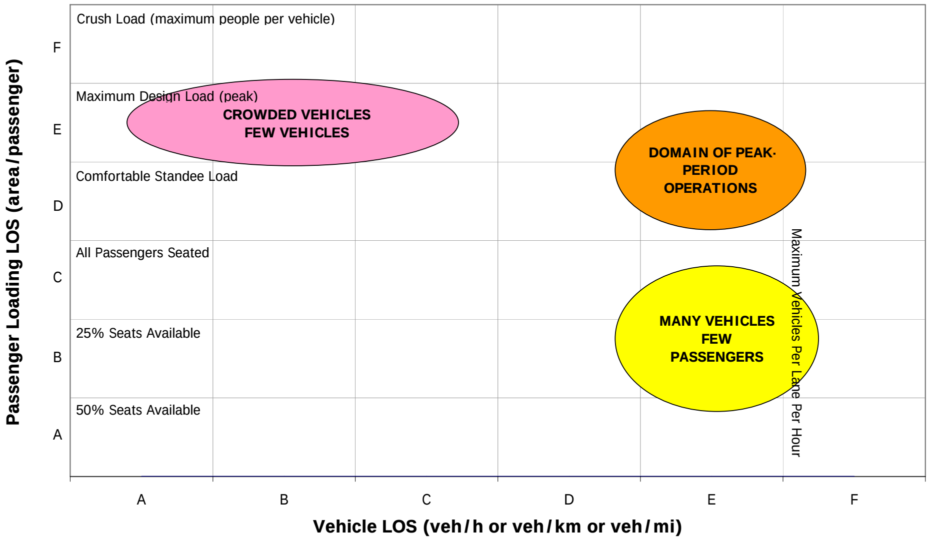
Buses generally form a small percentage of the total vehicular volume on a roadway...

...but have the ability to carry most of the people traveling on a roadway.

Under this set of assumptions, a lane serving 60 to 65 buses per hour is carrying as many people as a lane filled to capacity with automobiles, with considerable remaining capacity to add more buses and carry more people. Under these conditions, a bus would pass by a given point along the lane about once per minute on average. One of the challenges in adopting exclusive lanes for buses is the public perception that the lane is virtually empty of vehicles, even when it is carrying a substantial number of people.

Exhibit 1-4 illustrates the two-dimensional nature of urban bus capacity. It can be seen that it is possible to operate many buses, each carrying few passengers. From a highway capacity perspective, the number of vehicles could be at or near capacity, even if they run nearly empty. Alternatively, few vehicles could operate, each overcrowded. The long waiting times and crowded conditions represent a poor quality of service from the passenger perspective. Finally, the domain of peak-period operations in large cities commonly involves a large number of vehicles, each heavily loaded.

Exhibit 1-4
Relationship Between Person and Vehicle Capacity[R9]



Person Capacity

The number of people that can be carried by a particular transit route or facility depends on a number of factors, some under the control of the transit operator and some not. At the most basic level, person capacity, expressed in persons per hour, is determined by the product of transit vehicle capacity (vehicles/hour) and the passenger capacity of those vehicles (persons/vehicle). Person capacity is a function of vehicle size, type, occupancy, degree of interaction with other vehicles, headway, and passenger arrival characteristics.

The person capacity of a given transit route or facility can be defined as follows:

Person capacity defined.

> "The maximum number of people that can be carried past a given location during a given time period under specified operating conditions; without unreasonable delay, hazard, or restriction; and with reasonable certainty."

This definition of person capacity is less absolute than definitions of vehicle capacity, due to the numerous factors involved:

- *"A given location"*: Capacity is determined at a specific location, typically the segment of a route or facility that carries the most people, known as the maximum load segment. The number of boardings over the length of a route may be considerably greater than this capacity, depending on how often passengers get on and off; the important thing to note is that no more people than the route's person capacity will travel through the maximum load segment during the course of 1 hour.

- *"Specified operating conditions"*: The number of people that can be carried depends on the number of vehicles operated and the size of those vehicles. It is important to specify whether the reported capacity reflects the current schedule (how many people can be carried), vehicle capacity (how many people could be carried if as many vehicles as possible were provided), or some other condition.
- *"Without unreasonable delay"*: Person capacity is maximized when a constant queue of passengers exists to fill all available passenger spaces each time a vehicle arrives, as happens with amusement park rides, for example. Achieving this theoretical capacity requires that some or all passengers be passed up by the first vehicle to arrive, and often by subsequent vehicles. Transit passengers generally dislike pass-ups, particularly when there is a long wait involved for the next vehicle, although they may tolerate it for special event service, when they know another vehicle will be along shortly. Consequently, person capacity for transit must consider the number of people that can be carried, when it is desired that virtually all passengers will be able to board the first vehicle to arrive that goes to their destination.
- *"Without…hazard or restriction"*: A key assumption in determining person capacity is the passenger capacity of each vehicle. The reported person capacity will be greater when people are assumed to be packed in tightly, but in practice, North Americans will not tolerate such conditions and will wait for another vehicle. Similarly, many long-distance transit services design for all passengers being seated, with no standees, both for passenger comfort and (with freeway operations) liability reasons.
- *"With reasonable certainty"*: Capacity should reflect the number of people that can be carried on a sustained basis day after day, considering variations in passenger demand, traffic congestion, and other factors not under the control of the transit operator. More people than the reported capacity may sometimes be carried, but not most or all of the time.

Vehicle Capacity

The vehicle capacity of a given transit route or facility can be defined as follows:

> "The maximum number of transit vehicles (buses, trains, vessels, etc.) that can pass a given location during a given time period."

Vehicle capacity defined.

Vehicle capacity is known by different names in Parts 4 through 6 of this manual—for example, bus capacity, line capacity, and vessel capacity—but all of these names relate back to the number of transit vehicles that can be served during a given period of time, typically 1 hour. Ultimately, vehicle capacity depends on the minimum possible headway (time spacing) between individual transit vehicles. This minimum headway is dependent on control systems (e.g., traffic or train signals), passenger boarding and alighting demand at busy stops, and/or interactions with other vehicles (transit or otherwise).

In many cases, the vehicle capacity of a transit route will not be achieved in actual operation. Sometimes this is a result of resource limitations, which means that not enough transit vehicles are available to provide the maximum possible vehicle capacity. In many cases, there simply might not be sufficient passenger demand to justify operation at the design capacity. The net result either way is that the service frequency operated is below that which is theoretically possible.

The following considerations are also important:(R9)

1. Operations at “capacity” tend to strain transit systems, resulting in vehicle bunching and passenger delays. These operations do not represent desirable operating conditions. Moreover, most North American transit systems operate at capacity for a relatively short period of time, if at all.
2. Capacity relates closely to system performance and service quality in terms of speed, comfort, and service reliability. A single fixed number often can be misleading. The concept of “productive capacity,” the product of passenger flow and speed, provides an important index of system efficiency.(R11)
3. Capacities obtained by analytical methods must be cross-checked against actual operating experience for reasonableness.

TRANSIT CAPACITY FACTORS

The major factors that influence transit capacity are given in Exhibit 1-5. Additional mode-specific factors are presented in Parts 4 through 7 of the TCQSM. Some of the factors listed below affect the number of passengers per vehicle, while others affect the number of vehicles or vehicle units that can pass a given location within a specified time period.

Exhibit 1-5
Factors That Influence Transit Capacity(R8,R10)

VEHICLE CHARACTERISTICS

- Allowable number of units per vehicle (i.e., single-unit bus, or multiple-car train)
- Vehicle dimensions
- Seating configuration and capacity
- Number of wheelchair securement positions
- Number and height of steps
- Maximum speed
- Acceleration and deceleration rates
- Type of door opening mechanism
- Number, location, and width of doors

RIGHT-OF-WAY CHARACTERISTICS

- Cross-section design (# of lanes, tracks)
- Degree of separation from other traffic
- Intersection design and control
- Horizontal and vertical alignment

STOP CHARACTERISTICS

- Amount of time stopped
- Stop spacing
- Platform height vs. vehicle floor height
- Number and length of loading positions
- Fare collection method
- Type of fare
- Common vs. separate boarding/alighting areas
- Passenger access to stops

OPERATING CHARACTERISTICS

- Intercity vs. suburban operations at terminals
- Layover and schedule adjustment practices
- Time losses to obtain clock headways, provide driver relief
- Regularity of arrivals at a given stop

PASSENGER TRAFFIC CHARACTERISTICS

- Passenger concentrations and distribution at major stops
- Ridership peaking characteristics

STREET TRAFFIC CHARACTERISTICS

- Volume and nature of other traffic
- Presence of at-grade intersections

METHOD OF HEADWAY CONTROL

- Automatic or by train operator
- Policy spacing between vehicles

Dwell Time

Dwell time, the amount of time a transit vehicle spends at stops and stations serving passenger movements, is among the most important capacity factors. Dwell time at a given stop is directly related to the following factors:

- *Passenger boarding and alighting volumes.* The more people that must be served, the longer it takes to serve them.
- *Fare payment method.* Some fare payment methods require more time than others. Minimizing fare payment time is a key factor in reducing dwell time.

- *Vehicle type and size.* Passengers spend less time boarding and alighting low-floor buses than corresponding high-floor buses, particularly those passengers with strollers, bags or luggage, or disabilities. Multiple and/or wide doors that allow several people to board or alight simultaneously also help to expedite passenger movement.
- *In-vehicle circulation.* Boarding and alighting occurs more slowly when standees are present. The amount of space available for standees and the aisle width also influence how passengers circulate within the vehicle. Passengers who exit buses through the front door, rather than the rear door, can delay the time when passengers start to board.

Dwell time is indirectly related to stop spacing. Assuming walkable distances between stops and therefore a fixed passenger boarding demand, more stops over a given distance will spread out passenger volumes over a greater number of stops, resulting in smaller average dwell times at each stop. However, the greater number of stops will tend to slow down overall transit speeds, despite the shorter dwell times. As a result, consolidating stops can be a productive way to improve transit speeds, even though average dwell times increase, so long as dwell times at the stop with the longest dwell are not affected and walkable and accessible routes are available from a consolidated stop to the next closest stop.

Right-of-Way Characteristics

In general, the more exclusive the right-of-way—that is, the less interaction that transit vehicles have with other traffic—the greater the speed and capacity that can be achieved. In the case of light rail transit, though, this general rule does not always hold. As rights-of-way become more exclusive, speeds increase. These increased speeds require increased distances between trains in order to maintain an acceptable margin of safety, with the minimum headway determined in part by the type of signaling system used. As a result, the capacity constraint on a light rail system will often not be an on-street section but rather an off-street section operating under a train signaling system. At the same time, the lowest light rail running speeds will usually be encountered on the on-street sections, while the highest speeds will be achieved on the most exclusive right-of-way sections. Different types of right-of-way will have different capacities; the section with the lowest capacity (the "critical section") will control the overall line capacity.

Vehicle Characteristics

Vehicle characteristics influence the number of people who can be carried in a given vehicle. Two vehicles with exactly the same exterior dimensions can have greatly different passenger capacities, depending on the number of seats provided and the seats' orientation within the vehicle (i.e., longitudinal vs. transverse). A wider or longer vehicle will be able to carry more people than a narrower or shorter one. Low-floor buses generally have fewer seats than corresponding high-floor buses, because the wheelwells take up space that otherwise would have been used for seats.

Loading Diversity

Passenger demand is uneven, spread out over both space and time. The temporal and spatial distribution of transit passengers often prevents transit capacity from being fully utilized for the duration of the peak period. In the temporal sense, peaks within the peak period occur at major work start and finish times and can result in brief periods of operation at capacity, followed by under-capacity operation. Short-term fluctuations in ridership demand must be considered to avoid unacceptable passenger queuing or overcrowding. Variations in passenger arrival patterns and dwell times at stops will tend to reduce capacity. Temporal diversity is accommodated in capacity calculations through the use of a peak hour factor, which serves to reduce the theoretical person capacity to an achievable person capacity.

Spatial diversity can be manifested in a number of ways, from boarding and alighting locations at the macro scale to the distribution of passengers within the vehicle at the micro scale. A transit line with a relatively uniform distribution of boarding passengers among stops will usually have a higher capacity than one where passenger boarding is concentrated at a single stop. Loading is often uneven between cars in a single train or between buses operating together on a single route.

Economic Constraints

Transit agencies' economic realities can constrain capacity to a level below that suggested by passenger demand.

Economic factors often constrain capacity at a level below what is technically feasible and suggested by passenger demand. Typically, this takes the form of a shortage of vehicles to supply service on a given route, resulting in passengers being left behind and crowding conditions that deter would-be riders. A survey of rail transit systems(R5) found that the passing up of waiting passengers was relatively rare except on some subway lines in New York City and Toronto, and occasionally on the SkyTrain in Vancouver. However, in the New York and Toronto cases, trains were being operated at close to the minimum headway. In these cases, the constraint was not so much economic, barring the construction of new subway lines or extending platforms, but operational. In the Vancouver case, passengers would voluntarily wait for a less crowded train, indicating that crowding conditions were at least partially avoidable. Systems in other cities indicated that their available capacity was constrained by a shortage of cars, and that this capacity shortfall discouraged new ridership due to crowded conditions.

Agency Policies

Transit agency policies can influence capacity levels by dictating policy headways and vehicle loading standards. Policies are often set to ensure that scheduled service operates below capacity in order to provide a higher degree of passenger comfort. This can be manifested in the form of more frequent service or the use of larger vehicles than would be the case with lighter loading standards. Such policies can be the result of safety decisions, such as the banning of standees on buses operating on freeways, or a desire to ensure that the transit system remains attractive to new riders. The latter justification is especially important where transit is unable to provide a large travel time savings to the commuter and so must compete more directly with the automobile with respect to comfort.

MODAL CAPACITIES

Exhibit 1-6 compares the maximum person capacities that typically can be achieved in the United States and Canada for a selection of modes and facility types. Ranges shown reflect different assumptions on the number of cars in trains, dwell time lengths, and so on. Rail values represent persons per hour per track. HOV lane values assume shared use with carpools. Importantly, the person capacities shown reflect the upper limit of crowding that North Americans are typically willing to accept. Higher person capacities are achieved in other parts of the world—particularly in Asia and Latin America—in part because of the higher levels of crowding that are accepted.

Exhibit 1-6 also indicates the maximum passenger volumes observed in North America for various modes and facility types. These are occasionally slightly higher than the typical capacity ranges shown and reflect conditions outside the range of typical conditions used to develop the exhibit.

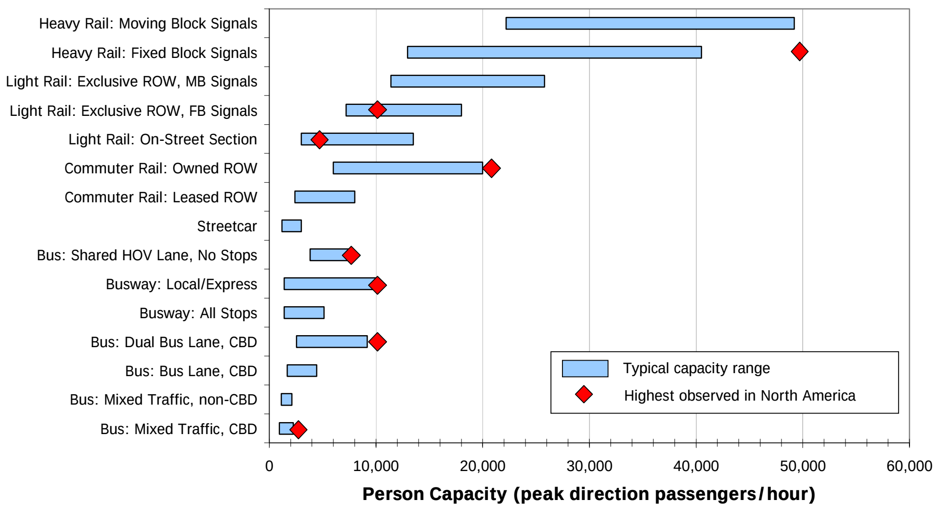


Exhibit 1-6
Person Capacity Ranges of U.S. and Canadian Transit Modes

SOURCES: TCQSM capacity procedures, *TCRP Report 13* (R5), *Transportation Planning Handbook* (R2)

NOTES: MB = moving block, FB = fixed block, ROW = right-of-way, HOV = high-occupancy vehicle, CBD = central business district

Ranges primarily reflect differing assumptions for dwell time and number of cars per train. Peak hour factor and passenger loading assumptions reflect TCQSM recommendations. “Highest observed” values beyond the ranges shown reflect non-typical conditions.

The bus-only lane on the New Jersey approach to the Lincoln Tunnel carries over 32,000 peak-hour, peak-direction passengers. However, buses make no stops en route and feed directly into the 200-plus-berth Port Authority Midtown Bus Terminal.

Exhibit 1-7 compares typical travel speed and capacity ranges for various transit modes on different types of facilities. The capacity ranges reflect the same factors listed above. The travel speeds include stops; the speed ranges reflect differences in average stop spacing, dwell times, route geometry characteristics, traffic congestion, and other factors.

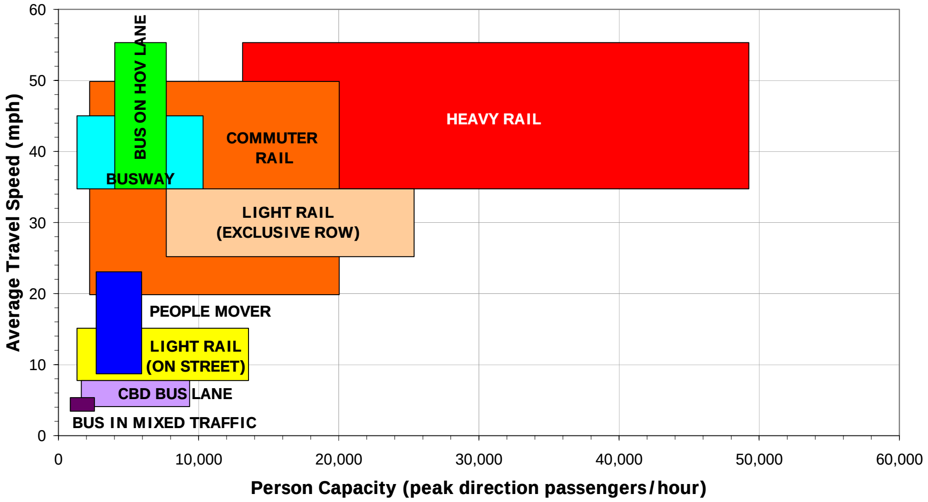


Exhibit 1-7
Typical Travel Speed and Capacity Ranges of U.S. and Canadian Transit Modes

The product of passenger capacity and speed is known as *productive capacity.*

SOURCES: TCQSM speed and capacity estimation procedures, *TCRP Report 13* (R5), *Transportation Planning Handbook* (R2), *Characteristics of Urban Transportation Systems* (R1)

NOTES: ROW = right-of-way

Speed ranges primarily reflect differing assumptions on stop spacing and dwell time. Capacity ranges primarily reflect differing assumptions for dwell time and number of cars per train. Peak hour factor and passenger loading assumptions reflect TCQSM recommendations.

This page is intentionally blank.

CHAPTER 4. REFERENCES

1. Cambridge Systematics, Inc., The Urban Institute, Sydec, Inc., Herbert S. Levinson, Abrams-Cherwony and Associates, and Lea and Elliott, *Characteristics of Urban Transportation Systems,* Revised Edition, Federal Transit Administration, Washington, DC (1992).
2. Edwards, Jr., John D. (editor), *Transportation Planning Handbook,* Prentice-Hall Inc., Englewood Cliffs, NJ (1992).
3. Kimpel, Thomas J., James G. Strathman, Kenneth J. Dueker, David Griffin, Richard L. Gerhart, and Kenneth Turner, "Time Point-Level Analysis of Passenger Demand and Transit Service Reliability," *Report TNW2000-03,* TransNow, Seattle, WA (July 2000). http://www.transnow.org/publication/Reports/TNW2000-03.pdf
4. Kittelson & Associates, Inc., Urbitran, Inc., LKC Consulting Services, Inc., MORPACE International, Inc., Queensland University of Technology, and Yuko Nakanishi, *TCRP Report 88: A Guidebook for Developing a Transit Performance-Measurement System,* TRB, Washington, DC (2003). http://gulliver.trb.org/publications/tcrp/tcrp_report_88/intro.pdf
5. Parkinson, Tom and Ian Fisher, *TCRP Report 13: Rail Transit Capacity,* TRB, National Academy Press, Washington, DC (1996). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_13-a.pdf
6. Pine, Randall, James Niemeyer, and Russell Chisholm, *TCRP Report 30: Transit Scheduling: Basic and Advanced Manuals,* TRB, National Academy Press, Washington, DC (1998). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_30-a.pdf
7. Pratt, Richard H., *TCRP Web Document 12: Traveler Response to Transportation System Changes: Interim Handbook,* TRB, Washington, DC (2000). http://gulliver.trb.org/publications/tcrp/tcrp_webdoc_12.pdf
8. Soberman, R.M. and H.A. Hazard (editors), *Canadian Transit Handbook,* University of Toronto and York University, Joint Program in Transportation, Toronto, Ontario (1980).
9. *Special Report 209: Highway Capacity Manual,* TRB, National Research Council, Washington, DC (1985).
10. *TCRP Web Document 6: Transit Capacity and Quality of Service Manual,* First Edition, TRB, Washington, DC (1999). http://gulliver.trb.org/publications/tcrp/tcrp_webdoc_6-a.pdf
11. Vuchic, V.R., *Urban Public Transportation: Systems and Technology,* Prentice-Hall, Inc., Englewood Cliffs, NJ (1981).
12. Webster, F. V. and P.H. Bly, *The Demand for Public Transport,* Transport and Road Research Laboratory, Crowthorne, Berkshire, England (1980).

This page is intentionally blank.

PART 2
TRANSIT IN NORTH AMERICA

CONTENTS

LIST OF EXHIBITS

This page is intentionally blank.

CHAPTER 1. INTRODUCTION

OVERVIEW

Part 2 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents a summary of transit's role and usage, and describes and provides statistics for the various transit modes used in North America. Chapters 2 through 5 introduce concepts covered in much greater detail in Parts 4 through 7 of the TCQSM.

Within the TCQSM, "North America" generally refers to the United States and Canada. Rail data also include Mexico.

- *Chapter 1* discusses the role of transit and provides summary national statistics of transit usage by mode.
- *Chapter 2* covers bus transit and its service, vehicle, and facility types.
- *Chapter 3* addresses rail transit, defines the different modes that are considered to be rail transit, and describes typical operating environments for those modes.
- *Chapter 4* describes ferry services and vessel types.
- *Chapter 5* summarizes the types of transit stops, stations, and terminals.
- *Chapter 6* provides references for material presented in Part 2.

ROLE OF TRANSIT

Transit plays two major roles in North America. The first is to accommodate *choice* riders—those riders who choose to use transit for their trip-making even though they have other means of travel, in particular, a motor vehicle. These riders may choose transit over other modes for a variety of reasons, including saving money (particularly parking costs), avoiding driving in congested traffic, being able to use travel time productively for other activities, and helping the environment. Choice riders particularly use transit during peak periods for work trips. As a result, transit increases the number of people that can be carried by urban transportation systems. In this role, transit is essential for mobility in the downtowns of some major cities—which could not survive without it—and in other concentrated employment centers.

Choice riders particularly use transit for work trips, especially in larger cities.

The other major transit role of transit is to provide basic mobility for those segments of the population too young, too old, or otherwise unable to drive due to physical, mental, or financial disadvantages. About 35% of the population in the United States and Canada do not possess a drivers license(R6) and must depend on others to transport them, in autos, on transit, or by other modes—walking, cycling, taxis, and so forth. This is the principal role for those transit services provided specifically for persons with disabilities and the dominant role in many smaller transit systems. Such transit users have been called *captive* riders.

Transit serves captive riders as well.

In the major cities in North America, transit serves higher numbers of both choice and captive riders. The variation in transit mode share among urban areas reflects differences in population, central business district employment and parking costs, extent of bus and rail transit services, and geographic characteristics.

Transit trips can be both time and cost competitive to the auto under certain operating conditions, where exclusive right-of-way operation, on-street transit lanes, or traffic signal priority can be provided. With the trend towards *Transportation System Management* solutions to urban transport problems, there has been an increased focus on moving persons and not simply vehicles on transportation systems. This has increased awareness on the part of local jurisdictions of the benefits transit preferential treatments can play in attracting transit ridership and reducing overall traffic congestion. With the higher transit ridership levels in larger cities, transit can provide more efficient use of energy and improve air quality.

Increased emphasis on moving persons in addition to vehicles on urban transportation systems.

Different transit service configurations.

Transit service can be provided in several operating configurations. *Fixed-route* service occurs where there is sufficient population or employment density to support higher transit volumes. *Demand-responsive* service occurs where transit trips are served on demand or by reservation, typically in lower-density areas and/or to accommodate riders unable to use the fixed-route service. Concepts combining characteristics of both service types, such as *deviated fixed-route* service, provide some regularity of service and improve transit accessibility for all riders.

Other forms of public transportation.

Other traditional forms of transportation provide an important component of overall public transportation. Taxis can serve as short feeders to transit and an emergency role for commuters who must return home outside the hours of commute service. They also serve as an effective alternative, particularly when trips are subsidized, for the elderly and persons with disabilities. School buses in the United States provided 94 billion passenger-miles (152 billion passenger-kilometers) of service in 1993,(R6) over four times the amount provided by all transit buses. The fleet of 550,000 school, church, and institutional buses in the U.S. is nine times larger than the 61,000 transit bus fleet. In Europe, most large Canadian cities, and a few U.S. cities, school trips are combined with transit, providing considerable savings for the school boards and additional revenues and economies of scale for the transit agency.

Importance of good pedestrian connections to transit.

Transit passengers must of necessity be pedestrians at one, or usually, both ends of their trips. Thus it is important that land uses surrounding transit stops incorporate good pedestrian linkages. In recent years, there has been an emergence of neo-traditional developments that provide for higher urban densities, thus promoting transit ridership as well as improving local pedestrian connections to transit. Safe pedestrian crossings of streets are also essential for pedestrian access to and from transit stops.

DOMINANCE OF LARGE SYSTEMS

North American transit experience.

Transit systems carry a majority of all peak-hour travelers to the downtown areas in many older major North American cities, but in other metropolitan areas, they carry a smaller proportion of downtown trips. Transit systems carry more than two-thirds of all peak-hour travelers to or from the New York, Chicago, and Toronto downtown areas, and more than one-third of all peak-hour travelers entering or leaving most other downtowns of major North American cities. At the very high end, in the densely occupied core of lower Manhattan in New York City, 84% of morning commuters arrive by public transportation.(R23)

Buses carry 86 percent of all peak-hour person-trips through the Lincoln Tunnel into New York City,(R23) about one-half of all peak-hour travelers on the Long Island and Gowanus Expressways in New York City, and more than one-quarter of all passengers on radial freeways approaching or leaving other large-city CBDs. Buses carry an even higher proportion of peak-hour travelers on many city streets. More than 80 percent of all peak-hour travelers are carried by buses on Hillside Avenue and Madison Avenue in New York City, Market Street in Philadelphia, and Main Street in Dallas. Buses accommodate more than one-half of all peak-hour person-trips on downtown streets in many other cities.(R18) Sixty percent of morning peak hour trips into lower Manhattan on Fifth Avenue occurred by bus in 1992.(R13)

These observations do not necessarily represent maximum possible bus volumes or total traffic volumes. They do, however, clearly indicate that while buses account for a relatively small proportion of the vehicles in a traffic stream, they can carry a sizable part of the total person flow. Rail rapid transit offers higher capacities and its fixed-route nature makes it more visible and attractive in dense areas. Light rail is gaining broader use in North America: Boston, Calgary, Philadelphia, Portland, Sacramento, St. Louis, San Diego, San Francisco, and Toronto are examples of cities with successful light rail lines.

STATISTICS

National Transit Database.

The Federal Transit Administration (FTA) maintains an extensive database of statistics, the National Transit Database (NTD), covering the larger agencies it funds. In 2000, the NTD included statistics on 433 bus operators, 416 demand-responsive agencies, and a range of less numerous modes.(R12) However, the database does not include many smaller bus systems that are exempted from its reporting requirements. As a result, the American Public Transportation Association (APTA) reports a much larger total number of bus systems—2,262.(R2)

Canadian Urban Transit Association data.

The Canadian Urban Transit Association (CUTA) collects statistics from its member systems. These data indicate there were 92 fixed-route transit systems in Canada in 2000,(R9) although many of the smaller systems are omitted. Most Canadian ridership figures are reported as *linked* trips, meaning that each transit trip is counted only once even if transfers are required. In contrast, FTA data counts *unlinked* trips, meaning that passengers are counted every time they step aboard a transit vehicle even if they are making a continuous trip. Canadian systems are not required to report passenger kilometers and so generally do not do so.

Unlinked vs. linked trips.

The NTD categorizes U.S. transit systems by urbanized area population and by the number of vehicles operated in maximum service. Population is used in Exhibit 2-1 for comparison purposes. This exhibit illustrates the number of transit systems, transit vehicles, and passenger trips in each of the three NTD population categories.

Exhibit 2-1
U.S. Transit Systems by Size Grouping (2000)(R12)

Population	# of Agencies*	# of Vehicles in Max. Service	% of Total	Unlinked Passenger Trips	% of Total
Under 200,000	254	7,277	8.6%	254,573,100	2.9%
200,000 to 1 million	122	14,530	17.1%	747,051,200	8.6%
Over 1 million	210	63,000	74.3%	7,718,266,600	88.5%
U.S. Total	588	84,807	100.0%	8,719,890,900	100.0%

* Sum of agencies reporting to FTA. Most smaller agencies are not required to report to the FTA; APTA reports the number of U.S. public transit systems in 2000 as 6,000.

Concentration of transit ridership.

As can be seen, a small number of systems carry nearly 90% of the total U.S. transit ridership. This group, in turn, is dominated by the New York region, which accounts for more than 35% of the total U.S. ridership. Taken from a different point of view, however, most U.S. transit agencies operate in areas with populations under 200,000. This fact is reinforced by Exhibit 2-2, which lists the number of U.S. providers of various public transportation modes. The greatest number of agencies by far are the demand-responsive and fixed-route bus modes, both of which are suited for areas with smaller populations that have no need for high-capacity transit modes, yet still require basic transportation services.

Exhibit 2-2
U.S. Public Transportation Providers by Mode (2000)(R2)

Mode	# of Agencies
Aerial tramway	1
Automated guideway transit	5
Fixed-route bus	2,262
Cable car	1
Commuter rail	19
Demand-responsive bus	5,252
Ferryboat*	33
Heavy rail	14
Inclined plane	5
Light rail	25
Monorail	2
Trolleybus	6
Vanpool	67
Total**	6,000

*Excludes international, rural, rural interstate, island, and urban park ferries.
**Total is not the sum of all modes since many agencies operate more than one mode.
NOTE: Table includes some services provided by private or quasi-public providers not included in later exhibits.

Unless otherwise noted, statistical exhibits only cover service directly operated or purchased by public agencies.

Exhibit 2-3 summarizes U.S. public transit ridership by transit mode along with the average trip length for each mode. Of note are the long average trip lengths for passengers using the commuter rail and demand-responsive modes, and the short trips that characterize electric trolleybus and "other rail" services. Services provided by private and non-profit operators under contract to a public agency are included in this and subsequent exhibits; however, other services provided by private or non-profit operators are not included unless specifically noted. Also, services provided by agencies exempt from reporting requirements (fewer than ten vehicles operated) are not included. In particular, the following types of services are not included in the ridership statistics:

- Commuter bus services provided by private operators not under contract to a public agency;
- Many demand-responsive services provided by non-profit organizations, as well as small (fewer than ten vehicle) public operators;
- Privately operated ferry transit services, which in New York City alone in 2000 accounted for more than 5 million annual passenger trips, not including contracted services;
- Vanpools sponsored by private companies or transportation management associations;
- Non-transit automated guideway operations, such as airport inter-terminal shuttles, which served more than 200 million annual passenger trips in 1995; and
- Other minor modes (e.g., private/non-profit or exempt vintage trolleys, inclined planes, and aerial ropeways) that serve a transit function.

Exhibit 2-3
Public Transit Ridership in the United States by Mode (2000)[R12]

Modal ridership and trip lengths.

Mode	Annual Unlinked Pass. Trips (millions)	Millions of pass-mi	Millions of pass-km	Avg. Trip Length (mi)	Avg. Trip Length (km)
Bus	5,677.7	21,241.0	34,176.8	3.7	6.0
Heavy rail	2,632.2	13,843.5	22,274.2	5.3	8.5
Commuter rail	412.9	9,402.0	15,127.8	22.8	36.6
Light rail	320.1	1,355.9	2,181.6	4.2	6.8
Electric trolleybus	122.4	191.9	308.8	1.6	2.5
Demand responsive	104.5	838.8	1,349.6	8.0	12.9
Ferry	53.3	330.0	531.0	6.2	10.0
Público	44.2	205.3	330.3	4.6	7.5
Vanpool	12.6	434.8	699.6	34.5	55.5
Cable car	9.2	10.5	16.9	1.1	1.8
AGT	6.4	6.3	10.1	1.0	1.6
Monorail	2.5	2.2	3.5	0.9	1.4
Inclined plane	1.8	0.6	1.0	0.3	0.5
Aerial tramway	0.9	0.5	0.8	0.6	1.0
Total	9,400.7	47,863.3	77,012.0	5.1	8.2

AGT: automated guideway transit

CHAPTER 2. BUS TRANSIT

OVERVIEW

The bus is the most commonly used form of public transport in North America. In 2000, it accounted for 62% of all U.S. passenger trips by transit and 61% of transit trips on the five largest Canadian transit systems. There were an estimated 2,262 bus systems in the U.S. in 2000.(R2) Exhibit 2-4 provides a list of the most-utilized bus systems in the U.S. and Canada, ranked by annual ridership. The figures shown consolidate all bus modes operated by each agency and thus include trolleybuses and contracted services. Note the very high ridership for San Francisco's Muni relative to its fleet size. This can be ascribed to the compactness of the service area and a high number of transfers resulting from the grid nature of the route structure.

Exhibit 2-4
Top 10 U.S. and Top 5 Canadian Bus Systems Based on Annual Ridership (R2,R12)

Transit Agency	2000 Annual Unlinked Pass. Trips (thousands)	2000 Buses Operated in Max. Service
	UNITED STATES	
MTA-New York City Transit	821,995	3,840
Los Angeles County MTA	359,002	2,017
Chicago Transit Authority	302,090	1,577
Muni (San Francisco)	174,856	634
SEPTA (Philadelphia)	172,014	1,191
New Jersey Transit	149,780	1,825
WMATA (Washington, DC)	129,524	1,179
MBTA (Boston)	104,154	924
MTA of Harris County (Houston)	86,736	1,017
MARTA (Atlanta)	83,119	580
	CANADA	
Toronto Transit Commission	380,660*	1,301*
MUCTC (Montréal)	362,801	NA
TransLink (Vancouver)	112,300*	940*
OC Transpo (Ottawa)	118,630*	750*
Calgary Transit	52,400*	620*

*2001 data provided by CUTA and individual agencies.

NOTE: The New York City DOT contracts service to seven private operators, who collectively carried more than 111 million passengers in 2000, using 1,084 buses in maximum service. This service is in addition to that provided by MTA-New York City Transit. NA = not available.

Top 10 U.S. and top 5 Canadian bus systems.

SERVICE TYPES

Fixed-Route

Local, limited-stop, and express bus service.

Fixed-route services are provided along a designated route and are operated at set times or headways. These services fall into three major operating categories. *Local services* provide service to all stops along a route and consequently provide relatively slow service and are best for short-distance trips. *Limited-stop services* are frequently overlaid over a local route or routes and provide a higher-speed service by stopping only at major destinations, such as key transfer points and major activity centers. *Express services* tend to be used for longer distance trips and provide local service near the end points of the route, with the intervening distance covered without passenger stops. Local passengers are often prohibited from riding the local portions of express services in core areas of the city where other local services are available.

Demand-Responsive

Demand-responsive vs. paratransit service.

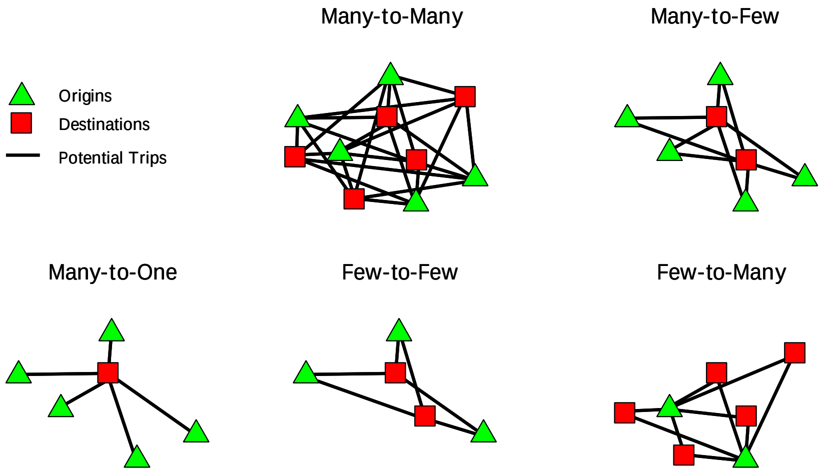
Demand-responsive transportation (DRT) is one of several types of *paratransit* service, where paratransit service is defined as those forms of public transportation that fall within the spectrum between the private automobile and conventional fixed-route transit.(R16) DRT, often called *dial-a-ride* service, fits within the middle range of paratransit service, as illustrated in Exhibit 2-5.

Exhibit 2-5
Paratransit Service Type Comparison(R16)

		HIRE AND DRIVE SERVICES	HAIL OR PHONE SERVICES			PREARRANGED RIDE-SHARING SERVICES		
	Private Auto	Daily & Short-Term Rental Car	Taxi	Dial-a-Ride	Jitney	Carpool	Subscription Bus	Fixed-Route Transit
Direct (D) or indirect (I) route?	D	D	D	I	I	I	I	I
Door-to-door?	Yes	Maybe	Yes	Yes	No	Yes	Maybe	No
Travel time spent as driver (D) or passenger (P)?	D	D	P	P	P	P/D	P	P
Ride shared (S) or personal (P)?	P	P	P/S	S	S	S	S	S
System routes fixed (F), semi-fixed (S), or variable (V)?	V	V	V	V	S	S	S	F
Access determined by prior arrangement (A), fixed schedule (F), phone (P), street hailing (H), or at user's discretion (U)?	U	U	H/P	P	H	A	A	F

DRT is variable route, activated in response to users' requests, provided as shared ride (typically door-to-door or curb-to-curb) and on a point-to-point basis. DRT point-to-point service can be operated as many origins to many destinations, many origins to few destinations, few origins to many destinations, few origins to few destinations, and many origins to one destination, as illustrated in Exhibit 2-6:

Exhibit 2-6
DRT Service Pattern Types



Specialized transportation.

When DRT service is provided to a targeted or special rider group, it is generally called *specialized transportation*. Most frequently, specialized transportation is point-to-point service pre-arranged by or for elderly riders and/or persons with disabilities. With passage of the Americans with Disabilities Act (ADA) in 1991, the focus of many specialized transportation programs became riders with disabilities unable to use fixed-route service, in response to the ADA's mandate that fixed-route transit systems provide "paratransit or other special service to individuals with disabilities that is comparable to the level of service provided to individuals without disabilities who use the fixed-route system."

Demand-responsive service is highly vehicle intensive. An average demand-responsive vehicle operating in the United States in 1995 provided 4,125 passenger trips per year. By comparison, buses and trolleybuses together carried an average of 106,620 passenger trips per vehicle in 1995 in the U.S.

Deviated Fixed-Route

Deviated fixed-route service—also called *route deviation* or *flex route* service—is essentially fixed-route service with flexibility to go off route to provide occasional pick-ups and drop-offs. If there are no requests for deviation, the service operates as a traditional fixed-route, fixed-schedule service. Requests for deviations can be handled in several ways. For pick-ups off the route, riders typically call the transit office in advance with their request for deviation. For drop-offs located off the route, riders may call the transit office in advance or ask the driver upon boarding. The specific procedures for accommodating deviation requests are determined by transit providers based on policy, level and type of demand, or other factors.

Deviated fixed-route service can be used to expand the potential service area of a single route in a low-density area, particularly in rural areas, by allowing deviations up to a set distance from the regular route to serve additional riders. It is also used by some transit providers as a way to meet ADA requirements mandating complementary paratransit service: ADA regulations consider deviated fixed-route to be "demand-responsive" service and, as such, it is not subject to complementary paratransit requirements.

ADA requirements for transit are mainly contained in 49 CFR Part 37, Subpart F.

Rural and Intercity

Rural services are often contracted or privately run.

Rural and intercity service can take the form of any of these types—fixed-route, demand-responsive, or deviated fixed-route. Service to outlying areas is often infrequent and is designed to accommodate persons traveling for medical, shopping, and other personal business needs rather than commuting. It is not uncommon for rural bus service to operate fewer than 5 days per week, with schedules designed to allow for a same-day return trip on days service is provided.

Transit services outside urban areas are often provided by private bus services. However, in some areas of the United States, public transit agencies provide service in rural areas and between regional population centers. Such is the case in New Jersey where the state transit operator (New Jersey Transit) provides service throughout the state. Heavy-duty highway-type coaches or minibuses are often used for such services, depending on demand.

Other Modes

Vanpools, jitneys, and públicos are included in NTD statistics, but are not addressed in detail in this manual.

The NTD defines three other rubber-tired roadway modes that are not addressed in detail in this manual. *Vanpools* provide shared rides in vans or buses between homes or a central location to a regular destination. Vanpools can be publicly or privately operated or sponsored, but only public operations are included in the NTD ridership summaries. *Jitneys* and *públicos* are privately owned passenger cars or vans operating on fixed routes as demand warrants, without fixed schedules or stops. Públicos are government-regulated (and thus appear in FTA statistics), while jitneys are not. Many jurisdictions prohibit jitneys.(R12)

OPERATING ENVIRONMENTS

Bus use of roadways.

Bus services can be operated on a variety of types of roadway, ranging from streets with mixed traffic to exclusive bus-only highways. Greater degrees of separation from other traffic provide transit vehicles and their riders with faster, more predictable journeys as the interference with other road users is reduced or eliminated. Providing special lanes or roads for buses also serves a marketing function as it indicates an institutional preference given to buses over the private automobile. Bus operation on dedicated rights-of-way, however, is not very common relative to mixed-traffic operation. About 515 miles (830 km) of roadway lanes with full-time occupancy restrictions favoring buses existed in 1995 in the United States.

Another 575 miles (930 km) of lanes offered preferential access for buses during at least part of the day. In contrast, about 150,000 miles (250,000 km) of roadway used by buses are shared with mixed traffic.(R2)

Segregated Right-of-Way

Busways typically provide a two-way roadway in a segregated right-of-way designated for the exclusive use of buses. Maximum operating speeds are typically in the 45 to 50 mph (70 to 80 km/h) range. Stations are provided for passenger service.

Industry usage of the terms *busway* and *transitway* is not consistent. The terms are often used interchangeably.

Well-known examples of grade-separated busways in North America include Pittsburgh's three busways, the downtown Seattle bus tunnel, and Ottawa's five busways. The Ottawa system includes 16 miles (26 km) of bus-only roadways,[1] which carry 9,000-10,000 passengers in 190 buses per hour in the peak direction into downtown Ottawa. Frequent bus service is accommodated by providing passing lanes at stations, which resemble light rail stations in scale.(R20)

The busways in Ottawa, Pittsburgh, Miami, and Brisbane, Australia provide both express and all-stop services.

At-grade busways in North America include the 8-mile (13-km) South Dade Busway in Miami, Florida; the 1.6-mile (2.6-km) busway south of Seattle's bus tunnel; and a 1.2-mile (2.0-km) median busway in the Vancouver suburb of Richmond. All of these facilities have traffic signals along them that act to meter the flow of buses and thus have lower overall travel speed and capacity characteristics compared with grade-separated busways. A number of South American cities have developed busways in the medians of arterial streets.

Guided busways are a form of busway developed for constrained rights-of-way and can be either grade-separated or at-grade. Lateral guidance is provided using a set of guidance wheels on the bus that roll against curbs developed on the side of the guideway. As of 2003, no facilities of this type existed in North America. The most extensive international application is in Adelaide, Australia (shown in Exhibit 2-7); other guided busways exist in Essen, Germany, and Leeds, England.

Exhibit 2-7
Busway Examples

(a) Grade-Separated Busway (Ottawa)   (b) Guided Busway (Adelaide, Australia)

(c) At-Grade Busway (Miami)   (d) Median Busway (Vancouver)

---

[1] The entire Transitway system, including reserved freeway lanes and arterial street bus lanes, totals 37 miles (60 km) in length.

High-Occupancy Vehicle (HOV) Lanes

HOV lanes may be bus-only or may allow other vehicles.

Where capacity permits, buses can successfully operate in HOV lanes. HOV lanes, illustrated in Exhibit 2-8, are preferential lanes that are available only to vehicles carrying a number of passengers above a set threshold occupancy. In practice the occupancy requirement varies widely, depending on local policies, and ranges from a minimum requirement of two occupants per vehicle to the exclusive bus lanes previously mentioned. Some jurisdictions also permit motorcycles or taxis to use HOV lanes, as well as all emergency vehicles. While, in theory, occupancy requirements can be raised in order to maintain a desired level of service and increase person-moving capacity, reductions in occupancy requirements have been much more common in order to reduce the negative public perception caused by "empty lane syndrome."(R13)

HOV lanes can be provided in the same direction as general traffic (*concurrent flow*) or by using an underutilized lane in the opposite direction (*contraflow*). Both types are used in North America. A well-known contraflow facility is the Lincoln Tunnel bus lane from New Jersey to Manhattan in New York City, which carries over 32,000 passengers per hour in 735 buses. In many cases, HOV lanes are in effect during peak periods only and are available to all traffic at other times. Short reserved lane segments, known as *queue bypasses* or *queue jumpers*, are often used to allow buses, and sometimes other HOVs, to bypass congestion points such as metered freeway ramps. In 1990, there were over 950 HOV ramp bypasses in North America.(R13)

Exhibit 2-8
HOV Lane Examples

(a) Lincoln Tunnel Approach (New Jersey)

(b) Shirley Highway (Northern Virginia)

Arterial Street Bus Lanes

Lanes reserved for buses, either on a full-time or part-time basis, are used in portions of many larger cities where relatively high numbers of buses are scheduled. These lanes reduce or eliminate traffic and on-street parking conflicts, thus providing faster and more reliable bus operations on surface streets. Where scheduled bus volumes are particularly high, more than one lane in each direction may be reserved for buses, as is the case on the Madison Avenue dual bus lanes in New York City, shown in Exhibit 2-9, and on 5th and 6th Avenues in Portland, Oregon. Entire streets reserved for buses, known as *bus malls,* are used in a number of cities but their use has waned in recent years. The more prominent remaining examples include the Nicollet Mall in Minneapolis, the Fulton Street Mall in Brooklyn, the 16th Street Mall in Denver, and the Granville Mall in Vancouver, British Columbia.

Exhibit 2-9
Arterial Street Bus Lane Examples

(a) Bus Mall (Denver)

(b) Dual Bus Lanes (New York)

(c) Exclusive Bus Lane (San Antonio)

(d) Part-Time Bus Lane (San Francisco)

Mixed Traffic

Mixed-traffic bus operation (Exhibit 2-10) accounts for over 99 percent of total bus route distance in North America. While operating buses in general traffic lanes is straightforward for planning and political purposes, it does result in buses being subject to delays caused by traffic. Mixed-traffic operation complicates capacity calculations for both bus and automobile flow since it exposes buses to automobile traffic congestion and slows automobiles as buses stop to serve passengers.

Exhibit 2-10
Mixed-Traffic Operation

The Portland photo shows operations during a temporary detour resulting from New Year's 2000 celebrations.

(a) Milwaukee

(b) Portland, Oregon

VEHICLE TYPES

Bus services can be provided by a number of vehicle types ranging from minibuses to articulated and double-deck buses. The composition of the U.S. transit bus fleet is shown in Exhibit 2-11. Examples of buses used in fixed-route and demand-responsive service are shown in Exhibits 2-12 and 2-13, respectively. (Larger demand-responsive vehicles are also sometimes used in fixed-route service.)

Exhibit 2-11
Non-Rail Vehicles in Active Transit Service in the U.S. (2000)(R12)

Vehicle Type	Directly Operated Bus Service
Class A Bus (>35 seats)	43,945
Class B Bus (25-35 seats)	5,822
Class C Bus (<25 seats)	5,113
Articulated Bus	1,881
Trolleybus	894
School Bus	6
Van	7,394
Automobile	223
Total	65,278

NOTE: Class A, B, and C bus totals do not include the specialized bus types listed separately.

Standard 40-foot (12-meter) buses with more than 35 seats are by far the dominant form of bus operated by U.S. transit systems and constitute more than 65% of the national transit bus fleet. Articulated buses 60 feet (18 meters) in length have been embraced by a smaller number of transit agencies, but their use is growing as agencies seek to improve capacity and comfort with relatively low increases in operating costs. Double-deck buses are not currently used for public transit in the United States; however, public transit fleets in Brampton, Ontario, and Victoria, British Columbia, include double-deck buses.

The requirements of the ADA and parallel policies in Canada have resulted in most new transit vehicles being designed to accommodate passengers using wheeled mobility aids, those who have difficulty with stairs, and those carrying luggage or other bulky items. In 2001, 86% of the U.S. transit bus fleet was accessible to wheelchairs.(R2) While providing wheelchair lifts has been the most common means of meeting these obligations, a recent trend has been the move toward low-floor buses. These buses allow easier boarding for all passengers by eliminating the need for steps and wheelchair lifts; however, the ramps used on low-floor buses are designed for level boarding from a curb and may not be able to be deployed in areas without curbs and sidewalks.

While most transit buses are diesel powered, natural gas and electric-powered buses are also used by some agencies for environmental (reduced or eliminated bus exhaust), noise (quieter acceleration), ride comfort (no transmission in electric-only buses), improved hill-climbing ability (electric trolleybus), and/or operating cost reasons (e.g., reduced fuel costs). Electric trolleybuses (also known as *trackless trolleys*) operate in seven cities in Canada and the United States, but constitute less than 2% of the total U.S. transit bus fleet.

Hybrid-electric buses have both an electric motor and a motor powered by other fuels, including diesel, compressed natural gas (CNG), or some other fuel. These buses allow some of the energy generated during braking to be stored and reused for propulsion. Trials of hybrid-electrics have been ongoing since the late 1990s, and these buses are now being purchased by agencies for regular service. Denver, for example, introduced 116-passenger hybrid CNG-electric buses on its 16th Avenue Mall service in 2001.

Exhibit 2-12
Examples of Buses Used in Fixed-Route Service

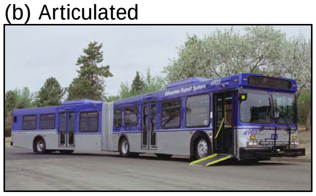
Bus Type	Typical Applications	Capacity/QOS Factors
(a) Standard Bus 	• Forms more than 80% of U.S. bus fleet	• Bus length influences seating capacity, bus width influences standing capacity • High floor
(b) Articulated 	• Routes where added capacity is desired without adding more buses • Routes where reduced number of buses, but same capacity, is desired	• 50% more seats and standing capacity than standard bus • High or low floor • Reducing frequency may increase passenger service times and overall travel times
(c) Low-Floor 	• Provides easier access by eliminating steps • Airport routes where passengers carry luggage	• Fewer seats than comparable standard bus • Faster boarding times, particularly for wheelchairs • Prefer streets developed with curbs for ramp deployment
(d) Electric Trolleybus 	• Routes replacing streetcars • Downtown tunnels • Routes on steep hills • Cities with city-owned electric utilities	• Quieter acceleration • No diesel exhaust • Unless dual-powered, can only operate on facilities equipped with overhead wires • Visual clutter from dual wires
(e) Over-the-Road Coach 	• Long-distance commuter routes • Intercity routes • Heavier-duty bus for high-speed running	• Larger, more comfortable seats • Usually overhead storage racks • Typically no standees allowed • High floor
(f) Electric 	• Short-distance circulator service, particularly in downtown areas	• Quieter acceleration • No diesel exhaust or overhead wires • Limited range before recharging or swapping batteries
(g) Special-Purpose Bus 	• Short-distance circulator or point-to-point service carrying high volumes of passengers • Bus/rail station distributor • Airport air-side shuttles	• Most passengers stand, but trips tend to be short • Multiple doors allow quick loading/unloading • Low floor
(h) Replica Trolley 	• Tourist-oriented circulator service • Special event service (e.g., city festival, county fair)	• Distinctive vehicle reassures passengers this is their bus • Increases transit service visibility • Seats may be less comfortable • High floor

Photo locations:
(a) Tallahassee
(b) Edmonton
(c) Victoria, British Columbia
(d) Philadelphia
(e) Cleveland
(f) Chattanooga
(g) Denver
(h) Albuquerque

Exhibit 2-13
Examples of Vehicles Used in Demand-Responsive Service

(a) Chillicothe, Missouri (b) Maple Ridge, British Columbia

OBSERVED BUS AND PASSENGER FLOWS

Streets and Highways

Observed bus volumes on urban freeways, city streets, and bus-only streets clearly show the reductive effects of bus stops on bus vehicle capacity. The highest bus volumes experienced in a transit corridor in North America, 735 buses per hour through the Lincoln Tunnel and on the Port Authority Midtown Bus Terminal access ramps in the New York metropolitan area are achieved on exclusive rights-of-way where buses make no stops (and where a 210-berth bus terminal is provided to receive these and other buses).(R18) Where bus stops or layovers are involved, reported bus volumes are much lower. Exhibit 2-14 shows bus flow experience for a number of North American cities.

Exhibit 2-14
Observed Peak Direction Peak Hour Passenger Volumes on U.S. and Canadian Bus Transit Routes (1995-97)(R10,R21,R26)

Location	Facility	Peak Hour Peak Direction Buses	Peak Hour Peak Direction Passengers	Average No. of Pass. per Bus
New Jersey	Lincoln Tunnel Approach	735*	32,600	44
Ottawa	West Transitway	225	11,100	49
New York City	Madison Avenue	180	10,000	55
Portland	6th Avenue	175	8,500	50
New York City	Long Island Expy.	165*	7,840	48
New York City	Gowanus Expy.	150*	7,500	35
Newark	Broad Street	150	6,000	40
Pittsburgh	East Busway	105	5,400	51
Northern Virginia	Shirley Highway	160*	5,000	35
San Francisco	Bay Bridge	135*	5,000	37
Denver	I-25	85*	2,775	33
Denver	Broadway/Lincoln	89	2,325	26
Boston	South/High Streets	50	2,000	40
Vancouver	Granville Mall	70	1,800	26
Vancouver	Highway 99	29	1,450	50

*no stops

Bus malls.

When intermediate stops are made, bus volumes rarely exceed 120 buses per hour. However, volumes of 180 to 200 buses per hour are feasible where buses may use two or more lanes to allow bus passing, especially where stops are short. An example is Hillside Avenue in New York City. Two parallel bus lanes in the same direction, such as along Madison Avenue in New York and the 5th and 6th Avenue Transit Mall in Portland, Oregon, also achieve this flow rate. Up to 45 buses one-way in a single lane in 15 minutes (a flow rate of 180 buses per hour) were observed on Chicago's former State Street Mall; however, this flow rate was achieved by advance marshaling of buses into three-bus platoons and by auxiliary rear-door fare collection during the evening peak hours to expedite passenger loading.(R27)

Several downtown streets carry bus volumes of 80 to 100 buses per hour where there are two or three loading areas per stop and where passenger boarding is not concentrated at a single stop. (This bus volume corresponds to about 5,000 to 7,500 passengers per hour, depending on passenger loads.)(R27)

Historic streetcar volumes.

These bus volumes provide initial capacity ranges that are suitable for general planning purposes. They compare with maximum streetcar volumes on city streets in the 1920s which approached 150 cars per track per hour, under conditions of extensive queuing and platoon loading at heavy stops.(R5) However, the streetcars had two operators and large rear platforms where boarding passengers could assemble. (R27)

Terminals

Peak hour bus flows observed at 13 major bus terminals in the United States and Canada range from 2.5 buses per berth at the George Washington Bridge Terminal in New York to 19 buses per berth at the Eglinton Station, Toronto.(R27)

Buses occupy loading areas at bus terminals for much longer periods of time than they occupy loading areas at on-street bus stops.

The high berth productivity in Toronto reflects the special design of the terminal (with multiple positions in each berthing area); the wide doors on the buses using the terminal; the free transfer between bus and subway, which allows use of all doors; and separate boarding and alighting areas. The relatively low productivity at the New York terminals reflects the substantial number of intercity buses that use the terminals (which occupy berths for longer periods of time) and the single-entrance doors provided on many suburban buses.(R27)

This experience suggests an average of 8 to 10 buses per berth per hour for commuter operations. Intercity berths typically can accommodate 1 to 2 buses per hour.(R27)

BUS PRIORITY TREATMENTS

Much attention has been paid to expediting transit flow by providing various forms of priority treatment. Such treatments are aimed at improving schedule adherence and reducing travel times and delays for transit users. They may attract new riders, increase transit capacity, and/or improve the transit quality of service.

A growing number of cities have established exclusive bus lanes and other bus priority measures to improve person-flow over city streets and highways. Bus priority measures are an essential part of transportation system management (TSM) programs that attempt to maximize transport system efficiency consistent with social, economic, and environmental objectives.

Effective distribution of buses in downtown areas remains an important challenge, and communities are giving this issue increased attention. Freeway-related treatments generally provide good access to the downtown perimeter, but do not substantially improve service within the downtown core. Terminals are not always located near major employment concentrations and may require secondary distribution. Because concurrent-flow curb bus lanes have not always been effective, there have been several efforts to install contraflow bus lanes in downtown areas. Traffic signal priority for buses is another measure effectively used to minimize bus delay and increase service quality. As a capital-intensive solution to downtown bus distribution, a 1.3-mile (2.1-km), five-station bus tunnel opened in downtown Seattle in 1991. Bus routes using the tunnel are operated with a special fleet of dual-mode buses which run on electric power in the tunnel and diesel power on the surface portions of their routes. Both ends of the tunnel connect to freeway ramps.

Many bus priority measures have produced important passenger benefits, especially those relating to freeways. Some have achieved time savings of 5 to 30 minutes—savings that compare favorably with those resulting from rail transit extensions or new systems. The contraflow bus lane leading to the Lincoln Tunnel in New Jersey, for example, provides a 20-minute time saving for bus passengers. However, even when passenger time savings are small, bus priority can still provide substantial schedule reliability improvements, which benefit both passengers and transit operators. A study of implementing traffic signal priority along a 6-mile (10-kilometer) corridor in Portland, Oregon, found average travel time savings of 2.5 minutes, but an improvement in reliability sufficient to remove 10 minutes of recovery time from the end of each trip.(R7)

Successful priority treatments are usually characterized by one or more of the following:(R19)

- An intensively developed downtown area with limited street capacity and high all-day parking costs,
- A long-term reliance on public transportation,
- Highway capacity limitations on approaches to downtown,
- Major water barriers that limit road access to the central business district (CBD) and channel bus flows,
- Fast non-stop bus runs for considerable distances,
- Bus priorities on approaches to major congestion points,
- Special downtown bus distribution (often off-street terminals), and
- Active traffic management, maintenance, operations, and enforcement programs.

BUS RAPID TRANSIT

Description

Bus Rapid Transit (BRT) is a relatively new term that describes a form of bus transit that has been in use since the 1970s. Certain elements of BRT, such as freeway running, have been used since the 1950s. BRT has drawn considerable interest in recent years, particularly as the amount of federal funding available for new rail starts has not matched the demand for such funding, and as the FTA has sponsored a consortium of transit agencies to develop BRT systems.

BRT is a complete rapid transit system that combines flexible service and new technologies to improve customer convenience and reduce delays. BRT includes the seven major service features listed below. Not all of these features need to exist in order for a service to be considered BRT, although all BRT systems typically include frequent service as part of the service package. In fact, implementing any of these BRT components will provide quality of service and/or capacity benefits:(R20)

- *Exclusive running ways.* Vehicles operate primarily in fast, easily identified busways and transit lanes. Vehicles can also operate in general traffic, achieving improved speed and reliability benefits through transit signal priority measures rather than exclusive facilities.
- *Enhanced stations.* Stations are attractive, easily accessible, and integrated with the surrounding community. A higher level of amenities is provided than at a regular bus stop. Bus-side station design includes provision for passing, so that express buses can bypass local buses stopped at the station.
- *Enhanced vehicles.* BRT uses high-capacity, rubber-tired vehicles that are easy to board and comfortable to ride. Many agencies are opting for larger windows, similar to rail vehicles, clean fuels, and on-board visual and audible stop announcements. A distinctive bus design, color, and/or graphics distinguish BRT buses from regular buses, providing reassurance to unfamiliar riders that this is their bus, and also raising awareness of the presence and frequency of service among current non-riders.

- *Frequent, all-day service.* BRT operates at high frequencies, reducing or eliminating the need for passengers to consult schedules. Long hours of service are also provided, to serve a variety of passenger trip types.

BRT can provide one-seat service from an origin to a major activity center, eliminating the transfer involved with feeder bus to rail service.

- *Flexible route structure.* BRT can be designed around a combination of local and express service to improve passenger service times. More extensive infrastructure, such as a busway, can be built as a trunk facility used by all routes for a portion of their trip, with routes splitting off the main facility to pick up and drop off passengers in local neighborhoods. A light rail facility providing the same function would require feeder bus service (and the associated transfer), as well as multiple tracks to provide the combined frequent express/local service.

Proof-of-payment fare collection entails passengers purchasing fares in advance at the station and having receipts available for inspection by roving agency staff.

- *Improved fare collection.* The time required to board passengers is minimized through the use of proof-of-payment fare collection (as is done on many light rail systems), or through technology such as smart cards that speeds the fare payment process. Multiple-door boarding may also be used to speed passenger boarding.
- *Applications of technology.* Intelligent Transportation System (ITS) technologies can be applied to provide bus arrival time information, next-stop announcements, automatic vehicle location, traffic signal priority, improved surveillance and security, and other functions.

Applications

Exhibit 2-15 provides examples of existing BRT services in North America, according to the FTA. (Express or limited-stop services with no other existing or planned aspects of BRT are not included.) The exhibit lists the features provided by each service as of 2002. (A number of systems were planning further enhancements over time.) Other regions that were designing BRT services as of 2002 included Charlotte, North Carolina; Cleveland, Ohio; Eugene, Oregon; Hartford, Connecticut; Minneapolis, Minnesota; Northern Virginia; San Juan, Puerto Rico; and Santa Clara, California.

Exhibit 2-15
North American BRT Applications (2002)

		Service Features					
Region	**Service Type**	**Method**	**Stations**	**Vehicles**	**Local-Express**	**Fares**	**ITS**
Boston	line-haul	EL/B	●	●			●
Honolulu	line-haul	EL		●			
Los Angeles	line-haul/rail feeder	SP	●	●	●		●
Miami	rail feeder	B	●		●		
Montréal	rail feeder	EL	●		●		
Oakland	line-haul	LS		●	●		
Ottawa	line-haul	B	●		●		
Pittsburgh	line-haul	B			●	POE	
Seattle	CBD distribution	B	●	●		POE	
Vancouver	line-haul	B/EL/SP	●	●	●		●

NOTE: All systems include frequent service as a service feature.
Method: Primary means used in 2002 to improve speed, other than a limited number of stops: B =busway, EL = exclusive lanes, SP = signal priority, LS = limited stops only. Many systems were planning to implement additional means in the future.
Stations: dot indicates upgraded amenities and/or distinctive station treatments.
Vehicles: dot indicates different vehicle and/or livery than regular bus fleet.
Local-express: dot indicates mix of local and express service along BRT route.
Fares: POE = pay on exit for outbound trips.
ITS: dot indicates Intelligent Transportation System applications other than signal priority (e.g., real-time info).

CHAPTER 3. RAIL TRANSIT

OVERVIEW

Rail transit systems in North America carry more than 5 billion passengers each year. As of 1995, a total of 53 agencies operated 207 routes of the four major rail transit modes—heavy rail, light rail, commuter rail, and automated guideway transit—with a total length of 5,100 miles (8,200 kilometers), providing 18 billion passenger-miles (29 billion passenger-kilometers) of service annually. Less common rail modes include monorails, funicular railways (inclined planes), aerial ropeways, and cable cars. Collectively, as part of public transit operations, these modes provided approximately 14.4 million annual unlinked passenger trips in 2000.(R12)

Two systems dominate. The largest operator is MTA-New York City Transit, which carried 1,678 million passengers in 2000, 50% of the U.S. rail total and 30% of the continent's total. The second largest operator, Sistema de Transporte Colectivo in Mexico City, carried 1,434 million passengers in 2000, 26% of the continent's total. Adding all New York City area rail operators together, New York accounts for approximately 2 billion annual rail trips, 59% of the U.S. total and 36% of the continent's total. The New York and Mexico City rail systems combined account for two-thirds of all North American unlinked rail trips.

Rail transit plays a vital role in five metropolitan areas, carrying over 50% of all work trips and, in three regions, over 70% of all downtown-oriented work trips. Rail transit plays an important but lesser role in another six regions. Other rail transit systems carry a smaller proportion of regional trips but fill other functions, such as defining corridors and encouraging densification and positive land-use development.

Ridership data are summarized in Exhibit 2-16 and Exhibit 2-17, while Exhibit 2-18 summarizes other key North American statistics for each rail mode.

Exhibit 2-16
North American Rail Ridership by Mode (millions) (2000)(R2,R12,R15)

Heavy rail carries 83% of all rail transit passengers in North America.

Mode	Annual Unlinked Trips	%
Heavy Rail	4,650.1	83.4%
Light Rail	475.2	8.5%
Commuter Rail	444.7	8.0%
Automated Guideway	6.4	0.1%
Total	5,576.4	100.0%

NOTE: Data include U.S., Canadian, and Mexican public transit operators.

Exhibit 2-17
National Transit Ridership Summary (millions) (2000)(R2,R12,R15)

Country	All Transit	Rail Transit	% by Rail
USA	9,401	3,368	36%
Canada	2,323	669	29%
Mexico	NA	1,540	NA

NA: not available

Exhibit 2-18
Comparison of Key North American Rail Mode Statistics (1995)(R25)

Type	Routes	Avg. Line Length (mi)	Total Length (mi)	Average Station Spacing (mi)	Average Line Speed (mph)
AGT	3	3.9	11.8	0.43	15.1
CR	77	45.8	3,524.5	3.55	32.7
LRT	51	8.6	440.2	0.52	13.7
HR	76	15.7	1,161.1	0.91	22.5

Type	Routes	Avg. Line Length (km)	Total Length (km)	Average Station Spacing (km)	Average Line Speed (km/h)
AGT	3	6.3	19.0	0.70	24.3
CR	77	73.7	5,672.1	5.71	52.7
LRT	51	13.9	708.5	0.83	22.1
HR	76	25.3	1,868.6	1.47	36.2

AGT: automated guideway transit, CR: commuter rail, LRT: light rail transit, HR: heavy rail

OPERATING ENVIRONMENTS

While the rail mode employed on a rail transit line has some bearing on capacity, the type of right-of-way used by the line is of vital importance. The three major types of rights-of-way are described below.

Exclusive Right-of-Way

The right-of-way is reserved for the exclusive use of transit vehicles. There is no interaction with other vehicle types. Intersections with other modes are grade-separated to avoid the potential for conflict. Exclusive rights-of-way provide maximum capacity and the fastest and most reliable service, although at higher capital costs than other right-of-way types. Automated guideway transit systems must operate on this type of right-of-way, as their automated operation precludes any mixing with other modes. This right-of-way type is most common for heavy rail systems and many commuter rail systems, and occurs on at least portions of many light rail systems.

Segregated Right-of-Way

Segregated rights-of-way provide many of the same benefits of exclusive rights-of-way but permit other modes to cross the right-of-way at defined locations such as grade crossings. Segregated rights-of-way are most commonly employed with commuter rail and light rail transit systems. The use of this right-of-way type for heavy rail transit systems has largely been eliminated.

Shared Right-of-Way

A shared right-of-way permits other traffic to mix with rail transit vehicles, as is the case with streetcar lines. While this right-of-way type is the least capital intensive, it does not provide the benefits in capacity, operating speed, and reliability that are provided by the other right-of-way types.

RAIL MODES

Heavy Rail

Introduction and characteristics.

Heavy rail transit (Exhibit 2-19) is by far the predominant urban rail travel mode in North America, in terms of system size and utilization. Exhibit 2-3 illustrated the lead heavy rail transit in the United States has over the other rail modes in both annual passenger trips and annual passenger miles. Heavy rail transit is characterized by fully grade-separated rights-of-way, high level platforms, and high-speed, electric multiple-unit cars.

The expeditious handling of passengers is enabled through the use of long trains of up to 11 cars running frequently. Loading and unloading of passengers at stations is rapid due to level access and multiple double-stream doors.

Power is generally collected from a third rail, but can also be received from overhead wires as in Cleveland, the Skokie Swift in Chicago, and a portion of the Blue Line in Boston. Third-rail power collection, frequent service, and high operating speeds generally necessitate the use of grade-separated pedestrian and vehicular crossings. A small number of grade crossings is an unusual feature of the Chicago system.

Exhibit 2-19
Heavy Rail Examples

(a) Chicago (b) Toronto

(c) Cleveland (d) San Francisco Bay Area

Status of heavy rail systems.

U.S. and Canadian heavy rail systems generally fall into two groups according to their time of initial construction. Pre-war systems are often characterized by high passenger densities and closely spaced stations, although the postwar systems in Toronto and Montréal also fall into this category. The newer U.S. systems tend to place a higher value on passenger comfort and operating speed, as expressed by less crowded trains and a more distant spacing of stations, especially in suburban areas. Newer systems also tend to provide extensive suburban park-and-ride facilities.

BART in the San Francisco Bay Area is a prime example of the latter category with its fast trains and provision of upholstered seats. BART station spacing outside downtown San Francisco and Oakland is great enough to allow the high overall speed required to compete with the automobile. Vancouver's SkyTrain and Toronto's Scarborough Rapid Transit lines are included in the heavy rail category rather than the light rail or automated guideway categories since they most closely resemble heavy rail transit systems in operating practices and right-of-way characteristics.[2]

Some overlap exists between heavy rail, light rail, and AGT.

The high costs of constructing fully grade-separated rights-of-way (subway or elevated) for heavy rail transit have limited expansion in recent decades. Exhibit 2-20 identifies the 18 existing heavy rail transit systems in North America.

Of the U.S. heavy rail systems, the three New York City systems carried two-thirds of all riders using this mode in 2000. Heavy rail transit's efficiency in moving large volumes of passengers in densely populated areas is evident in this, the largest metropolitan area in the United States. Heavy rail transit plays a key role in enabling such dense urban areas to exist. In 1995, 51.9% of business day travel into Lower Manhattan was by heavy rail transit. During the 7:00 to 10:00 a.m. time period, this share increased to 62.2%.(R24)

---

[2] Philadelphia's Norristown high-speed line is another illustration of the difficulty of characterizing some rail transit modes. The Norristown line is entirely grade-separated, uses third rail, and has high platforms (characteristics often associated with heavy rail), but uses one-car trains, makes many stops only on demand, and has on-board fare collection (characteristics often associated with light rail). SEPTA and the FTA classify it as heavy rail.

Exhibit 2-20
North American Heavy Rail Transit Systems (2000)(R2,R12,R15,R25)

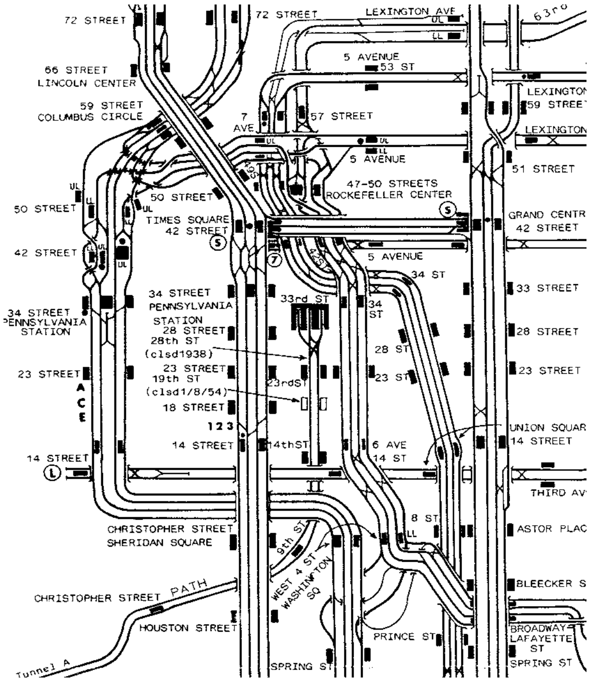
	Directional Route Length		Avg. Weekday	Vehicles Operated
Region	**(mi)**	**(km)**	**Boardings**	**in Max. Service**
Atlanta	92.1	148.2	274,000	178
Baltimore	29.4	47.3	47,800	66
Boston	76.3	122.8	448,400	320
Chicago	206.3	331.9	589,400	914
Cleveland	38.2	61.5	24,100	28
Los Angeles	31.9	51.3	83,200	58
Mexico City	250.7	403.4	4,405,400**	2,450**
Miami	53.2	85.6	47,200	80
Montréal	76.0	122.3	920,600	555*
New York (MTA-NYCT)	492.9	793.1	5,512,700	4,891
New York (MTA-Staten Isl.)	28.6	46.0	15,400	40
New York (PATH)	28.6	46.0	270,600	288
Philadelphia (SEPTA)	76.1	122.4	296,200	298
Philadelphia (PATCO)	31.5	50.7	38,000	96
San Francisco (BART)	190.1	305.9	310,300	523
San Juan	21.4	34.4	scheduled 2003 opening	
Toronto	70.2	113.0	881,900**	540**
Vancouver	35.8	57.6	146,400**	140**
Washington	193.5	311.3	738,200	632

*1995 data
**2001 data provided by the Canadian Urban Transit Association or individual agencies

Complexity of the New York subway.

The New York City subway system is one of the largest and most complex in the world. This extensive subway system carries almost twice as many riders as does the local bus system. Most lines are triple or quadruple tracked to allow the operation of express services. A large number of junctions permit trains to be operated on a variety of combinations of line segments to provide an extensive network of service. Exhibit 2-21 shows a diagram of the subway tracks in midtown Manhattan.

Exhibit 2-21
MTA-NYCT Subway Tracks in Midtown Manhattan

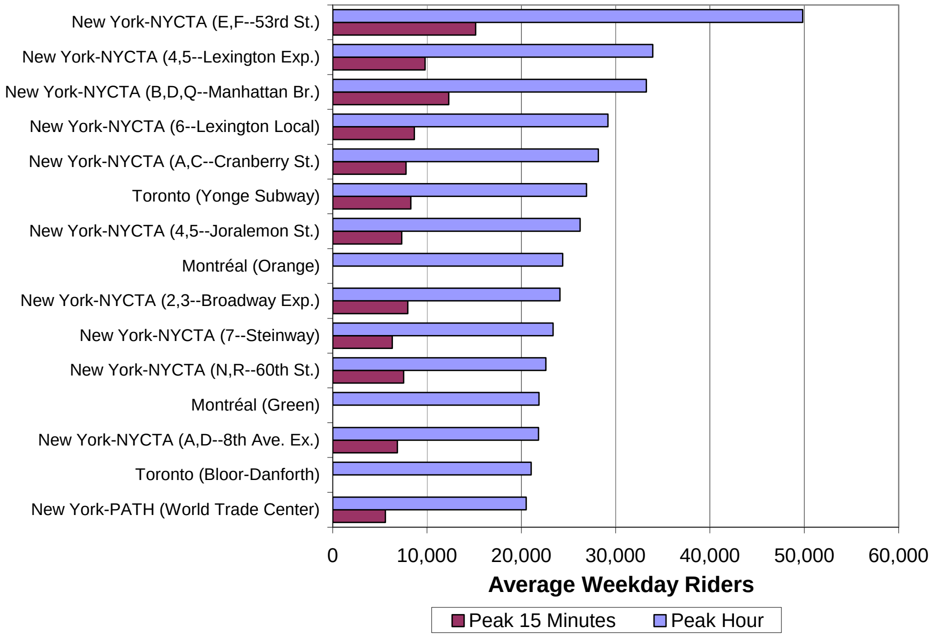


SOURCE: From *New York Railway Map*, courtesy John Yonge, © 1993 Quail Map Company, 31 Lincoln Road, Exeter, England.

Exhibit 2-22 illustrates the peak hour and peak 15-minute passenger flow rates for the 15 busiest heavy rail transit trunk lines in the U.S. and Canada. The graph uses trunks rather than routes in order to group those services sharing tracks together. All the trunks listed are double tracked and have at least one station used by all routes.

When four-track lines in New York are taken into consideration, the maximum load is a combination of the Lexington Avenue Express and Local at 63,200 passengers per peak hour direction, with almost comparable volumes on the combined Queens Boulevard lines at Queens Plaza. In comparison, the busiest two-track heavy rail line in the world is in Hong Kong, with 84,000 passengers per peak hour direction.

Exhibit 2-22
Peak Hour and Peak 15-minute Flows for the Busiest 15 U.S. and Canadian Heavy Rail Transit Trunk Lines (1995)[R25]



NOTE: Data could not be obtained for Philadelphia's SEPTA. However, it is unlikely that any of the SEPTA rapid transit lines would feature in this chart if data were available. Peak 15-minute flow data were not available for all lines for which peak hour data were available.

Light Rail Transit

Light rail transit, often known simply as LRT, began as a development of the streetcar to allow higher speeds and increased capacity. Light rail transit is characterized by its versatility of operation, as it can operate separated from other traffic below grade, at-grade, or on an elevated structure, or can operate together with motor vehicles on the surface (Exhibit 2-23). Service can be operated with single cars or multiple-car trains. Electric traction power is obtained from an overhead wire, thus eliminating the restrictions imposed by having a live third-rail at ground level. This flexibility helps to keep construction costs low and explains the popularity this mode has experienced since 1978 when the first of 14 new North American light rail transit systems was opened in Edmonton. These newer LRT systems have adopted a much higher level of segregation from other traffic than earlier systems enjoyed.

Diesel light rail.

A recent trend is the introduction of diesel light rail cars by European manufacturers. Trials of such cars have generated considerable interest in some areas, given the ease with which diesel light rail service can be established on existing rail lines. Ottawa opened a 5-mile (8-km) line connecting two busway stations in 2002. New Jersey Transit is constructing a diesel light rail line between Trenton and Camden, scheduled to open in 2003. It should be noted that the TRB Committee on Light Rail Transit's definition of light rail encompasses only electric-powered lines, and therefore would not consider diesel light rail to be "light rail transit." However, The TCQSM's capacity procedures are primarily based on right-of-way type, with mode a secondary consideration.

the TCQSM's capacity procedures are based primarily on right-of-way type and secondarily by mode. The basic light rail capacity procedures can be applied to diesel light rail, but differences in vehicle operating characteristics (such as acceleration) would need to be taken into account.

Three major types of light rail operations exist:

- *Light rail,* with relatively frequent service along mostly exclusive or segregated rights-of-way, using articulated cars and up to four-car trains.
- *Streetcars,* operating along mostly shared or segregated rights-of-way, with one-car (or rarely, two-car) trains. Vehicle types and ages can vary greatly.
- *Vintage trolleys* provide mainly tourist- or shopper-oriented service, often at relatively low frequencies, using either historic vehicles or newer vehicles designed to look like historic vehicles.

Exhibit 2-23
Light Rail Examples


(a) Light Rail (San Diego) (b) Light Rail (Portland, Oregon)


(c) Light Rail (Cleveland) (d) Streetcar (Philadelphia)


(e) Streetcar (San Francisco) (f) Vintage Trolley (Memphis)

As of 2002, there are 27 light rail and streetcar systems and 5 vintage trolley systems operated by public transit agencies in North America. An additional three light rail, one streetcar, and one vintage trolley systems will open by 2004. These systems are listed in Exhibit 2-24.

Exhibit 2-24
North American Light Rail Transit Systems (2000)(R2,R12,R15)

		Dir. Route Length		Avg. Weekday	Veh. Operated
Region	**Type**	**(mi)**	**(km)**	**Boardings**	**in Max. Service**
Baltimore	LR	57.6	92.7	27,400	40
Boston	LR/SC	51.0	82.1	255,600	154
Buffalo	LR	12.4	20.0	23,200	23
Calgary	LR	40.4	65.0	132,100	81
Cleveland	LR	30.8	49.6	14,100	25
Dallas	LR	40.8	65.6	37,700	48
Denver	LR	28.0	45.1	22,500	29
Edmonton	LR	13.9	22.4	38,000*	31*
Galveston, TX	VT	5.2	8.4	300**	4**
Guadalajara	LR	29.8	48.0	149,000	NA
Houston	LR	14.0	22.5	scheduled 2004 opening	
Jersey City (Hudson-Bergen)	LR	13.8	22.2	3,100	12
Kenosha, WI	VT	1.9	3.1	150	1
Little Rock	VT	4.2	6.8	scheduled 2004 opening	
Los Angeles	LR	82.4	132.6	91,300	51
Memphis	VT	5.8	9.3	3,500	9
Mexico City	LR	32.3	52.0	55,000	NA
Minneapolis	LR	23.2	37.3	scheduled 2004 opening	
Monterrey	LR	28.6	46.0	123,000	NA
New Orleans	SC/VT	16.0	25.7	14,900	23
Newark (City Subway)	LR	8.3	13.4	16,900	16
Ottawa	DLR	10.0	16.1	5,800*	2*
Philadelphia	LR/SC	69.3	111.5	83,100	108
Pittsburgh	LR/SC	34.8	56.0	24,600	47
Portland (MAX)	LR	64.9	104.4	73,600	56
Portland (Streetcar)	SC	4.8	7.7	4,200*	4*
Sacramento	LR	40.7	65.5	29,100	32
St. Louis	LR	34.0	54.7	41,500	26
Salt Lake City	LR	29.6	47.6	20,100	20
San Diego	LR	96.6	155.4	83,500	83
San Francisco	LR/SC	70.0	112.6	134,600	125
San Jose	LR	55.8	89.8	25,600	43
Seattle	VT	3.7	6.0	600	3
Southern New Jersey	DLR	68.0	109.4	scheduled 2003 opening	
Tacoma	SC	3.2	5.2	opened 2003	2†
Tampa	VT	4.6	7.4	1,200*	4*
Toronto	SC	136.4	219.5	196,000	155*

*2002 data from agency **1998 data †2003 data from agency
LR = light rail, DLR = diesel light rail, SC = streetcar, VT = vintage trolley, NA = not available
NOTE: Only those vintage trolleys operated by public transit agencies are included. The privately operated Tandy Subway in Fort Worth, 1.0-mi (1.6-km) long, closed in 2002.

Light rail passenger volumes.

Exhibit 2-25 gives typical peak hour peak direction passenger volumes, service frequencies, and train lengths for principal U.S. and Canadian light rail transit lines. Exhibit 2-26 provides an indication of the maximum peak passenger volumes carried on a number of light rail systems for which data are available. The exhibit illustrates the peak passenger volumes carried over the busiest segment of the LRT system; in many cases, this represents passengers being carried on more than one route.

Historic streetcar volumes.

Some streetcar and light rail lines carried substantially higher passenger flows in the peak years of 1946-1960. Post-World War II streetcars operated at as close as 30-second headways both on-street (Pittsburgh) and in tunnels (Philadelphia). Peak hour passenger flows were approximately 9,000 persons per hour.(R27) San Francisco's Market Street surface routes carried 4,900 peak hour one-way passengers per hour before they were placed underground.(R27) Now, the observed number of peak hour passengers at the maximum load point usually reflects demand rather than capacity. Peak 15-minute volumes expressed as hourly flow rates are about 15% higher.

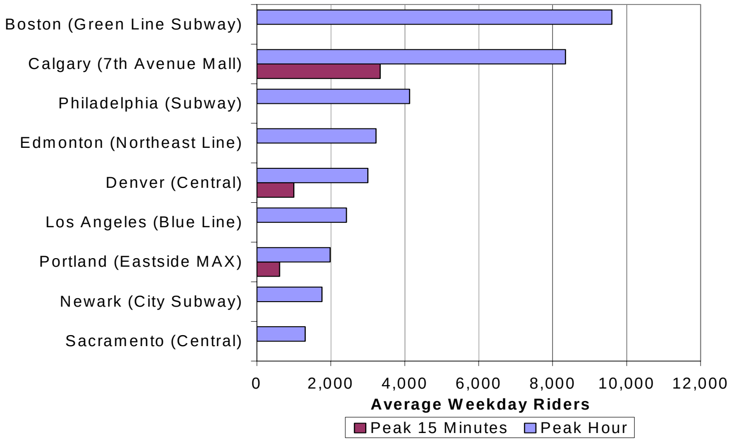
Exhibit 2-25
Observed U.S. and Canadian LRT Passenger Volumes: Peak Hour at the Peak Point for Selected Lines (1993-96 Data)(R25)

City	Location	Trains/ h	Cars/ h	Head-way (s)	Peak Hour p/dir	Peak Hour Load (p/ft)	Peak Hour Load (p/m)
Boston	Green Line Subway*	45	90	80	9,600	1.6	5.3
Calgary	South Line	11	33	320	4,950	2.1	6.8
Denver	Central	12	24	300	3,000	1.4	4.7
Edmonton	Northeast LRT	12	36	300	3,220	1.2	4.0
Los Angeles	Blue Line	9	18	400	2,420	1.6	5.4
Newark	City Subway	30	30	120	1,760	1.4	4.6
Philadelphia	Subway-Surface*	60	60	60	4,130	1.5	5.0
Portland	Eastside MAX	9	16	400	1,980	1.6	5.1
Sacramento	Sacramento LRT	4	12	900	1,310	1.5	4.9
Toronto	Queen at Broadway*	51	51	70	4,300	1.9	6.1

*Trunks with multiple-berth stations.

NOTE: In a single hour a route may have different lengths of trains and/or trains with cars of different lengths or seating configurations. Data represent the average car. In calculating the passengers per foot of car length, the car length is reduced by 9% to allow for space lost to driver cabs, stairwells, and other equipment. Data were not available for the heavily used Muni Metro subway in San Francisco.

Exhibit 2-26
Peak Hour and Peak 15-Minute Directional Flows for Selected U.S. and Canadian Light Rail Transit Trunks (1995)(R25)



NOTE: Data not available for the heavily used Muni Metro subway in San Francisco.

Commuter Rail

Commuter rail (Exhibit 2-27) is generally a long distance transit mode using trackage that is a part of the general railroad system but which may be used exclusively for passenger movement. A few commuter rail operations, such as the Long Island Rail Road and the New Canaan branch of MTA Metro-North's New Haven line, were built solely for passenger movement. Track may be owned by the transit system or access may be by agreement with a freight railroad. Similarly, train operation may be by the transit agency, the track owner, or a third-party contractor. Service is heavily oriented towards the peak commuting hours, particularly on the smaller systems. All-day service is operated on many of the mainlines of the larger commuter rail systems and the term *regional rail* is more appropriate in these cases.

Exhibit 2-27
Commuter Rail Examples

(a) Toronto

(b) Chicago

Commuter rail scheduling.

Commuter rail scheduling is often tailored to the peak travel demand rather than operating consistent headways throughout the peak period. Where track arrangements and signaling permit, operations can be complex with the use of local trains, limited-stop express trains and zoned express trains. Zoned express trains are commonly used on busy lines with many stations where express trains serve a group of stations then run non-stop to the major destination station(s).

Commuter Rail Propulsion and Equipment

Diesel and electric power are both used for traction on commuter rail lines. Electric traction is capital intensive but permits faster acceleration while reducing noise and air pollution. It is used mainly on busy routes, particularly where stops are spaced closely together or where long tunnels are encountered. Both power sources can be used for locomotive or multiple-unit operation. All cars in a multiple-unit train can be powered, or some can be unpowered "trailer" cars which must be operated in combination with powered cars. Electric multiple-unit cars are used extensively in the New York, Philadelphia, and Chicago regions, and the entire SEPTA regional rail system in Philadelphia is electrified. Dallas is currently the only city operating diesel multiple-unit cars in commuter rail service.

Multiple-unit cars are self-propelled, as opposed to needing a locomotive to provide power.

Locomotive-hauled commuter trains are standard for diesel operation and are becoming more common on electrified lines as a way to avoid the high costs of multiple-unit cars. New Jersey Transit and SEPTA have both purchased electric locomotives as an economical alternative to buying multiple-unit cars. Other systems value the flexibility of multiple-unit cars in varying train length. Montréal's STCUM commuter rail system has replaced a mixed fleet with a standard new electric multiple-unit design.

Commuter rail train length can be tailored to demand with cars added and removed as ridership dictates. This is particularly easy with multiple-unit equipment and can result in trains of anywhere from two to twelve cars in length. Where train length is constant all day, unneeded cars can be closed to passengers to reduce staffing needs and the risk of equipment damage.

Passenger comfort and car design.

Commuter rail is unique among the rail transit modes in that a high priority is placed on passenger comfort, as journeys are often long and the main source of competition is the automobile. All lines operate with a goal of a seat for every passenger except for the busy inner portions of routes where many lines funnel together and frequent service is provided. Such is the case for the 20-minute journey on the Long Island Rail Road between Jamaica and Penn Stations. Service between these points is very frequent (trains on this four-track corridor operate as close as 1 minute apart in the peak hours) as trains from multiple branches converge at Jamaica to continue to Manhattan.

Commuter rail cars are generally designed with the maximum number of seats possible, although this tradition is changing somewhat where persons in wheelchairs and bicycles are accommodated. A number of common approaches are taken to achieve maximum seating over the car length. The simplest is the use of 2+3 ("two-by-three") seating where five seats are placed in each row as opposed to the usual four. This can be done quite easily in wide railroad-type cars and brings the number of seats per car to around 120. It is not especially popular with passengers. This type of seating is used by many agencies, including the Long Island Rail Road and the MBTA in Boston, but it places a constraint on aisle width that may make the provision of wheelchair access difficult.

The other main approach to increasing car capacity is to add additional seating levels to the car, subject to any height restrictions, such as tunnels and underpasses, on the rail lines. The gallery-type car is one example and adds an upper seating level to the car with an open well to the lower level. The well serves to permit ticket collection and inspection from the lower level but does limit the upper level to single seats on each side. Gallery cars can typically seat 150 to 160 passengers and are used most extensively by Chicago's Metra commuter rail system. A more recent development is the bi-level car[3] which has upper and lower levels over the center of the car with an intermediate level at each end of the vehicle. Toronto's GO Transit popularized this design with relatively spacious seating for 160. It is now also being used by Metrolink in Los Angeles, the Coaster in San Diego, the Sounder in Seattle, Tri-Rail in Florida, and the West Coast Express in Vancouver. This style of car has become common on many European commuter rail (suburban) services.

Commuter rail platform height.

Passenger access to commuter rail trains can be from platform (high) or ground level (low). High-level boarding is commonly used on busy lines or at major stations to speed passenger movements. Standard railway type "traps" in the stepwells allow cars to use both types of platform but require the train crew to raise and lower the trap door above the steps. The electric multiple unit cars used by the Northern Indiana Commuter Transportation District on the South Shore line out of Chicago employ an extra set of doors at the center of the cars that are used exclusively at high platform stations while the car end doors are fitted with traps in the conventional manner for use at high and low platform stations. This arrangement is also used on the electric multiple-unit cars used on Montréal's Mount Royal tunnel line.

Commuter rail status.

As of 2002, commuter rail services operated in 18 North American metropolitan regions, with more than one agency providing service in three of these regions, as shown in Exhibit 2-28. There has been rapid growth in this mode as a result of the availability of government funding and the relatively low capital costs of the mode. This is offset by higher operating costs per passenger trip—particularly for lower-volume commuter rail services.

Exhibit 2-28
North American Commuter Rail Systems (2000)(R2,R12)

	Directional Route Length		Avg. Weekday	Veh. Operated in
Region	**(mi)**	**(km)**	**Boardings**	**Max. Service**
Baltimore (MARC)	373.4	600.9	20,900	110
Boston	710.2	1,143.0	129,500	379
Burlington	25.0*	40.2*	200*	2*
Chicago (Metra)	940.4	1,513.4	268,400	996
Chicago (N. Indiana)	179.8	289.4	12,800	52
Dallas-Ft. Worth	51.6	83.0	4,200	12
Los Angeles	770.0	1,239.2	26,300	134
Miami	142.2	228.8	7,400	20
Montréal	116.8	188.0	51,900	NA
New Haven	101.2	162.9	1,100	16
New Jersey	1,091.4	1,756.4	212,000	735
New York (Long Island RR)	638.2	1,027.1	355,000	954
New York (Metro-North)	545.7	878.2	249,100	772
Philadelphia (PennDOT)	144.4	232.4	700	9
Philadelphia (SEPTA)	449.2	722.9	104,200	291
San Diego	82.2	132.3	4,300	20
San Francisco (CalTrain)	153.6	247.2	30,600	93
San Jose (ACE)	172.0	276.8	3,500	12
Seattle	78.6	126.5	1,100	14
Syracuse	7.0	11.3	100*	1*
Toronto	448.7	722.0	117,100	296**
Vancouver	80.8	130.0	7,600	32**
Washington (VRE)	177.5	285.7	8,100	54

*2002 data
**2001 data from CUTA or individual agencies
NA: not available
Additional source: operator survey
NOTE: Burlington's Champlain Flyer ceased operations in March 2003. Syracuse's OnTrack City Express operates 11:15 a.m. to 6:30 p.m. Wednesday through Sunday.

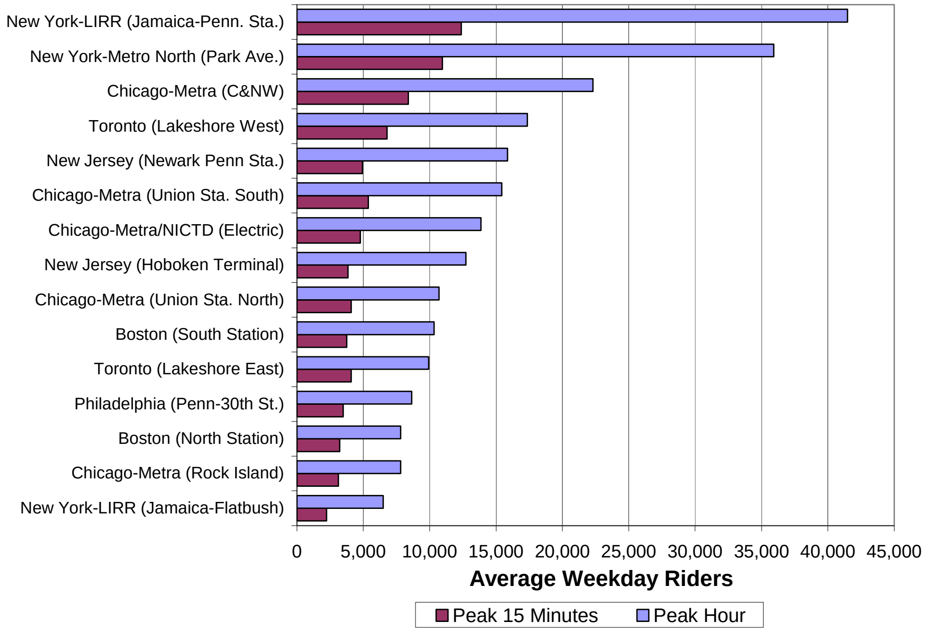
---

[3] Less commonly known as tri-level cars, as there are technically three floor levels.

Extensions and expansions are planned on other systems to enlarge the service area and provide additional parking for patrons. With many commuter rail lines serving low-density suburban areas, the provision of adequate customer parking is a key to maximizing ridership. To meet this need, "cornfield" stations are built to allow parking capacity to be expanded at low cost in relatively undeveloped areas.

Commuter rail ridership is highly concentrated—the New York and Chicago metropolitan systems are the four busiest on the continent, as shown in Exhibit 2-28. Toronto's GO Transit, one of the first of the new generation of commuter rail systems, ranks fifth. Exhibit 2-29 illustrates the peak hour and peak 15-minute flows handled on the busier commuter rail lines in North America.

Exhibit 2-29
Peak Hour and Peak 15-minute Flows for the Busiest 15 U.S. and Canadian Commuter Rail Trunk Lines (1995)(R25)



Automated Guideway Transit (AGT)

As their name indicates, AGT systems (Exhibit 2-30) are completely automated (vehicles without drivers), with personnel limited to a supervisory role. Their automated nature requires guideways to be fully separated from other traffic. Cars are generally small and service is frequent—the name "people mover" is often applied to these systems, which can take on the role of horizontal elevators. The technologies used vary widely and include rubber-tired electrically propelled vehicles, monorails, and cable-hauled vehicles.

AGT status.

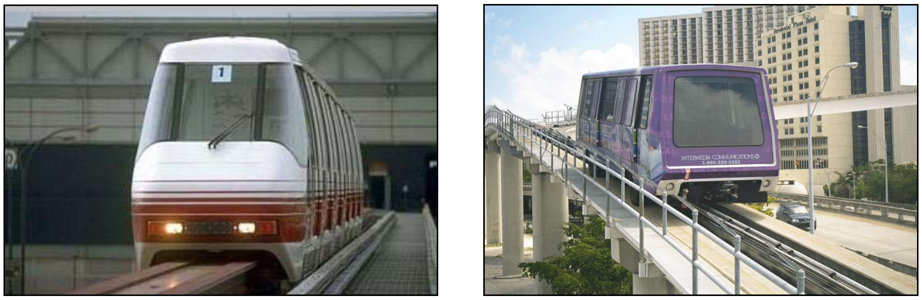
Nearly 40 AGT systems are operated in the United States today, with none operating in Canada. The SkyTrain in Vancouver and the Scarborough RT in Toronto, while automated and sharing the same basic technology that is used on the Detroit People Mover, have more in common with heavy rail systems than AGT lines in their service characteristics, ridership patterns, and operating practices, and so are included in the heavy rail listings.

AGT systems operate in four types of environments:

- Airports;
- Institutions (universities, shopping malls, government buildings);
- Leisure and amusement parks (e.g., Disneyland); and
- Public transit systems.

Most of these systems are operated by airports or by private entities, especially as amusement park circulation systems.

Exhibit 2-30
Automated Guideway Transit Examples



(a) Airport Shuttle (Newark)

(b) Downtown People Mover (Miami)

(c) Institutional (Honolulu)

(d) Leisure (Memphis)

AGT transit services.

There are three public transit AGT systems operating in the United States, serving the downtown areas of Detroit, Jacksonville, and Miami. The Detroit People Mover line has remained unchanged from its opening in 1987, while the Miami MetroMover added two extensions in 1994. Jacksonville opened the first 0.7-mile (1.1-kilometer) section of its Skyway in 1989, with new extensions opening from 1997 to 1999 to serve both sides of the St. Johns River.

A relatively large institutional system is the one at the West Virginia University campus in Morgantown. This 3-mile (5-kilometer) line features off-line stations that enable close headways, down to 15 seconds, and permit cars to bypass intermediate stations. The cars are small, accommodating only 21 passengers, and are operated singly. On-demand service is possible during off-peak hours.

Exhibit 2-31 lists ridership and other statistics for the North American AGT systems used for public transit.

Exhibit 2-31
North American AGT Systems Used for Public Transit (2000)[R12]

	Directional Route Length		Avg. Weekday	Vehicles Operated in
Region	**(mi)**	**(km)**	**Boardings**	**Maximum Service**
Detroit	2.9	4.7	4,200	7
Jacksonville	4.3	6.9	2,100	6
Miami	8.5	13.7	14,300	15

Daily ridership data for other North American AGT systems are shown in Exhibit 2-32. Caution should be exercised with many of these figures, as the non-transit systems are not required to provide the reporting accuracy mandated by the FTA. Ridership on many systems is also likely affected by seasonal patterns and less pronounced peaking (with the notable exception of airport systems) than occurs on transit systems. Regardless of these qualifications, the total daily ridership on the 36 non-transit systems amounts to over 500,000, compared to about 20,000 on the three transit AGT lines.

Exhibit 2-32
U.S. Non-Transit AGT Systems (2003)

Location	Technology	1995 Avg. Daily Ridership
AIRPORTS		
Atlanta, GA	People Mover	109,000
Chicago-O'Hare, IL	People Mover	12,000
Cincinnati, OH	Cable	30,000
Dallas-Fort Worth, TX	People Mover	50,000
Denver, CO	People Mover	50,000
Detroit, MI	Cable	NA
Houston, TX	People Mover	8,500
Las Vegas, NV	People Mover	15,000
Miami, FL	People Mover	15,000
Minneapolis, MN (Lindbergh Term.)	Cable	NA
Minneapolis, MN (parking)	Cable	NA
Newark, NJ	Monorail	NA
New York, NY (JFK AirTrain)	Automated Light Rail	opens 2003
Orlando, FL	People Mover	49,000
Pittsburgh, PA	People Mover	50,000
San Francisco, CA	People Mover	NA
Seattle-Tacoma WA	People Mover	43,000
Tampa, FL (concourses)	Monorail	71,000
Tampa, FL (parking)	Monorail	8,000
INSTITUTIONAL		
Clarian Health, Indianapolis, IN	People Mover	NA
Duke Univ. Hospital, NC	Cable	2,000
Getty Center, Los Angeles, CA	Cable	NA
Huntsville Hospital, AL	Cable	NA
Los Colinas, Dallas, TX	People Mover	NA
Mystic Transp. Center, Boston, MA	Cable	NA
Pearlridge Mall, Honolulu, HI	Monorail	4,000
Senate Subway, DC	Linear Induction	10,000
University of West Va., Morgantown	People Mover	16,000
LEISURE		
Bellagio-Monte Carlo, Las Vegas, NV	Belt	NA
Circus-Circus, Las Vegas, NV	Cable	11,000
Circus-Circus, Reno, NV	Cable	6,000
Circus-Water Park, Las Vegas, NV	Cable	2,000
Luxor-Mandalay Bay, Las Vegas, NV	Cable	10,000
Mudd Island, Memphis, TN	Cable Monorail	2,000
Mirage-Treasure Is., Las Vegas, NV	Cable	8,000
MGM-Sahara, Las Vegas, NV	Monorail	opens 2004
Primm Vly.-Buffalo Bill, Primm, NV	Monorail	NA
Whiskey Pete's, Primm, NV	Cable	NA
Total		532,500

NA: not available (Los Colinas) or not applicable (others)—systems opened after 1995
NOTE: "People Mover" indicates third-rail power collection, and either steel-wheeled or rubber-tired vehicles.
SOURCES: Transit Pulse, P.O. Box 249, Fields Corner Station, Boston, MA 02122; owner data

Monorail

Although often thought of as being relatively modern technology, monorails (Exhibit 2-33) have existed for over 100 years, with the first monorail, in Wuppertal, Germany, having opened in 1901.(R28) Vehicles typically straddle or are suspended from a single rail. Driverless monorails fall into the category of AGT, and include the systems identified as monorails in Exhibit 2-32, plus the Jacksonville Skyway. Monorails that use drivers are by definition not automated, and thus form their own category. For the purposes of determining capacity, monorails can use the grade-separated rail procedures provided in Part 5, with appropriate adjustments for the technology's particular performance characteristics.

The 0.9-mile (1.5-kilometer) Seattle Center monorail, originally constructed for the 1962 World's Fair, is the only existing U.S. example of a non-automated public transit monorail. It carried approximately 6,100 passengers a day in 1999.(R12) About 1 dozen privately operated monorails are in use at North American zoos and amusement parks. Outside the United States, several monorails are used for public transit service similar to an elevated heavy rail line. Examples include the Wuppertal, Germany monorail, seven systems in Japan, and a downtown circulator in Sydney, Australia.(R22)

Exhibit 2-33
Monorail Examples


(a) Straddle (Seattle) (b) Suspended (Wuppertal, Germany)

Funiculars, Inclines, and Elevators

Funicular railways, also known as *inclined planes* or simply *inclines*, are among the oldest successful forms of mechanized urban transport in the United States, with the first example, Pittsburgh's Monongahela Incline, opening in 1870 (and still in operation today). Funiculars are well suited for hilly areas, where most other transportation modes would be unable to operate, or at best would require circuitous routings. The steepest funicular in North America operates on a 100% (45°) slope, and a few international funiculars have even steeper grades.

Early funiculars were used to transport railroad cars and canal boats in rural areas, as well as to provide access to logging areas, mines, and other industrial sites. Funiculars have played a role in many transit systems, moving not just people, but cars, trucks, and streetcars up and down steep hillsides. An example of a remaining vehicle-carrying incline that is part of a transit system is in Johnstown, Pennsylvania. Nearby, in Pittsburgh, the Port Authority owns the 2 remaining inclines from a total of more than 15 that once graced the hilly locale.

Inclined plane status.

The number of remaining inclined planes in North America is small, but they are used extensively in other parts of the world to carry people up and down hillsides in both urban and rural environments. Switzerland alone has over 50 funiculars, including urban funiculars in Zürich and Lausanne. Many other cities worldwide have funiculars, including Barcelona, Budapest, Haifa, Heidelberg, Hong Kong, Paris, Prague, and Valparaíso, Chile (which has 15). Many of these systems are less than 30 years old or have been completely rebuilt in recent years. In addition, funiculars are still being built for access to industrial plants, particularly dams and hydroelectric power plants, and occasionally, ski resorts. New funiculars, primarily in Europe, also provide subway or metro station access. New designs rarely handle vehicles and make use of hauling equipment and controls derived from elevators.

The person capacity of older inclined planes is modest, but modern designs can carry large numbers of people.

Capacity is a function of length, number of intermediate stations (if any), number of cars (one or two), and speed. Person capacity is usually modest—on the order of a few hundred passengers per hour. However, high-speed, large-capacity funiculars are in use, and a new facility, designed for metro station access in Istanbul, has a planned capacity of 7,500 passengers per direction per hour.

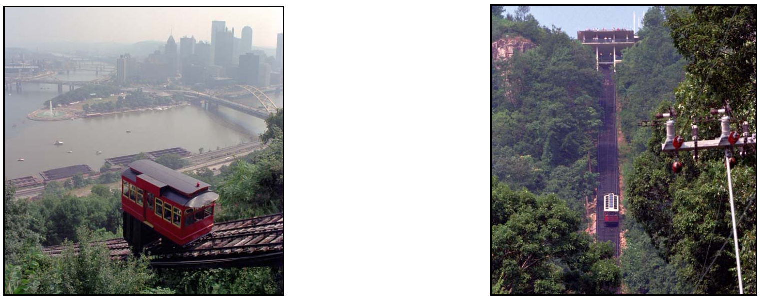
Most typical design involves two cars counterbalancing each other, connected by a fixed cable, using either a single railway-type track with a passing siding in the middle or double tracks. Single-track *inclined elevators* have just one car and often do not use railway track—see, for example, the Ketchikan example in Exhibit 2-34(e). When passing sidings are used, the cars are equipped with steel wheels with double flanges on one set of outer wheels per car, forcing the car to always take one side of the passing siding without the need for switch movement. Earlier designs used a second emergency cable, but this is now replaced by automatic brakes, derived from elevator technology, that grasp the running rails when any excess speed is detected. Passenger compartments can either be level, with one end supported by a truss, or sloped, with passenger seating areas arranged in tiers.

To minimize wear-and-tear on the cable, and make the design mechanically simpler, an ideal funicular alignment is a straight line, with no horizontal or vertical curves. To achieve this design, a combination of viaducts, cuttings, and/or tunnels may be required, as illustrated in Exhibit 2-34(c). However, many funiculars have curved alignments.

Public elevators, as shown in Exhibit 2-34(f), are occasionally used to provide pedestrian movement up and down steep hillsides where insufficient pedestrian volumes exist to justify other modes. These elevators allow pedestrians to bypass stairs or long, out-of-direction routes to the top or bottom of the hill.

Exhibit 2-35 provides statistics for North American funiculars.

Exhibit 2-34
Funicular and Elevator Examples



(a) Passenger Incline (Pittsburgh—Duquesne Incline) (b) Passenger Incline (Chattanooga)

(c) Passenger Incline (Mürren, Switzerland) (d) Vehicle Incline (Johnstown, Pennsylvania)

(e) Inclined Elevator (Ketchikan, Alaska) (f) Public Elevator (Oregon City, Oregon)

Exhibit 2-35
U.S. and Canadian Funiculars and Public Elevators (2001)(R2,R3)

Location	Average Weekday Boardings	Length (ft)	Length (m)	Maximum Grade (%)
PUBLIC TRANSIT FUNICULARS				
Chattanooga, TN (Lookout Mountain)	1,400	4,750	1,448	73
Johnstown, PA (Inclined Plane)	600	897	273	71
Pittsburgh, PA (Duquesne Incline)	1,200	400	122	50
Pittsburgh, PA (Monongahela Incline)	2,600	635	194	58
OTHER FUNICULARS				
Altoona, PA (Horseshoe Curve)	NA	270	82	37
Cañon City, CO (Royal Gorge)	NA	1,550	473	100
Diablo, WA (Seattle City Light)	NA	560	171	56
Dubuque, IA (Fenelon Place Elevator)	NA	296	90	83
Industry, CA (Industry Hills Resort)	NA	492	150	33
Los Angeles, CA (Angels Flight)	(closed)	298	91	33
Niagara Falls, ON	NA	170	52	73
Québec, QC	NA	287	87	93
PUBLIC ELEVATORS				
Oregon City, OR	NA	Not applicable		

Additional sources: Owner data. Single-track inclined elevators not included in exhibit.
NA: not available.

Aerial Ropeways

Aerial ropeways (Exhibit 2-36) encompass a number of modes that transport people or freight in a *carrier* suspended from an aerial rope (wire cable). The carrier consists of the following components:

- A device for supporting the carrier from the rope: either a *carriage* consisting of two or more wheels mounted on a frame that runs along the rope, or a *fixed* or *detachable grip* that clamps onto the rope;
- A unit for transporting persons or freight: an enclosed *cabin,* a partially or fully enclosed *gondola,* or an open or partially enclosed *chair*; and
- A *hanger* to connect the other two pieces.

The rope may serve to both suspend and haul the carrier (*monocable*); or two ropes may be used: a fixed track rope for suspension and a moving haul rope for propulsion (*bicable*); or multiple ropes may be used to provide greater wind stability. Carriers can operate singly back-and-forth, or as part of a two-carrier shuttle operation, or as part of a multiple-carrier continuously circulating system.

The common aerial ropeway modes are the following:

- *Aerial tramways,* which are suspended by a carriage from a stationary track rope, and propelled by a separate haul rope. Tramways have one or, more commonly, two relatively large (20 to 180 passenger) cabins that move back and forth between two stations. Passenger loading occurs while the carrier is stopped in the station.
- *Detachable-grip aerial lifts*, consisting of a large number of relatively small (6 to 15 passenger) gondolas[4] or 2 to 8 passenger chairs that travel around a continuously circulating ropeway. The carriers move at higher speeds along the line, but detach from the line at stations to slow to a creep speed (typically 0.8 ft/s or 0.25 m/s) for passenger loading.
- *Fixed-grip aerial lifts,* which are similar to detachable-grip lifts, with the important exception that the carriers remain attached to the rope through stations. Passenger loading and unloading either occurs at the ropeway line speed (typical for ski lifts), or by slowing or stopping the rope when a carrier

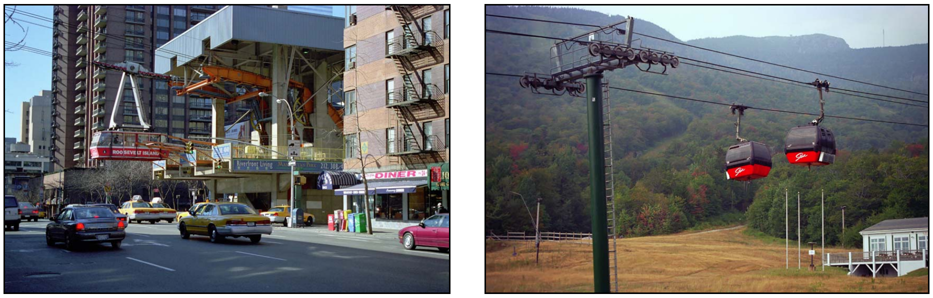
---

[4] The term "gondola" is frequently used to apply to the entire aerial lift, rather than just the passenger carrier, although this is incorrect usage, according to the ANSI B77.1 definition.

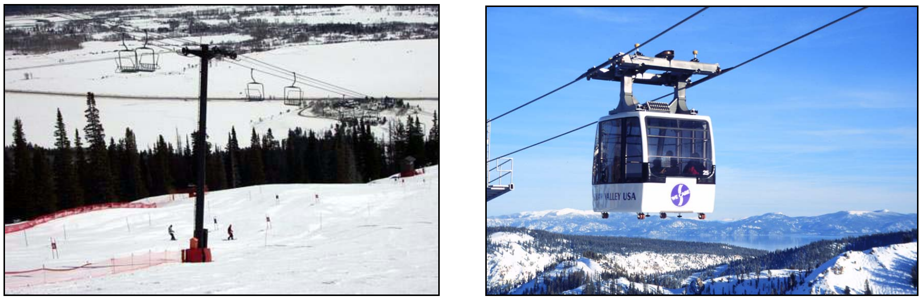
arrives in a station (typical for gondolas). Some fixed-grip gondolas are designed as *pulse* systems, where several carriers are attached to the rope in close sequence. This allows the rope to be slowed or stopped fewer times, as several carriers can be loaded or unloaded simultaneously in stations.

- *Funitels* are a relatively new variation of detachable-grip aerial lifts, with the cabin suspended by two hangers from two haul ropes, allowing for longer spans between towers and improved operations during windy conditions.

Exhibit 2-36
Aerial Ropeway Examples



(a) Aerial Tramway (New York) (b) Detachable-Grip Gondola (Stowe, Vermont)



Nathan Kendall/Squaw Valley Ski Corp.

(c) Detachable-Grip Chair Lift (Jackson, Wyoming) (d) Funitel (Squaw Valley, California)

Aerial ropeways are most often associated with ski areas, but are also used to carry passengers across obstacles such as rivers or narrow canyons, and as aerial rides over zoos and amusement parks. A few are used for public transportation. The Roosevelt Island aerial tramway in New York City, connecting the island to Manhattan, carries approximately 3,000 people each weekday. A gondola system in Telluride, Colorado, transports residents, skiers, and employees between the historic section of Telluride, nearby ski runs, and the Mountain Village resort area, reducing automobile trips between the two communities and the air pollution that forms in the communities' box canyons. In 2006, the Delaware River Port Authority plans to complete a detachable-grip gondola across the river between Philadelphia and Camden, primarily to serve tourists visiting attractions on both sides of the river. Finally, several North American ski areas use aerial ropeways for site access from remote parking areas, as an alternative to shuttle buses.

Aerial ropeway alignments are typically straight lines, but allow changes in grade (vertical curves) over the route. Intermediate stations are most often used when a change in horizontal alignment is required, resulting in two or more separate ropeway segments—detachable-grip carriers can be shuttled between each segment, but passengers must disembark from other types of carriers and walk within the station to the loading area for the next segment. Gondola systems and chair lifts can also have changes in horizontal alignment without intermediate stations, but this kind of arrangement is much more mechanically complex and is rarely used.

Exhibit 2-37 lists aerial tramway, detachable-grip gondola, and funitel systems in use in North America, along with their main function and technical data.

Exhibit 2-37
U.S. and Canadian Aerial Ropeways (2002)

	Primary	Length		Climb		Carrier
Location	**Function**	**(ft)**	**(m)**	**(ft)**	**(m)**	**Cap. (p)**
AERIAL TRAMWAYS						
Albuquerque, NM (Sandia Peak)	scenic	14,657	4,469	4,000	1,220	50
Alyeska, AK (Tramway)	ski	3,867	1,179	2,024	617	60
Big Sky, MT (Lone Peak)	ski	2,828	862	1,450	442	15
Boston Bar, BC (Hells Gate)	scenic	1,118	341	500	152	25
Cañon City, CO (Royal Gorge)	scenic	2,200	670	0	0	35*
El Paso, TX (Wyler)	scenic	2,500	760	940	287	8
Estes Park, CO (Aerial Tramway)	scenic			1,200	365	
Franconia Notch, NH (Cannon Mtn.)	ski	5,139	1,567	2,146	654	70
Gatlinburg, TN (Ober Gatlinburg)	scenic	11,000	3,350	1,335	405	120
Heavenly Valley, CA (Aerial Tram)	ski			1,710	521	25
Jackson, WY (Aerial Tram)	ski	12,595	3,840	4,139	1,262	45
Jasper, AB (Tramway)	scenic	6,550	2,000	3,191	973	30
Jay Peak, VT (Aerial Tramway)	ski	7,776	2,371	2,153	656	60
Juneau, AK (Mt. Roberts)	scenic	3,087	941	1,745	532	60
New York, NY (Roosevelt Island)	urban	3,100	945	0	0	125
Niagara Falls, ON (Spanish Aero Car)	scenic	1,768	539	0	0	40*
Palm Springs, CA (Tramway)	scenic	10,775	3,285	5,874	1,791	80
Québec, QC (Chute-Montmorency)	scenic					40
Snowbasin, UT (Olympic Tram)	ski	1,165	355	510	155	15
Snowbird, UT (Aerial Tram)	ski			2,900	885	125
Squaw Valley, CA (Cable Car)	ski			2,000	610	115
Stone Mountain, GA (Skylift)	scenic			825	252	
Vancouver, BC (Grouse Mtn. Red)	ski			2,800	850	100
Vancouver, BC (Grouse Mtn. Blue)	ski			2,800	850	40
DETACHABLE-GRIP GONDOLAS						
Aspen, CO (Silver Queen)	ski			3,267	996	
Banff, AB (Sulphur Mountain)	scenic	5,117	1,560	2,289	698	4
Big Sky, MT (Gondola One)	ski	8,530	2,601	1,525	465	4
Blackcomb, BC (Excalibur)	ski			1,486	453	
Deer Valley, UT (Gondola)	ski	5,170	1,576	1,322	403	
Gore Mountain, NY (Northwoods)	ski			1,700	520	8
Heavenly Valley, CA (Gondola)	ski	12,672	3,863	2,583	788	8
Jackson, WY (Bridger)	ski			2,781	848	
Joseph, OR (Wallowa Lake)	scenic	9,650	2,942	3,700	1,130	4
Killington, VT (K1 Express)	ski	6,600	2,010	1,690	515	8
Killington, VT (Skyeship)	ski	13,000	3,950	2,520	768	8
Loon Mountain, NH (Gondola)	ski	7,133	2,175	2,100	640	4
Mammoth Mountain, CA (Panorama)	ski			3,100	945	
Northstar, CA (Big Springs)	ski			470	143	
Panorama, BC (Village)	ski access			3,100	945	
Park City, UT (Canyons)	ski access	2,682	818	181	55	8
Silver Mountain, ID (Gondola)	ski access	16,368	4,990	3,100	945	8
Ski Apache, NM (Gondola)	ski			1,800	550	4
Snowbasin, UT (Middle Bowl Exp.)	ski	9,494	2,895	2,310	704	
Snowbasin, UT (Strawberry Express)	ski	9,576	2,920	2,472	754	
Steamboat Springs, CO (Gondola)	ski			2,200	670	8
Stowe, VT (Gondola)	ski			2,080	634	8
Stratton, VT (Gondola)	ski			2,000	610	12
Sugar Bowl, CA (Village)	ski access	3,202	976	87	27	4
Sunshine Village, AB (Sunshine)	ski access	16,400	5,000	1,640	500	8
Telluride, CO (Gondola I/II)	ski access	13,100	4,000	***	***	8
Telluride, CO (Gondola III)	ski access			0	0	8
Vail, CO (Eagle Bahn)	ski			2,220	677	
Whistler, BC (Creekside)	ski			2,112	644	
Whistler, BC (Village)	ski			3,893	1,187	
Whiteface, VT (Cloudspitter)	ski			2,456	749	8
FUNITELS						
Squaw Valley, CA (Gold Coast)	ski	9,065	2,764	1,742	531	28

*one carrier only (single reversible tramway)

***from Telluride, climbs 1,785 ft (544 m) to an intermediate station, then drops 995 ft (303 m) to a third station

NOTE: Table does not include the numerous fixed-grip gondola systems.
access = used to transport passengers from remote parking to an activity center.
scenic = used to provide scenic views of mountains, canyons, etc.
ski = used primarily to access ski runs; some are also used for scenic rides during the summer.
urban = used in an urban setting to transport commuters and/or tourists.

SOURCE: Owner data.

Cable Cars

Cable cars are now only found in San Francisco, but were once used briefly throughout the United States.

Cable cars (Exhibit 2-38) now operate only in San Francisco, where the first line opened in 1873.[5] Although associated with San Francisco's steep hills, more than two dozen other U.S. cities, including relatively flat cities such as Chicago and New York, briefly employed this transit mode as a faster, more economical alternative to the horse-drawn streetcar. Most cable lines were converted to electric streetcar lines between 1895 and 1906 due to lower operating costs and greater reliability, but lines in San Francisco, Seattle, and Tacoma that were too steep for streetcars continued well into the 20th century.(R14)

Three cable car routes remain in San Francisco as a National Historic Landmark and carried 9.2 million riders in 2000.(R12) The cars are pulled along by continuous underground cables (wire ropes) that move at a constant speed of 9 mph (15 km/h). A grip mechanism on the car is lowered into a slot between the tracks to grab onto the cable and propel the car. The grip is released from the cable as needed for passenger stops, curves, and locations where other cables cross over the line.(R14)

Cable car systems are not very efficient, as 55 to 75% of the energy used is lost to friction. However, cars can stop and start as needed, more-or-less independently of the other cars on the system, and a large number of cars can be carried by a small number of ropes. The Chicago City Railway operated around 300 cars during rush hours on its State Street line in 1892, which comprised four separate rope sections totaling 8.7 miles (13.9 km) in length.(R14)

Cable-hauled automated people movers often use technology adapted from cable cars and aerial ropeways.

Modern automated people movers (APMs) that use cable propulsion have retained many of the original cable car technological concepts, albeit in an improved form. Modern cable-hauled APMs often include gripping mechanisms and, in some cases, turntables at the end of the line. Some of these APMs can be accelerated to line speed out of each station, in a similar manner as detachable-grip aerial ropeways. Once at line speed, a grip on these APMs attaches to the haul rope, and the vehicle is moved at relatively high speed along the line. At the approach to the next station, the vehicle detaches from the rope, and mechanical systems brake the vehicle into the station. This technology addresses two of the major issues with the original cable cars: (1) having only two speeds, stop and line speed (up to 14 mph or 22 km/h), which caused jerky, uncomfortable acceleration for passengers and (2) rope wear each time cars gripped the cable, as the cable slid briefly through the slower moving grip before the grip took hold and caught up to the cable's speed. The airport shuttle at the Cincinnati-Northern Kentucky Airport is an example of a detachable-grip APM, while the Mystic Transit Center APM (Exhibit 2-38b) is an example of an APM with a permanently attached cable. Other examples were listed in Exhibit 2-32.

Exhibit 2-38
Cable Car Examples

(a) Cable Car (San Francisco) (b) Cable-Hauled APM (Boston)

---

[5] An elevated cable car system opened in New York City in 1868, but failed within 2 years and was converted to steam locomotive operation in 1871.(R14)

This page is intentionally blank.

CHAPTER 4. FERRY TRANSIT

OVERVIEW

Ferry services (Exhibit 2-39) play a role in the transit systems of a number of North American cities, providing pedestrian, bicycle, and—in some cases—vehicle transport across waterways where transportation connections are desirable but conditions do not justify a bridge or tunnel or alternative bridges and tunnels are congested.

The Staten Island Ferry carries more passengers than many rail transit routes.

The busiest route in North America, New York's Staten Island Ferry, carries more passengers per day (70,000) than all but the busiest light rail and commuter rail routes, and more than many heavy rail routes. In addition, five private operators provide a variety of commuter services into Brooklyn and Manhattan, as well as special services to New York's major league baseball stadiums.

Other services carry more modest numbers of passengers, but still play vital roles in their area's transportation system. Vancouver's SeaBus ferry, for example, operates high-speed vessels between North Vancouver and downtown Vancouver and connects to Vancouver's rapid transit, commuter rail, and bus systems. In the San Francisco Bay Area, as of 2002, four publicly operated services[6] and one privately operated service operated a total of seven routes, as well as special services to San Francisco's baseball stadium. The Washington State Ferry system operates nine routes, carrying private automobiles, bicycles, and walk-on passengers, and—on the route between Vashon Island and Seattle—King County Metro buses.

The Alaska Marine Highway System provides the sole means of access, other than by air, to a number of communities in southeastern and southwestern Alaska, including the state capital, Juneau. BC Ferries performs roles similar to both the Alaska and the Washington ferry systems along the British Columbia coast.

Internationally, ferries play an important role in providing cross-harbor transportation, as in Sydney, Australia, and Hong Kong, and along rivers, as in Brisbane, Australia, and London.

Ferries have quickly provided needed capacity during emergencies.

Ferries offer flexible routing, subject only to dock availability, and services can be implemented relatively quickly. This adaptability has helped two metropolitan areas cope with emergencies in the recent past. For example, when the 1989 Loma Prieta earthquake closed the Bay Bridge between Oakland and San Francisco for 1 month, new ferry routes from three East Bay communities were open within 1 week, with a fourth route open within 2 weeks. The combination of the four new routes, plus one existing route, carried an average of 20,000 passengers per weekday while the bridge was closed. The service was popular enough that two of the once-temporary routes continue to exist as a combined route.(R4,R8) Following the World Trade Center attacks in New York in 2001, new trans-Hudson ferry routes were opened to replace the lost capacity resulting from damage to the PATH heavy rail station at the World Trade Center. In the first 6 months following the attacks, trans-Hudson ferry ridership nearly doubled to 67,000 passengers per day.(R1)

SERVICE AND VESSEL TYPES

Many different types of ferry services exist, and the vessels used tend to be custom-built to meet the specific needs of the service to be operated. Considerations include passenger and vehicle demand, dock configurations, speed, and

---

[6] All of the public services, with the exception of the Golden Gate Ferry services, are contracted to private operators.

environmental issues (e.g., wake and exhaust). Part 6 of the TCQSM focuses on urban scheduled ferry transit services; however, other types of ferry services are described here for completeness.

Urban Services

Urban ferry services provide trips into or within major cities, and experience similar peaks in passenger demand as other urban transportation modes. Typical travel times range from a few minutes to 45 to 60 minutes, and service is often provided once per hour or more frequently. There are four major types of urban services:

- *Point-to-point services,* typical of most urban ferry services, crossing harbors or major rivers;
- *Linear multiple-stop services,* either along a river (e.g., the East River service in New York) or a waterfront (e.g., Boston);
- *Circulators,* with fixed routes but often not fixed schedules, that serve destinations around the edge of, or a designated portion of, a harbor or riverfront via a loop route; and
- *Water taxis,* which have fixed landing sites, but pick up passengers on demand, similar to a regular taxi service.[7]

Because ferries can only take passengers to the water's edge, intermodal transfers are usually required at one, and often, both ends of the ferry trip. Options for providing this transfer include park-and-ride lots; feeder bus service; roll-on, roll-off bus service (for auto ferries); and terminals located close to rail service (as in New York and at San Francisco's Ferry Building).

Coastal Services

Coastal services provide inter-city and inter-island trips on salt water and large freshwater lakes, such as the Great Lakes. Travel times are typically in the range of one to a few hours, but can be fairly short for service to nearby islands, to more than 1 day (e.g., some of the Alaska Marine Highway routes). Service frequencies range from several trips per day to one trip per week. Vehicles are often transported in a roll-on, roll-off mode (or rarely, as cargo, in a lift-on, lift-off mode—for example, service along the northern shore of the Gulf of St. Lawrence in Québec).

Rural Services

Rural ferries cross rivers and narrow lakes in areas where traffic volumes do not justify constructing a bridge. Routes are short and are often operated on demand. Vessels tend to be small (a capacity of 6 to 12 automobiles is common). Walk-on passengers and bicycles are generally infrequent.

Vessel Types

Examples of vessels used for various types of ferry services are presented in Exhibit 2-39. Vessels can also be categorized in terms of their physical and mechanical characteristics; examples of these are provided in Part 6.

---

[7] Some harbor circulator and multiple-stop services also call themselves "water taxis," although they operate on fixed routes and sometimes with fixed schedules.

Exhibit 2-39
Ferry Service Examples

(a) Harbor Point-to-Point (New York)

(b) Harbor Point-to-Point (Vancouver)

(c) River Circulator (Brisbane, Australia)

(d) River Point-to-Point (Brisbane, Australia)

(e) Vehicle/Passenger Ferry (Seattle)

(f) Vehicle/Passenger Ferry (New Orleans)

(g) Rural Ferry (Wheatland, Oregon)

(h) Coastal Ferry (Juneau, Alaska)

RIDERSHIP

Exhibit 2-40 provides ridership data for North American ferry systems operated by public transit agencies and identifies a selection of privately operated services in major metropolitan areas.

Exhibit 2-40
U.S. and Canadian Ferry Systems (2000)(R11,R12)

	Directional Route Length		Avg. Weekday	Vessels Op. in
Region	**(mi)**	**(km)**	**Boardings**	**Max. Service**
	PUBLIC TRANSIT			
Boston (MBTA)	45.0	72.4	5,200	12
Bremerton, WA (Kitsap Transit)	5.7	9.2	1,000	2
Corpus Christi	0.8	1.3	300	1
Halifax	NA	NA	4,800*	3*
Hartford	1.0	1.6	600*	2
Long Beach	0.5	0.8	70	2
New Orleans	3.0	4.8	8,500	5
New York (Metro-North)	11.0	17.8	NA	1
New York (NYC DOT)	10.4	16.7	60,900	4
New York (Port Authority)	3.4	5.5	8,900	4
Norfolk	1.0	1.6	1,000**	3**
Philadelphia (RiverLink)	1.2	1.9	NA	NA
Portland, ME	20.0	32.2	2,800	4
Providence	50.4	81.1	200‡	NA
San Francisco (Alameda-Oakland)	27.6	44.4	2,100	3
San Francisco (Golden Gate)	43.0	69.2	6,200	5
San Francisco (Harbor Bay)	17.3	27.8	750‡	NA
San Francisco (Vallejo Transit)	79.0	127.1	2,300	2
San Juan	10.0	16.1	2,900	4
Seattle (Washington State)	245.8	395.5	40,700	28
Tacoma (Pierce County)	11.1	17.9	500	1
Vancouver (SeaBus)	4.0	6.4	14,700†	2†
	MAJOR PRIVATE SYSTEMS			
Boston (Airport Water Shuttle)	2.3	3.7	NA	NA
Boston (City Water Taxi)	NA	NA	NA	NA
Boston (Harbor Express)	61.0	98.2	2,600‡	NA
Chicago (RiverBus)	NA	NA	NA	NA
Ft. Lauderdale (Water Taxi)	NA	NA	NA	NA
New York (Circle Line)	12.5	20.1	29,700‡	NA
New York (Fox Navigation)	190.5	306.5	NA	NA
New York (NY Fast Ferry)	50.2	80.7	1,300‡	NA
New York (NY Waterway)	55.0	88.5	35,000†	NA
New York (Seastreak)	51.6	99.2	1,400‡	NA
San Diego (SD-Coronado)	3.5	5.6	3,400‡	NA
San Francisco (Blue & Gold)	10.6	17.0	3,000‡	NA
Seattle (Elliott Bay)	NA	NA	NA	NA

NA: not available
*1996 data **1999 data †2001 data
‡1999 estimate, based on dividing annual ridership by 150 (average of commuter-oriented services with both weekday and annual ridership values available), except for New York's Circle Line, which operates tourist services to the Statue of Liberty and Ellis Island and whose ridership was divided by 365.
NOTE: Some public system services are contracted to private operators who also operate independent services. Some private services accept public transit fare instruments.

CHAPTER 5. STOPS, STATIONS, AND TERMINALS

OVERVIEW

Transit stops, stations, and terminals come in many sizes, with differing levels of activity and passenger amenities, but all serve as points where transit passengers begin, end, or continue their transit trips. For this reason, the quality of the passenger environment at stops, stations, and terminals can be as important to passengers as the quality of the in-vehicle portion of the trip.

Passengers begin, end, and continue their transit trips at these facilities.

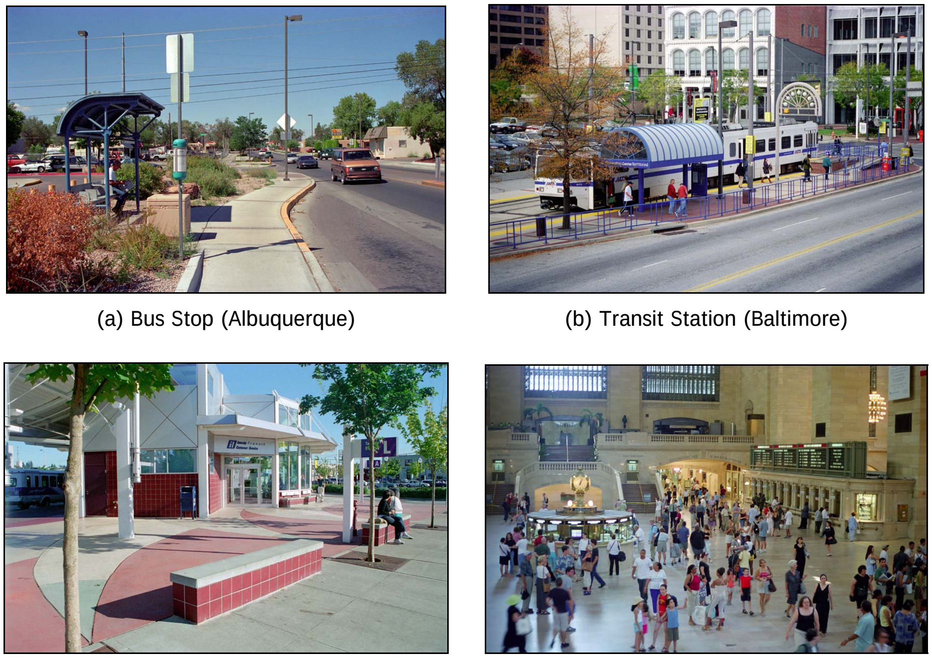
Stops, stations, and terminals can include a number of elements, including transit stops, waiting areas, walkways, doors, stairs, escalators, elevators, fare gates, ticket machines, information displays, shops, and park-and-ride lots. Station element design involves a combination of estimating passenger flows—particularly those flows occurring during micro-peaks when a heavily loaded bus or train arrives and discharges it passengers—and providing sufficient space for passengers, as determined by a design level of service.

Station design must accommodate persons with disabilities, but attention should be given to designs that are convenient to passengers with disabilities (e.g., elevators co-located with stairways), rather then merely ADA-compliant (e.g., an elevator provided in a remote location). Design should also consider the possibility of some station elements, such as ticket machines, being out of service, and the potential delays passengers may experience when those events happen. Finally, design must consider emergency evacuation requirements dictated by fire codes.

TRANSIT STOP TYPES

Part 7 of the TCQSM considers four categories of transit stops. These are bus stops, transit stations, transit centers, and transit terminals. Exhibit 2-41 provides examples of each of these.

Exhibit 2-41
Transit Stop Types


(a) Bus Stop (Albuquerque)

(b) Transit Station (Baltimore)

(c) Transit Center (Olympia, Washington)

(d) Transit Terminal (New York)

Bus Stops

Bus stops are the most common of the four categories and frequently are served by only one or a small number of routes. However, downtown stops served by multiple routes may be very busy during peak times and require multiple loading positions for buses (*loading areas* or *berths*). The most basic stop, used by *hail-and-ride* services where passengers flag down buses along the route, has no infrastructure at all. However, most fixed-route services provide designated stops, marked by bus stop signs, to manage the number of stops buses must make and to ensure that passenger boardings and alightings take place in safe and appropriate locations. New or relocated stops must meet ADA requirements, which include provisions for a landing pad for the wheelchair lift or ramp, minimum horizontal clearances, and maximum slopes, among other factors. The sidewalk adjacent to the bus stop is frequently used as the passenger waiting area. Depending on passenger volumes at the stop, additional infrastructure could include a bench or shelter, and informational signage.

Transit Stations

Transit stations include rail and busway stations. The routes serving these stations have higher capacities, and consequently the stations must be designed to serve greater numbers of people than the typical bus stop. The higher passenger volumes also permit more extensive passenger infrastructure than normally would be provided at a bus stop. This infrastructure usually includes a canopy covering a portion of the platform, limited seating, ticket machines (when fares are not collected on-board), information displays, trash receptacles, and newspaper vending. Busier stations may also have vending kiosks, electronic information displays, park-and-ride lots, and passenger drop-off areas (*kiss-and-rides*). Heavy rail and commuter rail stations may also have a station agent located on-site to monitor the station and provide information to customers. Vertical circulation elements (stairs, elevators, and possibly escalators) are needed at heavy rail and commuter rail stations, and possibly at light rail and busway stations. When passengers are allowed to cross the tracks or guideway at light rail and busway stations, consideration should be given to signing, striping, gates, fences, and similar devices that delineate and control access to the area used by transit vehicles.

Further information about pedestrian safety at light rail crossings can be found in *TCRP Report 69*.(R17)

Transit Centers

The term *transit center* is normally applied to facilities where multiple bus routes converge, allowing transfers between lines. Rail service is sometimes also provided, but the bus-to-bus transfer activity is at least as important as the bus-to-rail activity. Individual stops, with a shelter or canopy, are typically provided for each direction of travel of each bus route serving the station. Facility design should accommodate the movement of passengers between bus stop locations, as well as access to and from adjacent land uses. Concession and information services may be provided in a central location. Larger transit centers may also have an associated park-and-ride lot.

Intermodal Terminals

Intermodal terminals are designed for transfers between modes and typically experience the highest passenger volumes of the four categories of transit stops. Longer distances are generally involved in making transfers than at a transit center, and vertical movements may also be required. Terminals will have all of the passenger infrastructure listed for the other transit stop categories and may also be integrated with retail shopping, services, and entertainment.

CHAPTER 6. REFERENCES

1. Albano, Joseph, "The Effects of 9/11 on Ferry Service in New York Harbor," presented at the 2002 APTA Intermodal Operations Planning Workshop, Brooklyn, NY (August 2002).
2. American Public Transportation Association, *Transit Fact Book,* APTA, Washington, DC (2001).
3. Azéma, Michel, *Funimag,* http://www.funimag.com/, accessed March 21, 2002.
4. Bay Area Council, *Water Transit Initiative Action Plan,* San Francisco, CA (1999). http://www.bayareacouncil.org/watertransit/bawt_actionplan/bawt_actionplan.html
5. Blake, H.W. and W. Jackson, *Electric Railway Transportation,* McGraw-Hill Book Company, New York, NY (1924).
6. Bureau of Transportation Statistics, *National Transportation Statistics, 1996,* U.S. Department of Transportation, Washington, DC (1996).
7. Callas, Steve, "Tri-Met's Transit Signal Priority System and Evaluation," presented at the 81st Annual Meeting of the Transportation Research Board, Washington, DC (2002).
8. Caltrans, *Bay Area Commuter Guide* (October 25, 1989).
9. Canadian Urban Transit Association, *Summary of Canadian Transit Statistics – 2000 Data,* CUTA, Toronto, Ontario (2001).
10. Danaher, Alan, Tom Parkinson, Paul Ryus, and Lewis Nowlin, "TCRP A-15 Development of Transit Capacity and Quality of Service Principles, Practices, and Procedures," *Interim Report,* available on loan from the Transit Cooperative Research Program, Washington, DC (1997).
11. Federal Highway Administration, *National Ferry Database,* U.S. Department of Transportation, Washington, DC (2001).
12. Federal Transit Administration, *National Transit Database,* U.S. Department of Transportation, Washington, DC (2000). http://www.fta.dot.gov/ntl/database.html
13. Fuhs, Charles H., *NCHRP Synthesis of Highway Practice 185: Preferential Lane Treatments for High-Occupancy Vehicles,* TRB, National Academy Press, Washington, DC (1993).
14. Hilton, George W., *The Cable Car in America,* Revised Edition, Stanford University Press, Stanford, CA (1997).
15. Instituto Nacional de Estadística Geografía e Informática, *Banco de Informacíon Económica,* http://dgcnesyp.inegi.gob.mx/bdine/bancos.htm, accessed January 2, 2003.
16. Kirby, Ronald F., Kiran U. Bhatt, Michael A. Kemp, Robert G. McGillivray, and Martin Wohl, *Para-Transit: Neglected Options for Urban Mobility,* The Urban Institute, Washington, DC (1974).
17. Korve Engineering, Richards & Associates, Interactive Elements, Inc., and University of North Carolina Highway Safety Research Center, *TCRP Report 69: Light Rail Service: Pedestrian and Vehicle Safety,* TRB, National Academy Press, Washington, DC (2001). http://trb.org/trb/publications/tcrp/tcrp_rpt_69.pdf

18. Levinson, H.S., W.F. Hoey, D.B. Sanders, and F.H. Wyan, *NCHRP Report 143: Bus Use of Highways – State of the Art,* National Academy Press, Washington, DC (1973).
19. Levinson, H.S., C.L. Adams, and W.F. Hoey, *NCHRP Report 155: Bus Use of Highways – Planning and Design Guidelines,* TRB, National Academy Press, Washington, DC (1975).
20. Levinson, Herbert, Samuel Zimmerman, Jennifer Clinger, Scott Rutherford, Rodney L. Smith, John Cracknell, and Richard Soberman, *TCRP Report 90: Bus Rapid Transit, Volume 1: Case Studies in Bus Rapid Transit,* TRB, Washington, DC (2003). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_90v1.pdf
21. Levinson, Herbert S. and Kevin R. St. Jacques. Bus Lane Capacity Revisited. In *Transportation Research Record 1618,* TRB, National Research Council, Washington, DC (1998).
22. Monorail Society, The, "Transit Monorails of the World," http://www.monorails.org/tMspages/Where.html, accessed March 21, 2002.
23. New York Metropolitan Transportation Council, *Hub-Bound Travel 1992,* New York, NY (1993).
24. New York Metropolitan Transportation Council, *Hub-Bound Travel 1995,* New York, NY (1997).
25. Parkinson, Tom and Ian Fisher, *TCRP Report 13: Rail Transit Capacity,* TRB, National Academy Press, Washington, DC (1996). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_13-a.pdf
26. St. Jacques, Kevin and Herbert S. Levinson, *TCRP Report 26: Operational Analysis of Bus Lanes on Arterials,* TRB, National Academy Press, Washington, DC (1997). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_26-a.pdf
27. *Special Report 209: Highway Capacity Manual,* TRB, National Research Council, Washington, DC (1985).
28. Wuppertaler Stadtwerke AG, *Ausbau Schwebebahn: Daten, Fakten, Hintergründe,* Wuppertal, Germany (1998).

PART 3
QUALITY OF SERVICE

CONTENTS

LIST OF EXHIBITS

CHAPTER 1. QUALITY OF SERVICE FUNDAMENTALS

OVERVIEW

Quality of service reflects the passenger's perception of transit performance. The performance measures used to describe this perception are different from both the economic performance measures typically reported to the FTA and the vehicle-focused performance measures used in the *Highway Capacity Manual.* Quality of service depends to a great extent on the operating decisions made by a transit system within the constraints of its budget, particularly decisions on where transit service should be provided, how often and how long it is provided, and the kind of service that is provided. Quality of service also measures how successful an agency is in providing service to its customers, which has ridership implications. These implications were discussed in Part 1.

Organization of Part 3.

Part 3 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents methods for measuring key aspects of quality of service. These aspects are ones that have been identified by a number of sources as being particularly important to passengers and are ones that are readily quantified. Part 3 also discusses other aspects of quality of service that may be important to the customers of a particular agency.

- *Chapter 1* discusses transit performance measures in general and contrasts passenger-based quality of service measures with other kinds of transit performance measures.
- *Chapter 2* discusses ways to measure key elements of quality of service.
- *Chapter 3* presents level of service (LOS) ranges for measures that address fixed-route transit availability and service provision and which are applicable to transit stops, route segments, and/or systems.
- *Chapter 4* presents level of service ranges for measures that address demand-responsive service availability and provision.
- *Chapter 5* contains references for material presented in Part 3.
- *Chapter 6* presents example problems that apply quality of service measures to real-world situations.
- *Appendix A* provides substitute exhibits in metric units for Part 3 exhibits that use U.S. customary units only.

Exhibits that also appear in Appendix A are indicated by a margin note like this.

Definitions

In the North American transit industry, many definitions are not standardized or are specific to a particular transit system. Caution is needed with the terms *quality of service* and *level of service*, which carry a variety of meanings. *Level of service,* for example, often is used literally to mean the amount of service both in frequency and hours of service—the latter sometimes referred to as the "span" of service.

This manual uses the following definitions of transit performance measures, quality of service, service measures, and levels of service:

- *Transit performance measure:* a quantitative or qualitative factor used to evaluate a particular aspect of transit service.
- *Quality of service:* the overall measured or perceived performance of transit service from the passenger's point of view.

- *Transit service measure:* a quantitative performance measure that best describes a particular aspect of transit service and represents the passenger's point of view. It is also known as a *measure of effectiveness.*
- *Levels of Service.* Designated ranges of values for a particular service measure, such as "A" (highest) to "F" (lowest), based on a transit passenger's perception of a particular aspect of transit service.

The primary differences between performance measures and service measures are the following:

1. Service measures represent the passenger's point of view, while performance measures can reflect any number of points of view.
2. In order to be useful to users, service measures should be relatively easy to measure and interpret. It is recognized, however, that system-wide measures will necessarily be more complex than stop- or route-level measures.
3. Levels of service are developed only for service measures.

Levels of Service

The selection of LOS thresholds for each of the service measures presented in this manual represent the collective professional judgment of the TCRP Project A-15A team and panel. However, the LOS ranges—in particular, LOS "F" for fixed-route service and LOS "8" for demand-responsive service—are not intended to set national standards. It is left to local transit operators and policy agencies to decide how or whether to describe performance in terms of levels of service. It is also left to local decision-makers to determine which LOS ranges should be considered acceptable, given the unique characteristics of each agency and the community served. To aid in this effort, this manual provides guidance on the changes in service quality perceived by passengers at each LOS threshold.

Level of Service Framework

Fixed-Route Service

Chapter 3 divides fixed-route quality of service measures into two main categories: (1) availability and (2) comfort and convenience. The availability measures address the spatial and temporal availability of transit service. If transit service is located too far away from a potential user or if service does not run at the times a user requires it, that user would not consider transit service to be available and thus the quality of service would be poor. Assuming, however, that transit service is available, the comfort and convenience measures can be used to evaluate a user's perception of the quality of his or her transit experience.

Different elements of a transit system require different performance measures. The following categories are used in Chapter 3:

- *Transit Stops:* measures addressing transit availability and comfort and convenience at a single location. Since these measures depend on passenger volumes, scheduling, routing, and stop and station design, performance measure values in this category will tend to vary from one location to another.
- *Route Segments/Corridors*: measures that address availability and comfort and convenience along a portion of a transit route, a roadway, or a set of parallel transportation facilities serving common origins and destinations. These measure values will tend to have less variation over the length of a route segment, regardless of conditions at an individual stop.

- *Systems*: measures of availability and comfort and convenience for more than one transit route operating within a specified area (e.g., a district, city, or metropolitan area). System measures can also address door-to-door travel.

Lower-level measures (e.g., stop-level) are also applicable at higher levels (i.e., the route or system levels). Combining the two performance measure categories with the three transit system elements produces the matrix shown in Exhibit 3-1.

Since route segments are composed of a series of stops, stop-level measures are also applicable at the segment level.

Exhibit 3-1
Quality of Service Framework: Fixed-Route

	Service Measures		
	Transit Stop	**Route Segment**	**System**
Availability	Frequency	Hours of Service	Service Coverage
Comfort & Convenience	Passenger Load	Reliability	Transit-Auto Travel Time

It is recognized that these measures may not always be sufficient to fully describe fixed-route service quality. Chapter 3 describes other measures that analysts may also wish to consider to supplement the measures listed above. Analysts may also find it helpful to present the service measures in the form of a transit "report card" that compares several different aspects of transit service at once.

Demand-Responsive Service

Demand-responsive service is delivered differently than fixed-route service, and its passengers have different service expectations than fixed-route passengers. As a result, a separate framework is provided for demand-responsive service measures. Chapter 4 uses the same categories of availability and comfort and convenience used in Chapter 3. However, because demand-responsive service has no designated stops, two aspects of availability and three aspects of comfort and convenience are presented, rather than measures for specific location types. No measure of service coverage is provided, as this is measured indirectly by the other two availability measures (i.e., there is no service span where there is no coverage). Exhibit 3-2 presents the quality of service framework for demand-responsive service.

Exhibit 3-2
Quality of Service Framework: Demand-Responsive

	Service Measures		
Availability	Response Time	Service Span	
Comfort & Convenience	On-Time Performance	Trips Not Served	DRT-Auto Travel Time

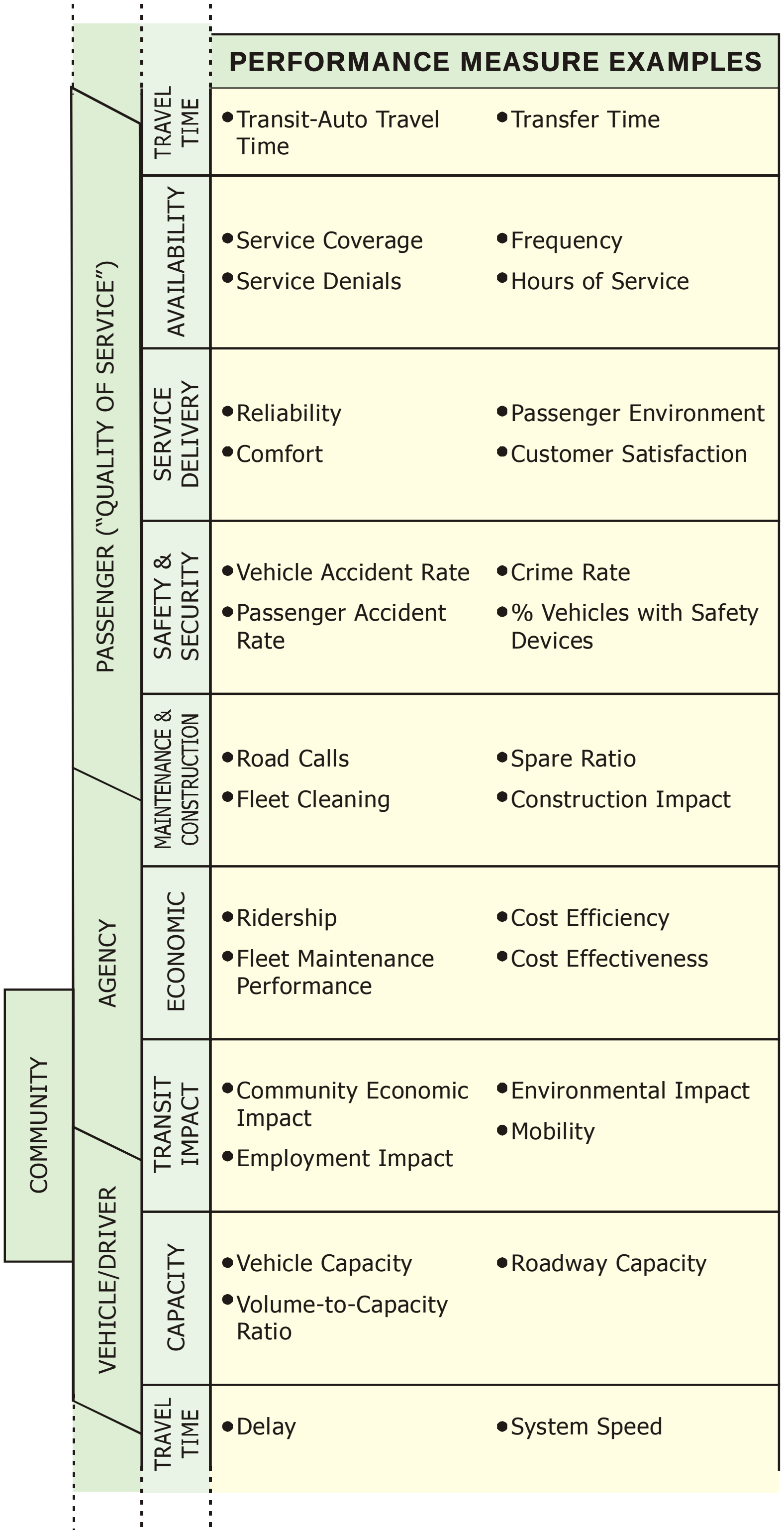
TRANSIT PERFORMANCE MEASURES

To get a sense of what quality of service is, it is useful to understand what it is not. Exhibit 3-3 illustrates one way that transit performance measures can be categorized and shows how quality of service fits into the spectrum of transit performance measures.

At the broadest level, there are a variety of performance measures that have been developed to describe different aspects of transit service. These measures can be organized into particular categories, such as service availability or maintenance and construction. *TCRP Report 88*(R17) identifies the following categories:

- *Availability*: measures assessing how easily potential passengers can use transit for various kinds of trips;
- *Service Monitoring*: measures that assess passengers' day-to-day experiences using transit;
- *Community*: measures of transit's role in meeting broad community objectives, and transit's impact on the community it serves;
- *Travel Time*: how long it takes to make a trip by transit, by itself, in comparison with another mode, or in comparison with an ideal value;

Exhibit 3-3
Transit Performance Measure Categories and Examples[R17]



	PERFORMANCE MEASURE EXAMPLES	
TRAVEL TIME	• Transit-Auto Travel Time	• Transfer Time
AVAILABILITY	• Service Coverage • Service Denials	• Frequency • Hours of Service
SERVICE DELIVERY	• Reliability • Comfort	• Passenger Environment • Customer Satisfaction
SAFETY & SECURITY	• Vehicle Accident Rate • Passenger Accident Rate	• Crime Rate • % Vehicles with Safety Devices
MAINTENANCE & CONSTRUCTION	• Road Calls • Fleet Cleaning	• Spare Ratio • Construction Impact
ECONOMIC	• Ridership • Fleet Maintenance Performance	• Cost Efficiency • Cost Effectiveness
TRANSIT IMPACT	• Community Economic Impact • Employment Impact	• Environmental Impact • Mobility
CAPACITY	• Vehicle Capacity • Volume-to-Capacity Ratio	• Roadway Capacity
TRAVEL TIME	• Delay	• System Speed

Transit performance measures can represent the passenger, agency, driver/vehicle, and/or community point of view.

Travel time overlaps the vehicle/driver and passenger points of view.

- *Safety and Security*: the likelihood that one will be involved in an accident (*safety*) or become a victim of crime (*security*) while using transit;
- *Maintenance and Construction*: the effectiveness of the agency's maintenance program and the impacts of transit construction on passengers;
- *Economic*: measures of transit performance from a business perspective; and
- *Capacity*: the ability of transit facilities to move people and transit vehicles.

Some of these categories more directly affect passengers' experience while using transit than others. Each category can be assigned to one or more points of view, reflecting the primary viewpoint(s) of the measures in that category.

Agency point of view.

The *agency point of view* reflects transit performance from the perspective of the transit agency as a business. Although transit agencies are naturally concerned with all aspects of transit service provision, the categories listed under the agency point-of-view—particularly economics and maintenance and construction—are ones of greater interest to agencies than to the other groups. These measures are also the ones that, at present, are more likely to be tracked by transit agencies.

One reason that agency-oriented measures are more commonly tracked than others is that this category includes most of the measures routinely collected in the United States for the FTA's National Transit Database (formerly Section 15) annual reporting process. Most of the NTD measures relate to cost and utilization. These measures are important to the agency—and indirectly to passengers—by reflecting the amount of service an agency can afford to provide on a route or the system as a whole. The utilization measures (e.g., ridership) indirectly measure passenger satisfaction with the quality of service provided. However, with a few exceptions related to safety and service availability (e.g., vehicle revenue hours per directional mile and vehicles operated in maximum service per directional mile), the NTD measures do not directly reflect the passenger point of view.

Vehicle/driver point of view.

The *vehicle/driver point of view* includes measures of vehicular speed and delay, such as those routinely calculated for streets and highways using the procedures given in the *Highway Capacity Manual.* This point of view also includes measures of facility capacity in terms of the numbers of transit vehicles or total vehicles that can be accommodated. Because transit vehicles carry passengers, these measures also reflect the passenger point of view: passengers on board a transit vehicle traveling at an average speed of 12 mph (20 km/h) individually experience this same average travel speed. However, because these vehicle-oriented measures do not take passenger loading into account, the passenger point of view is hidden, as all vehicles are treated equally, regardless of the number of passengers in each vehicle. For example, while a single-occupant vehicle and a 40-passenger bus traveling on the same street may experience the same amount of delay due to on-street congestion and traffic signal delays, the person-delay experienced by the bus is 40 times as great as the single-occupant vehicle.

Community point of view.

The *community point of view* measures transit's role in meeting broad community objectives. Measures in this area include measures of the *impact* of transit service on different aspects of a community, such as employment, property values, or economic growth. This viewpoint also includes measures of how transit contributes to community *mobility* and measures of transit's effect on the *environment.* Many of these measures reflect things that are important to passengers, but which may not be directly perceived by passengers or by others on an individual trip basis.

Quality of service focuses on the passenger point of view.

Quality of service focuses on those aspects of transit service that directly influence how passengers perceive the quality of a particular transit trip. These factors are discussed in the following sections.

TRANSIT TRIP DECISION-MAKING PROCESS

Urban transport involves millions of individual travel decisions. Some are made infrequently—to take a job in a particular location, to locate a home outside an area with transit service, or to purchase a second car. Other decisions—when to make a trip or which mode to use—are made for every trip.

Availability

Is transit service available to a potential passenger?

When service is not available, other aspects of service quality do not matter for a given trip.

A key decision is determining whether or not transit service is even an option for a particular trip. Transit service is only an option for a trip when service is available at or near the locations and times that one wants to travel, when one can get to and from the transit stops, when sufficient capacity is available to make the trip at the desired time, and when one knows how to use the service. If any one of these factors is not satisfied for a particular trip, transit will not be an option for that trip—either a different mode will be used, the trip will be taken at a less convenient time, or the trip will not be made at all. When service is not available, other aspects of transit service quality will not matter to that passenger for that trip, as the trip will not be made by transit (or at all), regardless of how good the service is in other locations or at other times.

These factors can be summarized as shown below and as depicted in Exhibit 3-4 in the form of a flowchart:

- *Spatial availability*: Where is service provided, and can one get to it?
- *Temporal availability*: When is service provided?
- *Information availability*: How does one use the service?
- *Capacity availability*: Is passenger space available for the desired trip?

Comfort and Convenience

If transit service is available, will a potential passenger find it comfortable and convenient?

When all of the factors listed above are met, then transit becomes an option for a given trip. At this point, passengers weigh the comfort and convenience of transit against competing modes. Some of the things that a potential passenger may consider include the following:

- How long is the walk? Can one walk safely along and across the streets leading to and from transit stops? Is there a functional and continuous accessible path to the stop, and is the stop ADA accessible?
- Is the service reliable?
- How long is the wait? Is shelter available at the stop while waiting?
- Are there security concerns—walking, waiting, or riding?
- How comfortable is the trip? Will one have to stand? Are there an adequate number of securement spaces? Are the vehicles and transit facilities clean?
- How much will the trip cost?
- How many transfers are required?
- How long will the trip take in total? How long relative to other modes?

Unlike the first decision—whether transit is an option for the trip—the questions listed above are not necessarily all-or-nothing. People have their own personal values that they apply to a given question, and each person will weigh the answers to these questions differently. Regular transit users familiar with the service may perceive transit service more favorably than non-users. In the end, the choice to use transit will depend on the availability of other modes and how the quality of transit service compares with that of competing modes.

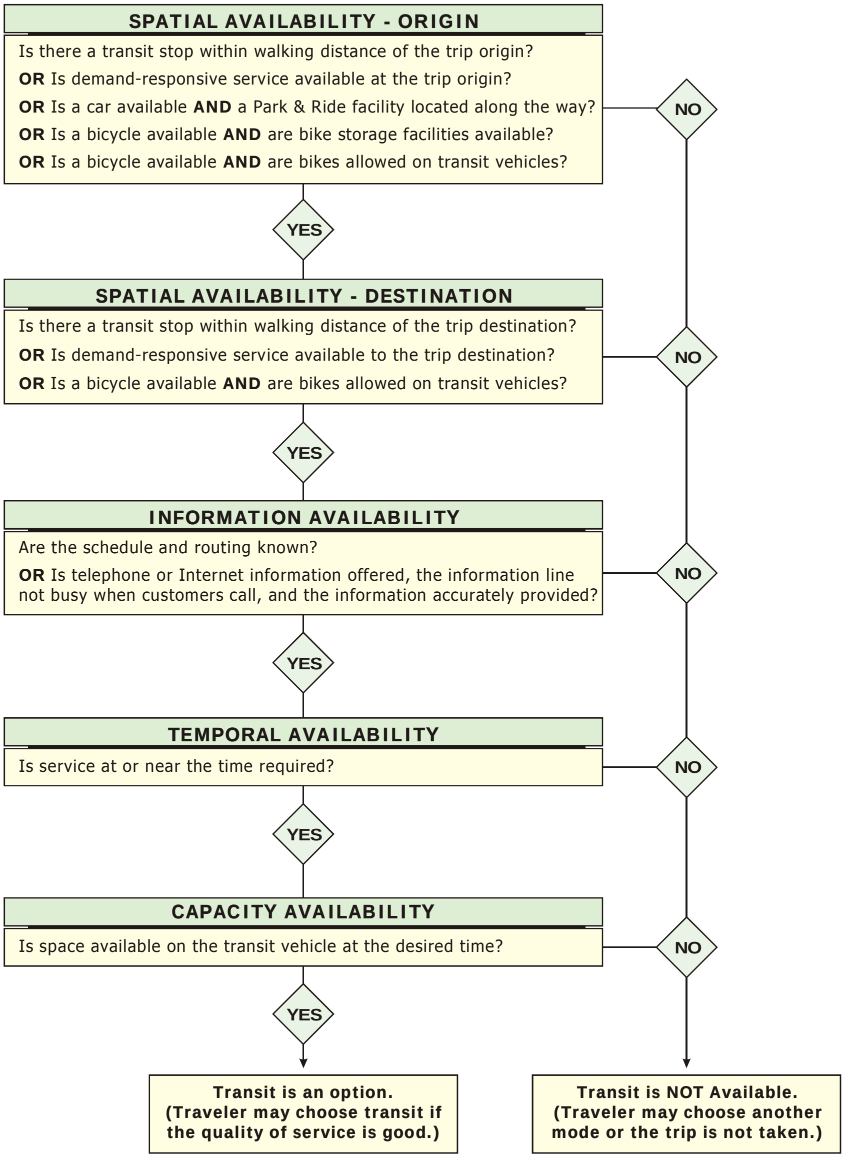


Exhibit 3-4
Transit Availability Factors

Service Delivery

Service delivery measures look at passengers' daily experiences using transit.

Service delivery assesses passengers' day-to-day experiences using transit—how well does the agency deliver the service it promises and how well does it meet customers' expectations? Even when transit service is available to someone, if a trip by transit is inconvenient or uncomfortable, a person with a choice will likely choose another mode, while a person without a choice may be greatly inconvenienced and be less likely to continue to use transit once another choice becomes available. Service delivery encompasses four main factors:(R17)

1. *Reliability*: how often service is provided when promised;
2. *Customer service*: the quality of direct contacts between passengers and agency staff and customers' overall perception of service quality;
3. *Comfort*: passengers' physical comfort as they wait for and use transit service; and
4. *Goal accomplishment*: how well an agency achieves its promised service improvement goals.

Travel Time

Time- and speed-related measures can be used by themselves or converted into other forms to aid in comparisons.

Travel time addresses the amount of time it takes to make a trip by transit and the speed that passengers travel while making their trips. Travel time values can be reported by themselves, in comparison with other modes, or in comparison with ideal values. Time can be aggregated by the number of people (e.g., person-minutes of delay) or converted into a monetary value for use in comparing the costs of two alternative trips.

Safety and Security

Passengers' perceptions of safety and security are as important to consider as actual conditions.

This category relates to the likelihood that one will be involved in an accident (*safety*) or become the victim of a crime (*security*) while using transit. Measures of safety and security are often more qualitative, as riders' perceptions of the safety and security of transit, as well as actual conditions, enter into their mode choice decision. Some "irritation" factors, such as encountering unruly passengers on a regular basis or having to listen to someone else's radio, may not show up in security-related performance measures but may contribute to a passenger's sense of unease, even if the actual risk of being involved in a crime is minimal or non-existent.

Maintenance

Maintenance quality has direct and indirect impacts on quality of service.

The quality of a transit agency's maintenance program has direct and indirect impacts on passengers' perceptions of service quality. A transit vehicle that breaks down while in service, for example, impacts passengers' travel time for that trip and their overall sense of system reliability. Having insufficient spare buses available may mean that some vehicle runs never get made, which, in turn, reduces transit service availability, increases the level of crowding on the subsequent trips, and affects passengers' perceptions of reliability. Dirty vehicles may suggest to passengers a lack of attention to less visible aspects of transit service, while graffiti, window etchings, and so forth may suggest a lack of security.

SUMMARY

This chapter showed that transit performance can be measured from a variety of points of view but that quality of service focuses on the passenger point of view. The chapter discussed the key aspects of quality of service: *availability*—is transit an option for a given trip—and *comfort and convenience*—how a transit trip compares with the same trip made by a different mode. Finally, five categories of performance measures that relate to quality of service—availability, service provision, travel time, safety and security, and maintenance—were introduced. These categories will be reviewed further in the next chapter, and specific performance measures will be identified for each category.

CHAPTER 2. QUALITY OF SERVICE FACTORS

INTRODUCTION

The previous chapter introduced broad categories of issues relating to quality of service. This chapter looks at each of these factors in much greater detail. The chapter also presents different ways of measuring performance and identifies many qualitative and quantitative performance measures that relate to quality of service. Finally, the chapter discusses the aspects of service quality that have been found generally to be the most important to passengers on a national basis and can also be relatively easily quantified. These service quality aspects were used to develop the quality of service framework presented in this manual.

AVAILABILITY FACTORS

Service Coverage

If transit service is located too far away from a potential passenger, transit use is not an option.

As discussed in Chapter 1, the presence or absence of transit service near one's origin and destination is a key factor in one's choice to use transit. Ideally, transit service will be provided within a reasonable walking distance of one's origin and destination, or demand-responsive service will be available at one's doorstep. The presence of accessible transit stops, as well as accessible routes to transit stops, is a necessity for many persons with disabilities who wish to use fixed-route transit. In addition, upgrading existing facilities to meet Americans with Disabilities Act (ADA) regulations also results in a more comfortable walking environment for other transit users. When transit service is not provided near one's origin, driving to a park-and-ride lot or riding a bicycle to transit may be viable alternatives.

Service coverage considers both ends of a trip.

Service coverage considers both ends of a trip, for example, home and work. Transit service at one's origin is of little use if service is not provided near one's destination. Options for getting from a transit stop to one's destination are more limited than the options for getting from one's origin to a transit stop. The car one drove to a park-and-ride lot will not be available at the destination nor will a bicycle left behind in a storage facility. A bicycle carried on a bus-mounted bicycle rack or brought on board a train will be available at the destination, as long as space was available for the bicycle on the transit vehicle.

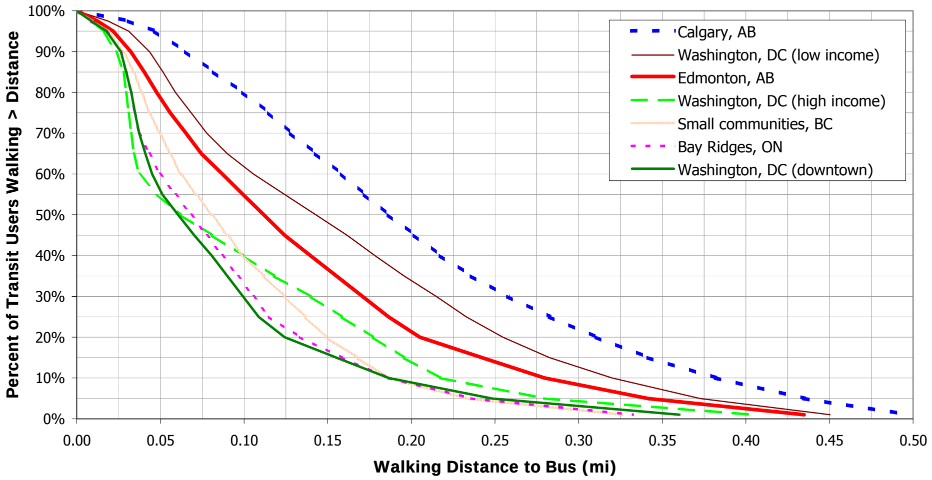
Pedestrian Access

Walking Distance to Transit

The maximum distance that people will walk to transit varies depending on the situation. Exhibit 3-5 shows the results of several studies of walking distances to transit in North American cities. Although there is some variation between cities and income groups among the studies represented in the exhibit, it can be seen that most passengers (75 to 80% on average) walk one-quarter mile (400 meters) or less to bus stops. At an average walking speed of 3 mph (5 km/h), this is equivalent to a maximum walking time of 5 minutes. These times and distances can be doubled for rail transit.(R26) Bus service that emulates rail transit—frequent service throughout much of the day, relatively long stop spacing, passenger amenities at stops, etc.—is expected to have the same walking access characteristics as rail transit (e.g., a maximum walking time of 10 minutes). However, at the time of writing, no research had yet been conducted to confirm this expectation.

Exhibit 3-5
Walking Distance to Bus Stops[R3,R20,R29,R36]

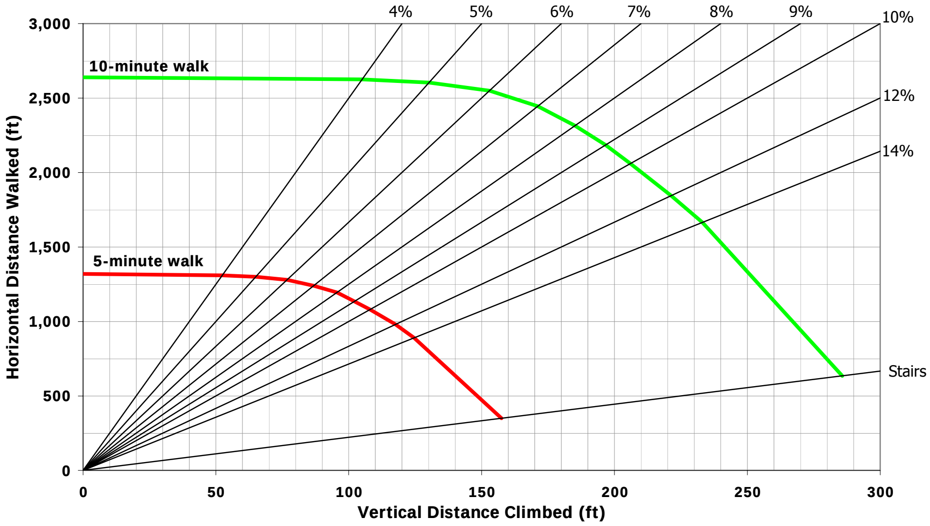
An alternative exhibit using metric units appears in Appendix A.



Other factors can shorten the distance that people will walk to transit stops. A poor pedestrian environment, discussed below, will discourage pedestrian travel. The elderly typically do not walk as far as younger adults. Finally, people will tend to walk shorter distances in hilly areas, due to the effort involved. Exhibit 3-6 shows the results of a study in Pittsburgh on the relationship between walking speeds and grades. It can be seen that at grades of 5% or less (5 feet climbed for each 100 feet traveled horizontally), grades have little impact on travel speed, but that above 5%, the distance that can be traveled within 5 or 10 minutes (0.25 mi/400 m or 0.5 mi/800 m on level terrain) diminishes.

Exhibit 3-6
Effect of Grade on Distance Walked[R23]

An alternative exhibit using metric units appears in Appendix A.



Pedestrian Environment

Even when a transit stop is located within a reasonable walking distance of one's origin and destination, the walking environment may not be supportive of transit. Lack of sidewalks, poorly maintained sidewalks, and lack of street lighting all discourage pedestrian travel. Wide or busy streets without safe and convenient means to cross the street also discourage pedestrian travel. Street-crossing difficulty poses particular difficulties for transit operators: an arterial street generally provides better transit speeds, but potential passengers using stops along the street must cross the street at some point during their round trip—either when they depart or when they return—and may not be able to easily access the service between signalized crossing points. The difficulty pedestrians experience crossing streets can be expressed by the amount of delay they experience waiting for the WALK signal (at signalized crossings) or for a safe gap in traffic (at unsignalized crossings). Pedestrians start exhibiting risk-taking behavior (e.g., jaywalking or running across the street) when their delay exceeds 30 seconds.(R16)

Street Patterns

A neighborhood's street pattern may affect transit access. A grid street pattern, such as those found in older cities, offers direct access to and from streets with transit service from the surrounding neighborhoods. When service is offered on parallel streets, some locations may have a choice of routes to use for a particular trip, resulting in a higher quality of service. On the other hand, subdivisions that back onto streets with transit service, with only one way in and out, will generally have a much smaller proportion of their residences located within a 0.25-mile (400-meter) walking distance of a transit stop, even when the majority of the subdivision is located within a one-quarter-mile air distance of one or more transit stops.

Walking distances to transit may be considerably greater than straight-line ("air") distances.

Americans with Disabilities Act (ADA) Considerations

Passengers with disabilities often must have sidewalk facilities, curb cuts, and bus stop loading areas between their origin and a transit stop and between their destination and a transit stop in order to have the ability to access fixed-route transit service. Without these facilities, passengers with disabilities must rely on paratransit service, which generally provides customers with fewer choices in travel times and usually costs substantially more for transit operators to provide.

Coordination between transit agencies and public works agencies is desirable to make sure transit access is prioritized.

Bicycle Access

Linking bicycles and transit provides benefits to both modes of travel. Access to transit allows bicyclists to make longer trips, and to traverse barriers (such as freeways) that would otherwise eliminate cycling as an option. Transit also provides an option for bicyclists when weather turns unexpectedly bad, their headlight fails, or they find themselves too tired to make it all the way home. Improving bicycle access attracts new transit riders and expands transit's catchment area. A number of systems that have provided bicycle facilities—particularly bus-mounted bicycle racks—have found them to be popular and well-used. Lane Transit District in Eugene, Oregon, for example, averaged 700 to 800 daily bicycle boardings in 2001.

Effective links between bicycling and transit relies on three components:(R12)

- Bicycle connections to stops and stations,
- Bicycle parking at stops and stations, and
- On-vehicle bicycle-carrying facilities.

The federal match for transit enhancement grants to link bicycles and transit can be up to 95% of project cost, while non-bicycle related transit enhancement grants are limited to an 80% federal share. Some transit systems with bus-mounted bicycle racks also use the racks as advertising space that is visible when the rack is not in use.

Bicycle Trip Lengths

Typical bicycling speeds are approximately 12 to 15 mph (20 to 25 km/h), or about four to five times higher than walking speeds. This speed advantage allows transit users to access routes much farther away from their origin or destination than they could if they walked. Typical bicycle trip lengths are approximately 2 to 4 miles (3.5 to 7 km) for casual riders and 4 to 6 miles (7 to 10 km) and longer for experienced riders.(R12) Each portion of a bicycle access-to-transit trip will typically be shorter than these bicycle-only trip lengths, but even a short trip can increase the catchment area of transit stops or stations significantly. Assuming a conservative 5-minute travel time (as used for walking trips), bicycle access to a bus stop would have an approximate radius of 1 to 1.25 miles (1.6 to 2.0 km), which would increase the coverage area of a stop by up to 25 times that for walk-only trips.

Roadway Environment

Just as with pedestrian access to transit, safe and convenient facilities need to be provided to encourage bicycle access. On-street connections should allow cyclists to use bicycle-friendly streets (e.g., low-volume collector or arterial streets that have been modified for cycling) to reach transit stations. Physical modifications made to these streets should be designed based on AASHTO or other appropriate standards. These might include marked bicycle lanes, striped wide shoulder lanes, wide outside lanes, "bike route" signs, and other treatments.(R12)

Bicycle Parking

Security is the most important issue with bicycle parking at transit stops. In the United States, bicycle theft rates are about twice as high as Germany's and five times higher than Japan's. Bicycle thefts cost Americans an estimated $400 million per year.(R12)

Security concerns about enclosures that are not visible from the outside may limit potential bicycle storage options.

Secure parking for bicycles can be provided in the form of racks, lockers, or cages. These facilities should be located in highly visible and well-lit areas that are also out of the way of direct pedestrian traffic flow. Other considerations include facility design that enhances bicycle security (e.g., using only racks that accommodate high-security bicycle locks, providing security camera surveillance, etc.).

On-Vehicle Bicycle-Carrying Facilities

In 2001, more than 25% of all public transit vehicles in the United States were equipped with bicycle racks, such as the one shown in Exhibit 3-7(c).(R2) These are typically folding devices that are mounted on the front of buses and carry two bicycles. A few bus operators allow bicycles to be brought on board during off-peak times. Rail transit operators often allow bicycles aboard trains but may restrict the times of day, directions of travel, and/or locations within the train where bicycles are allowed.

Many agencies that have started a bikes-on-transit program have required users to obtain a permit. However, as agencies have gained positive experiences with bicycle passengers, and as bicycle rack designs have been simplified, some agencies have dropped their permit requirement.

Exhibit 3-7
Bicycle Facility Examples

(a) Bicycle Racks (Olympia, Washington)

(b) Bicycle Lockers (San Jose)

(c) Bus-mounted Bicycle Rack (Honolulu)

(d) Bikes on Ferry (Larkspur, California)

Park-and-Ride Access

Walking is not the primary access mode for certain types of transit services, particularly express bus and commuter rail services. For these modes, automobile access via park-and-ride lots is the primary means of passenger access. Park-and-ride lots also help support transit access in lower-density areas where fixed-route service is not economical, as it focuses transit boarding demand to a small number of points.

An Overview of the Park-and-Ride User

A number of surveys were reviewed for the Maricopa Association of Governments (MAG) to determine the characteristics of park-and-ride users in the Sacramento, Northern Virginia, Chicago, Seattle, and Phoenix areas.(R19) Key characteristics of these park-and-ride users are summarized below:

- Park-and-ride users are choice riders,
- Park-and-ride users have significantly higher incomes than local bus riders,
- The majority of park-and-ride users (more than 60%) traveled to the CBD for work more than four times per week,
- Parking at the destination was expensive,
- Convenient, frequent bus service was offered, and
- Most riders found park-and-ride facilities because they could see them from their regular commute routes.

The MAG review also lists the characteristics of a successful park-and-ride lot. Some of the key points are summarized below:(R19)

- *Location*: the literature reveals that a successful park-and-ride facility should be located at least 4 to 6 miles (7 to 10 km)—preferably 10 miles (16 km)—from a major destination.

- *Transit Service*:
    - Frequent express service (the primary demand-generating characteristic of successful park-and-ride facilities),
    - Close proximity to a freeway or light rail,
    - HOV access for at least a portion of the transit trip, and
    - Visibility from adjacent arterials.
- *Auto access to the park-and-ride facility*: access should be made as convenient and as rapid as possible. The transit portion of a patron's trip should (in most cases) represent more than 50% of the total journey time from the patron's home to final destination.(R6)
- *Auto-to-Transit Cost Ratio*: parking costs are an important element in determining the cost of auto access. The parking cost at the trip destination is typically considerably higher than the round-trip transit fare.

Types of Park-and-Ride Facilities

Park-and-ride facilities are a type of intermodal transfer facility. They provide a staging location for travelers to transfer between the auto mode and transit or between a single-occupant vehicle and other higher occupancy vehicles (HOV or carpool modes). Park-and-ride facilities are usually classified by location or function. A hierarchy of lots can be described as follows:(R37)

- *Informal park-and-ride lots* are transit stops where motorists regularly drive their cars and leave them parked on the street or on an adjacent property. These are often more difficult to discern than lots officially connected with a transit stop.
- *Joint use lots* share the parking facility with another activity such as a church, theater, shopping mall, or special events center. The park-and-ride activity can be either the secondary or primary use of the facility, depending upon the desired orientation and opportunity provided.
- *Park-and-pool lots* are typically smaller lots that are intended exclusively for the use of carpool and vanpool vehicles. These can be joint use or may be part of a development plan where the developer dedicates a number of spaces.
- *Suburban park-and-ride lots* are typically located at the outer edges of the urban area.
- *Transit centers* are facilities where interchange between local and express transit service occurs.
- *Satellite parking lots* are generally placed at the edge of an activity center to provide inexpensive alternatives to on-site parking within the activity center itself and to reduce traffic congestion within the activity center.

Park-and-ride lots can also be classified by land use, location, and/or distance from the destination. A different demand estimation technique is usually developed for each lot type:(R13,R37)

- *Peripheral lots* include facilities built at the edge of a downtown, and other intensely developed, highly congested activity centers, such as universities or auto-free zones. These lots intercept travelers prior to the activity center, storing vehicles in a location where parking costs are relatively inexpensive.
- *Local urban lots* fill the gap between the suburban market and the downtown. They lie typically between 1 to 4 miles (2 to 7 km) from the downtown and are often served only by local or local-express transit routes.

- *Urban corridor lots* are located along major commute corridors and are typically served by line-haul transit. HOV corridor lots are a subset of this category and are located adjacent to major highways that provide HOV lanes.
- *Suburban/urban fringe lots* are located 4 to 30 miles (7 to 50 km) from the downtown and provide an intermodal (change of vehicle) service. The more distant lots generally are not served by transit, although this is not universally true.
- *Remote/rural lots* are generally located outside the urban area in a rural or small-town setting. Typical distances range from 40 to 80 miles (65 to 130 km).

Park-and-Ride Market Areas

Market shed analysis relies on the definition of a service area or market shed. Theory suggests that, once a market area is defined for park-and-ride lots, socioeconomic data can be collected regarding the people living within the market shed. These data can then be used to predict demand for specific park-and-ride facilities. A number of studies have attempted to identify a single standardized market shape and size. The literature indicates that the most common market areas for park-and-ride services reflect parabolic, semicircular, or circular shapes.

A standardized service shape for park-and-ride lots is not feasible.

Because of the different characteristics of metropolitan areas, a standardized service shape that describes the entire park-and-ride lot market area that is suitable for application throughout North America is not feasible. However, some common characteristics of park-and-ride lots can be described.

Patrons using a specific park-and-ride facility will be expected to come from a catchment area primarily upstream from the park-and-ride facility. Backtracking, the phenomenon of patrons who live between the park-and-ride lot and the employment destination who drive upstream to gain access to a lot for a downstream location is limited. However, where multiple major activity centers exist within an area and are served by a particular lot, passengers may arrive from all directions.

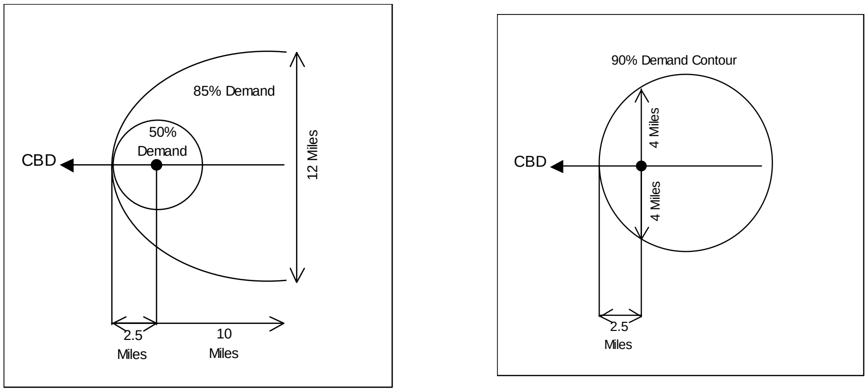
A study of Seattle-area park-and-ride lots found that for suburban lots, 50% of the park-and-ride facility's demand is typically generated within a 2.5-mile (4-km) radius of the facility, and that an additional 35% comes from an area defined by a parabola extending 10 miles (16 km) upstream of the lot and having a long chord of 10 to 12 miles (16 to 19 km).(R28) This market area is illustrated in Exhibit 3-8(a).

Studies conducted in several Texas metropolitan areas suggest a parabolic model or an offset circular model would be appropriate for a park-and-ride service coverage area.(R37) The offset circular model is illustrated in Exhibit 3-8(b).

A study conducted for the North Central Texas Council of Governments found that the average market shed for "non-suburban" (i.e., peripheral) lots is typically more dispersed around a common center than the suburban park-and-ride types, as shown in Exhibit 3-8(c).(R25) These findings were confirmed in a similar study from the Puget Sound region, which examined two lots that operate as peripheral park-and-ride facilities.(R37)

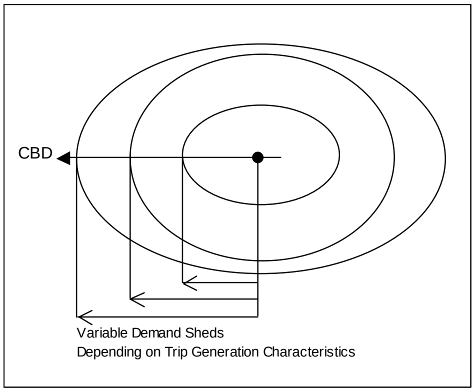
Finally, simple assumptions are often used for remote lots. In Florida, approximately 50% of remote lot users live within 3 miles (5 km) of the lot and about 90% come from within 19 miles (30 km).

Exhibit 3-8
Example Park-and-Ride Market Areas(R25, R28, R37)



(a) Suburban Lot (Seattle)

(b) Suburban Lot (Texas)



(c) Peripheral Lot (Texas)

Scheduling

How often transit service is provided and when it is provided during the day are important factors in one's decision to use transit. The more frequent the service, the shorter the wait time when a bus or train is missed or when the exact schedule is not known, and the greater the flexibility that customers have in selecting travel times. The number of hours during the day when service is provided is also highly important: if service is not provided at the times one desires to travel, transit will not be an option for that trip. As the number of hours and days that service is provided increases, the number of trip types that can be served by transit greatly increases. Providing service into the evening hours, for example, allows someone who normally uses transit to commute to work to continue to use transit on days when that person must work late or wishes to remain downtown after work for other activities.

Capacity

Insufficient capacity can impact transit service availability. If a bus or train is full when it arrives at a stop, transit service is not available at that time to the people waiting there. The effective service frequency for these passengers is reduced from what is implied by the schedule, as they are forced to wait for the next vehicle or find another means of making their trip. Lack of available securement space or a non-functional lift will impact fixed-route service availability for persons with disabilities. In demand-responsive service, capacity constraints take the form of *service denials,* where a trip cannot be provided at the requested time, even though service is operated at that time. Courts have held that a pattern of service denials is not allowed under the ADA. However, service denials can be and are used by general public demand-responsive providers as a means of rationing capacity to control costs.

Information

Riders need to know where and when transit service is available and how to use it.

Passengers need to know how to use transit service, where to go to access it, where to get off near their destination, whether any transfers are required, and when transit services are scheduled to depart and arrive. Without this information, potential passengers will not be able to use transit service, even though it would otherwise be an option for their trip. Visitors to an area and infrequent transit users (e.g., people who use transit when their car is being serviced) particularly need this information, but they can be the most difficult people to get information to. Even regular transit users may require information about specific routes when they need to travel to a location they rarely visit.

Timely and correct information is also vital under other circumstances:

- When regular service adjustments are made, such as schedule changes or route modifications;
- When temporary service changes are required, for example, due to road construction or track maintenance; and
- When service problems arise, so passengers know the nature of the problem and have enough information to decide how to adjust their travel plans.

Information can be provided to passengers by a variety of means:

Information must be available in accessible formats.

- *Printed, distributable information*, such as timetables, maps, service change notices, rider newsletters, etc., preferably available at a number of locations;
- *Posted information*, such as system maps posted at stations or on vehicles, or notices of out-of-service elevators;
- *Audible announcements* of rail stations, train directions, major bus stops, fare zone boundaries, etc. assist not only passengers with visual impairments, but also passengers unfamiliar with the route or area;
- *Visual displays* to assist passengers with hearing impairments and to supplement on-board announcements that may be muffled by other noise.
- *Transit infrastructure,* such as shelters, signs directing motorists to park-and-ride lots, and bus stop signs that indicate the presence of service to people not currently using transit;
- *Telephone information*, customized to an individual customer's needs; and
- *Internet information* available 24 hours per day to anyone with Internet access.

No matter how passengers obtain information, it should be correct and up-to-date. Schedule information posted at stops, for instance, should be updated each time the schedule is updated. Information provided to passengers by agency employees during service disruptions should be as accurate and complete as possible under the circumstances, but should avoid being too specific (e.g., the train will be underway in "X" minutes) when there is the possibility that the circumstances could change.

Real-time information reassures passengers and lets them make informed choices.

Real-time information is useful for reassuring passengers about when the next vehicle will arrive. For example, if a bus does not arrive at its scheduled time, a passenger arriving at the stop shortly before that time will not know whether the bus left early, is running behind schedule, or is not in service. In addition, knowing that there will be a wait until the next bus arrives allows passengers to decide whether to run an errand or take a different bus rather than wait at the stop. Finally, when vehicle bunching occurs, knowing when the following vehicles will arrive is also useful: when passengers know that another vehicle will arrive in 1 or 2 minutes, some will choose not to board the first, typically crowded, vehicle in favor of a later, less-crowded vehicle. This helps spread out passenger loads among the vehicles and may help keep the lead vehicle from falling further behind schedule.

COMFORT AND CONVENIENCE FACTORS

Passenger Loads

The ability to find a seat on a transit vehicle is an important passenger comfort factor for longer trips.

Transit is less attractive when passengers must stand for long periods of time, especially when transit vehicles are highly crowded. When passengers must stand, it becomes difficult for them to use their travel time productively, which eliminates a potential advantage of transit over the private automobile. Crowded vehicles also slow down transit operations, as it takes more time for passengers to get on and off, and rail passengers may try to hold doors open in order to squeeze onto the train.

Most transit agencies assess the degree of passenger crowding on a transit vehicle based on the occupancy of the vehicle relative to the number of seats, expressed as a *load factor*. A factor of 1.0 means that all the seats are occupied. The importance of vehicle loading varies by the type of service. In general, transit provides load factors at or below 1.0 for long-distance commute trips and high-speed mixed-traffic operations. Inner-city rail service may approach 2.0 or even more, while other services will be in between.

Some agencies' service standards balance service frequencies with passenger loads. When boarding volumes are relatively low, service frequencies will also be low, to avoid running nearly empty buses, but sufficient buses will be provided to ensure that all passengers can have a seat. At higher boarding volumes, not all passengers will be able to get a seat, but frequencies are set high enough to ensure that passengers will not have to wait long for the next bus.

Because the number of seats provided varies greatly between otherwise identical rail vehicles operated by different transit systems, measuring loading by the number of passengers per unit vehicle length is often more appropriate for rail capacity calculations than using a load factor.

Reliability

Reliability includes both on-time performance and the evenness of headways between transit vehicles.

Reliability affects the amount of time passengers must wait at a transit stop for a transit vehicle to arrive, as well as the consistency of a passenger's arrival time at a destination from day to day. Reliability also affects a passenger's total trip time: if persons believe a transit vehicle may depart early, they may arrive earlier than they would otherwise to ensure not missing the bus or train. Similarly, if passengers are not confident of arriving at their destination on time, they may choose an earlier departure than they would otherwise, to ensure that they arrive on time, even if it means often arriving much earlier than desired.

Bus bunching has capacity impacts, as the offered capacity cannot be fully utilized.

Reliability encompasses both on-time performance and the regularity of headways between successive transit vehicles. Uneven headways result in uneven passenger loadings, with a late transit vehicle picking up not only its regular passengers but those passengers that have arrived early for the following vehicle, with the result that the vehicle falls farther and farther behind schedule and more passengers must stand. In contrast, the vehicles following will have lighter-than-normal passenger loads and will tend to run ahead of schedule. With buses, this "bunching" phenomenon is irritating both to passengers of the bunched buses and to passengers waiting for other buses who see several buses for another route pass by while they wait for their own bus. With signaled rail operations, bunched trains often have to wait at track signals until the train ahead of them moves a safe distance forward. The resulting unscheduled waits are not popular with passengers, particularly when no on-board announcements are given explaining the delay.

Reliability is influenced by a number of factors, some under the control of transit operators and some not. These factors include:

Factors affecting the reliability of transit service.

- *Traffic conditions* (for on-street, mixed-traffic operations), including traffic congestion, traffic signal delays, parking maneuvers, incidents, etc.;
- *Road construction* and *track maintenance,* which create delays and may force a detour from the normal route;
- *Vehicle and maintenance quality*, which influence the probability that a vehicle will break down while in service;
- *Vehicle and staff availability*, reflecting whether there are sufficient vehicles available to operate the scheduled trips (some vehicles will be undergoing maintenance and others may be out-of-service for various reasons) and whether sufficient operators are available on a given day to operate those vehicles;
- *Transit preferential treatments*, such as exclusive bus lanes or conditional traffic signal priority that operates only when a bus is behind schedule, that at least partially offset traffic effects on transit operations;
- *Schedule achievability*, reflecting whether the route can be operated under usual traffic conditions and passenger loads, with sufficient layover time provided for operators and sufficient recovery time to allow most trips to depart on time even when they arrived at the end of the route late;
- *Evenness of passenger demand,* both between successive vehicles and from day to day for a given vehicle and run;
- *Differences in operator driving skills,*(R39) route familiarity, and adherence to the schedule—particularly in terms of early ("hot") running;
- *Wheelchair lift and ramp usage,* including the frequency of deployment and the amount of time required to secure wheelchairs;
- *Route length and the number of stops,* which increase a vehicle's exposure to events that may delay it—delays occurring earlier along a route result in longer overall trip times than similar delays occurring later along a route;(R1,R38) and
- *Operations control strategies* used to react to reliability problems as they develop, thus minimizing the impact of the problems.(R21)

Travel Time

A longer trip by transit than by automobile may be seen by passengers as being less convenient; this may be mitigated somewhat if the on-board transit time can be used productively where the in-car time would not be.

Total trip time includes the travel time from one's origin to a transit stop, waiting time for a transit vehicle, travel time on-board a vehicle, travel time from a transit stop to one's destination, and any time required for transfers between routes during the trip. The importance of each of these factors varies from person to person. Some persons will view the trip as an opportunity for exercise during the walk to transit and for catching up on reading or work while aboard a vehicle. Other persons will compare the overall door-to-door travel time of a trip by transit with the time for the same trip by private automobile. Total trip time is influenced by a number of factors, including the route and stop spacing (affecting the distance required to walk to transit), the service frequency (affecting wait time), traffic congestion, signal timing, and the fare-collection system used (affecting travel time while on a transit vehicle).

Travel time can be measured by itself or in relation to other competing modes—for example, by the difference between auto and transit travel times or by the ratio of those two times.

Transfers

Requiring transfers can make service more efficient for operators, but can be less convenient for passengers, depending on the circumstances. Each transfer adds to a passenger's total trip time, due to the wait required between buses, although this factor can be minimized by implementing timed transfers. However, introducing a transfer into what was previously a one-seat service from origin to destination may have a net positive benefit for passengers, if the new route that the passengers transfer to offers a net time savings, service frequency improvements, or other passenger benefits over the old service.(R31)

Transfers also raise the possibility that a missed connection will occur, which would increase the length of a passenger's trip by the amount of one headway. Transfers also increase the complexity of a transit trip to first-time passengers. Requiring a surcharge for transfers can inhibit ridership.

Passenger Perceptions of Time

Passengers perceive the passage of time differently for each portion of their trip—walk time to transit, wait time at the stop, in-vehicle time, and transfer time. *TCRP Web Document 12*(R31) documents the results of a number of studies of the relative importance of travel time. Exhibit 3-9 presents these results for work trips. A value of 2, for example, indicates that one minute of a particular travel time component (e.g., wait time) is perceived by passengers as being twice as onerous as one minute of in-vehicle time.

Exhibit 3-9
Relative Importance of Travel Time Components for Work Trips(R31)

	In-vehicle Time	Walk Time	Initial Wait Time	Transfer Time
Average	1.0	2.2	2.1	2.5
Range	1.0	0.8-4.4	0.8-5.1	1.1-4.4

Some studies have also identified a transfer penalty in addition to the higher importance of transfer time relative to in-vehicle time. Reported transfer penalties are typically in the range of 12 to 17 minutes.(R31) The transfer penalty for trips with neither end at home can be very high: a study used to develop the Minneapolis-St. Paul area's mode choice model found a penalty of 27 minutes for non-home, work-based trips, and 2 hours for non-home, non-work based trips.(R27)

Safety and Security

Passengers' perceptions of safety must be considered in addition to actual conditions.

Riders' perceptions of the safety and security of transit, as well as actual conditions, enter into the mode choice decision. Safety includes the potential for being involved in a crash, as well as slips and falls while negotiating stairs or other elements of the transit system. Security covers both the real and perceived chance of being the victim of a crime while using transit. It also covers irritants, such as encountering unruly passengers on a regular basis or having to listen to someone else's radio.

Security at transit stops can be improved by placing stops in well-lit areas and by having well-marked emergency phones or help points available. Passengers may also feel more comfortable when other passengers are around (i.e., when one is not the only passenger on the car of a train or the only one waiting at a stop). Transit systems use a variety of methods to enhance security on-board transit vehicles, including having uniformed and plainclothes police officers ride transit, establishing community volunteer programs, providing two-way radios and silent alarms for emergency communication, and using surveillance cameras.

Cost

Free parking at a worksite is a disincentive to transit use.

Potential passengers weigh the cost and value of using transit versus the out-of-pocket costs and value of using other modes. Out-of-pocket transit costs consist of the cost of the fare for each trip or the cost of a monthly pass (and possibly the cost of parking at a station), while out-of-pocket automobile costs include road and bridge tolls and parking charges. Other automobile costs, such as fuel, maintenance, insurance, taxes, and the cost of buying an automobile generally do not occur for individual trips and thus usually do not enter into a person's consideration for a particular trip. Thus, if a person does not pay a toll to drive someplace and free parking is provided at the destination, transit will be at a disadvantage because there will be no immediate out-of-pocket cost for driving, while there will be for transit. Some Transportation Demand Management (TDM) techniques seek to overcome this obstacle by encouraging employers who provide free parking (in effect, subsidizing the true cost of providing parking) to also provide subsidized transit passes or other means of encouraging transit use as an alternative to the private automobile.

Appearance and Comfort

Having clean, attractive transit stops, stations, and vehicles improves transit's image, even among non-riders. For example, the presence of shelters can help non-users become aware of the existence of transit service in the areas that they normally travel past in their automobiles. On the other hand, a dirty or vandalized shelter or vehicle can raise questions in the minds of non-users about the comfort and quality of transit service, and about other aspects of the service, such as maintenance, that may not be as obvious. Some transit systems (for example, Bay Area Rapid Transit in the San Francisco Bay Area, Housatonic Area Regional Transit in Danbury, Connecticut, the Tidewater Transportation Commission in Norfolk, Virginia, and MTA-New York City Transit) have established standards for transit facility appearance and cleanliness and have also established inspection programs.(R9,R17,R41)

TCRP Report 88(R17) provides more information on these "passenger environment survey" programs.

Passengers are also interested in personal comfort while using transit, including

- Appropriate *climate control* for local conditions, such as heating in the winter and air conditioning in the summer;
- *Seat comfort,* including seat size, amount of padding, and leg room; and
- *Ride comfort,* including the severity of acceleration and braking, vehicle sway, odors, and vehicle noise. Ride comfort is particularly important for older passengers and persons with disabilities.

Amenities: frills or necessities?

Many elements of transit infrastructure help make transit comfortable for passengers and make transit more competitive with the automobile. This infrastructure is often referred to as *amenities*; however, some have argued that the term "amenities" implies something extra and not necessarily required. Passengers sweltering on a non-air conditioned bus on a hot day would likely not agree that air conditioning is a frill, rather than a necessity.

TCRP Report 19(R40) provides guidelines for designing, locating, and installing transit amenities.

The types of amenities provided are generally related to the number of boarding passengers at a stop. Examples of transit amenities, some of which are illustrated in Part 7, include the following:(R40)

- *Benches,* to allow passengers to sit while waiting for a transit vehicle.
- *Shelters,* to provide protection from wind, rain, and snow in northern climates and from the sun in southern climates. In cold climates, some agencies provide pushbutton-operated overhead heaters at shelters located at major transit centers.
- *Lighting,* to improve passengers' sense of security at the stop.

- *Informational signing,* to identify the routes using the stop, their destinations (both intermediate and ultimate), and/or scheduled or actual arrival times.
- *Trash receptacles,* to reduce the amount of litter around the transit stop. However, because of security concerns, some agencies are choosing to remove trash receptacles.
- *Telephones,* to allow passengers to make personal calls while waiting for a transit vehicle, as well as providing for the ability to make emergency calls. Telephones should be programmed to allow outgoing calls only to discourage loitering around the stop.
- *Vending facilities,* ranging from newspaper racks at commuter bus stops to manned newsstands, flower stands, food carts, transit ticket and pass sales, and similar facilities at rail stations and bus transfer centers.
- *Air conditioning* on transit vehicles, to provide a comfortable ride on hot and humid days, as well as *heating* in stations and on vehicles in colder climates.

MEASURING QUALITY OF SERVICE

Quantitative Measures

Certain aspects of transit performance can be quantified—that is, expressed as a number. Numerical values, by themselves, provide no information about how "good" or "bad" a particular result is, or whether one value is particularly different from another value, from a passenger's point of view. In order to provide this interpretation, performance results can be compared with a fixed standard or with past performance. Alternatively, the results can be expressed in a format that provides built-in interpretation. Two such formats are described below.

Levels of Service

Origin of the level of service concept.

The concept of LOS was originally developed in the 1965 *Highway Capacity Manual*. Under this concept, the potential values for a particular performance measure are divided into six ranges, with each range assigned a letter grade ranging from "A" (highest quality) to "F" (lowest quality). Ideally, the threshold between each letter grade represents a point where the service quality becomes noticeably different to travelers, whether they are motorists or transit riders. Within each letter grade, travelers ideally would notice no significant difference in service quality between different performance measure results assigned to that LOS grade. In practice, the change in traveler perceptions between adjacent LOS grades is often more of a transition than a distinct step at the threshold.

The key aspects of levels of service are two-fold:

1. The LOS ranges should reflect a traveler's point-of-view. LOS "A", therefore, is not necessarily representative of optimum conditions from a transit provider's point-of-view.
2. LOS "F" should represent an undesirable condition from a traveler's point-of-view. The service provider may choose to set higher standards based on their needs or policy goals.

LOS grades should not be interpreted as being the same as school grades.

Because of their similarity to letter grades received in school, a potential danger of levels of service is that they may lead persons unfamiliar with the LOS concept to the incorrect conclusion that LOS "A" should be the target that service providers should aim for (i.e., "I wouldn't accept my child bringing home C's and D's from school; why should we accept those grades in our transit service?"). In many cases, providing too good an LOS can be just as bad as providing a poor LOS, as agency resources are diverted to unproductive service instead of being used to improve service quality in areas where improvement is really needed. What users might consider to be the best possible service quality is often uneconomical to provide, and service providers must strike a balance between service quality and affordable service. Nevertheless, LOS "F" should be considered undesirable both scholastically and in terms of transit performance.

Fixed-route transit service uses letter grades to measure LOS.

A major reason why this manual has adopted LOS letter grades for fixed-route service is consistency with how other modes already measure quality of service. Many planning organizations (e.g., planning departments and MPOs), and decision-making bodies (e.g., city councils and boards of commissioners) are already familiar with LOS letter grades as they are applied to highways. Adopting a similar system for fixed-route transit and other modes allows all transportation modes to share a common language on how quality of service is measured, and eases the learning curve for planners and decision-makers who may be less familiar with transit operations than with roadway operations.

Demand-responsive service uses numerical scores for LOS.

This manual also uses the LOS concept to describe passengers' perceptions of the quality of demand-responsive service. However, demand-responsive service has fundamental differences from fixed-route service, particularly in the manner of access, degree of trip spontaneity, and flexibility in choosing origins and destinations. Thus, one cannot easily directly compare the quality of demand-responsive service with fixed-route service. Therefore, demand-responsive LOS uses a 1 to 8 numerical scale, rather than an "A" to "F" letter scale, to describe differences in passenger perceptions. Because of the great range of types of demand-responsive services, from same-day taxi-based services in urban areas to rural service provided once or twice per month, a greater number of service levels are used for demand-responsive service, in order to adequately describe differences in passenger perceptions.

Indexes

Performance measure users can quickly become overwhelmed as the number of performance measures being tracked and reported increases. One technique to minimize the number of measures reported, while maximizing the number of quality of service factors measured, is to develop a quality of service index. Such an index can incorporate several different performance measures, and each component can be assigned a weight reflecting its relative importance. Weights would be determined locally (e.g., from the results of a survey). The typical form of an index is as follows:

$$i = c_n\left(w_1 p_1 + w_2 p_2 + \cdots + w_x p_x\right)$$

Equation 3-1

where:

i = index value;
c_n = constant to normalize the maximum index value to a particular value;
w_x = weight of performance measure x; and
p_x = value of performance measure x.

Indexes can simplify performance reporting, but can mask changes in individual quality factors.

Although indexes are useful for developing an overall measure of service quality, the impact of changes in individual index components are hidden. A significant decline in one aspect of service quality, for example, could be offset by small gains in other aspects of service quality.

Qualitative Measures

Quantitative measures assess things that are directly observable about transit service. In contrast, qualitative measures assess passengers' perceptions. The latter measures' value lies in identifying aspects of service quality that are difficult or impossible to measure directly—things such as security, staff courtesy, value for the money, and so on. One commonly used, but indirect, method of identifying customer opinions is by tracking complaints and compliments that are made. Complaint tracking is inexpensive, but has the disadvantage of being reactive—a customer has already been made so unhappy that he or she has taken the time to complain. Complaint tracking also is only useful when customers feel that their complaints are taken seriously. If passengers lose this feeling, they may stop complaining, not because the problem has gone away, but because nothing ever appears to be done about the complaints.

Two methods used by transit agencies to help identify problems before they become serious enough to generate many complaints are customer satisfaction surveys and passenger environment surveys, which are described below.

Customer Satisfaction Surveys

Customer surveys help transit operators identify the quality of service factors of greatest importance to their customers. They can also be used to help prioritize future quality of service improvement initiatives, measure the degree of success of past initiatives, and track changes in service quality over time. Surveys can identify not only areas of existing passenger satisfaction or dissatisfaction, but the degree to which particular factors influence customer satisfaction. Thus, these surveys can help identify the quality of service factors of greatest importance to the riders of a particular transit system. Exhibit 3-10 shows examples of service attributes that could be rated as part of a customer satisfaction survey, with each attribute rated on a 1 to 5 or 1 to 10 scale, for instance.

TCRP Report 47(R22) identifies a "impact score" process that transit operators can use to identify the most important quality of service factors for their passengers, based on the results of a customer satisfaction survey. First, a *gap score* is developed for each service attribute, consisting of the difference between the average rating for the attribute among those who did not experience a problem with that attribute during the previous 30 days and the average rating among those who did experience a problem. The greater the gap score, the more important that a problem with that attribute is to passengers.

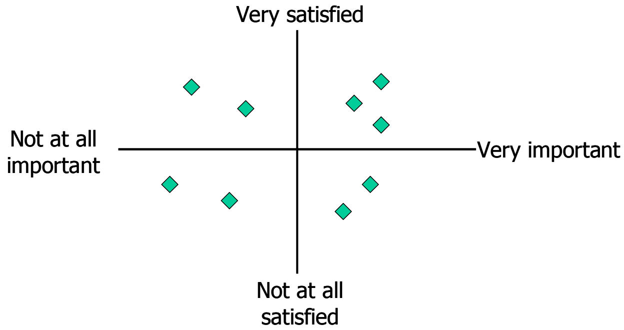
Exhibit 3-10
Examples of Transit Service Attributes(R22)

Absence of graffiti
Absence of offensive odors
Accessibility to persons with disabilities
Availability of handrails or grab bars
Availability of monthly discount passes
Availability of schedule information
Availability of schedules/maps at stops
Availability of seats on train/bus
Availability of shelter and benches at stops
Cleanliness of interior, seats, windows
Cleanliness of stations/stops
Cleanliness of train/bus exterior
Clear and timely announcements of stops
Comfort of seats on train/bus
Connecting bus service to main bus stops
Cost effectiveness, affordability, and value
Cost of making transfers
Display of customer service number
Ease of opening doors when getting on/off
Ease of paying fare, purchasing tokens
Explanations and announcements of delays
Fairness/consistency of fare structure
Freedom from nuisance behaviors of riders
Frequency of delays from breakdowns/emergencies
Frequency of service on Saturdays/Sundays
Frequent service so that wait times are short
Friendly, courteous, quick service from personnel
Having station/stop near one's destination
Having station/stop near one's home
Hours of service during weekdays
Number of transfer points outside downtown
Physical condition of stations/stops
Physical condition of vehicles and infrastructure
Posted minutes to next train/bus at stations/stops
Quietness of the vehicles and system
Reliable trains/buses that come on schedule
Route/direction information visible on trains/buses
Safe and competent drivers/conductors
Safety from crime at stations/stops
Safety from crime on trains/buses
Short wait time for transfers
Signs/information in Spanish as well as English
Smoothness of ride and stops
Station/stop names visible from train/bus
Temperature on train/bus—not hot/cold
The train/bus traveling at a safe speed
Trains/buses that are not overcrowded
Transit personnel who know system

Second, an *occurrence rate* for each service attribute reflects the percentage of survey respondents who experienced a problem with that attribute during the previous 30 days. The higher the occurrence rate, the greater the number of passengers that experience problems with that service attribute. Finally, an *impact score* is calculated that multiplies the gap score by the occurrence rate. The higher an attribute's impact score, the greater the impact that changes in this attribute's quality will have on overall customer satisfaction. Attributes can be sorted by impact score to develop a prioritized list of service quality factors requiring attention.

An alternative way to look at customer satisfaction survey results is through *quadrant analysis.* Service attributes can be plotted on a chart similar to the one shown in Exhibit 3-11, with the customer-rated importance of an attribute plotted against the customer-rated satisfaction with that attribute. Attributes with the greatest impact on customer satisfaction will appear in the lower-right quadrant, while those with the least impact will appear in the upper-left quadrant.

Exhibit 3-11
Customer Satisfaction Quadrant Analysis(R22)



A full description of how to perform a customer satisfaction survey and use the results of such a survey is beyond the scope of this manual. However, *TCRP Report 47* provides detailed information on this topic.(R22)

See *TCRP Report 47* for more information on customer satisfaction surveys.

Passenger Environment Surveys

Passenger environment surveys use a "secret shopper" technique, in which trained checkers travel through the transit system, rating a variety of trip attributes in order to provide a quantitative evaluation of factors that passengers would think of qualitatively.(R17) For example, BART rates the interior cleanliness of train cars on a 0 (lowest) to 7 (highest) scale. Points are deducted for each incidence of small litter (smaller than a 3-by-5-inch or 76-by-127-mm card), large litter, food, broken glass, spills, and biohazards, with different point values applying to each category.(R41)

Factors evaluated by MTA-New York City Transit for buses and rail vehicles include(R17)

- *Cleanliness and Appearance*—amount of litter; exterior dirt conditions; floor and seat cleanliness; graffiti; and window condition;
- *Customer Information*—readable and correct vehicle signage; presence of priority seating stickers (bus); correct and legible maps; correct and adequate bus stop signage; and audible, understandable, and accurate public address announcements;
- *Equipment*—climate control conditions; operative kneeling feature, wheelchair lift, windows, and rear door (bus); or door panel condition and lighting (rail); and
- *Operators*—proper uniforming; proper display of badges and proper use of kneeling feature (bus).

Factors evaluated by MTA-New York City Transit for rail stations include(R17)

- *Cleanliness and Appearance*—amount of litter; station floor and seat cleanliness; and graffiti;
- *Customer Information*—readable and correct signage; correct and legible maps; and audible, understandable, and accurate public address announcements;
- *Equipment*—functional speakers in stations; escalators/elevators in operation; public telephones in working order; station control areas that have a working booth microphone; trash receptacles usable in stations; functional token/MetroCard vending machines; and functional turnstiles; and
- *Station Agents*—proper uniforming and proper display of badges.

Additional information on preparing and conducting passenger environment surveys can be found in *TCRP Report 88*.(R17)

QUALITY OF SERVICE FRAMEWORK DEVELOPMENT

Service Measure Selection

Given the large number of passenger-focused performance measures to choose from, careful consideration was given to identifying a selection of measures that best fit the following criteria:

- Measures that best represented the passenger point-of-view,
- Measures that could be easily quantified in terms of levels of service, and
- Measures that were already being used by a number of agencies.

Customer Satisfaction Survey Results

TCRP Project B-11, "Customer-Defined Service Quality"(R22) developed a system for transit operators to identify the most important customer-service issues affecting their system. As part of this project, pilot tests of the project's customer satisfaction surveying techniques helped to identify some of the factors important to transit riders, regardless of the individual agency.

The project selected an urban rail system, a suburban bus system, and a small city bus system for its pilot tests, and distributed more than 13,000 surveys, with response rates ranging from 33.6% to 46.3%. The project also conducted a sampling of follow-up phone surveys. The surveys asked riders to rate 46 transit system attributes on a scale of 1 to 10 and to identify whether they had experienced a problem with that attribute within the last 30 days.

For ease of comparison, the 46 surveyed attributes can be grouped into the following nine categories: comfort, nuisances, scheduling, fares, cleanliness, in-person information, passive information, safety, and transfers. When analyzing the top 10 attributes that were existing problems, scheduling was the top area of concern, followed by comfort and nuisances. However, when potential problems were analyzed, fares and scheduling were the top concern, followed by comfort and safety, with nuisances the category with the least potential for high levels of concern.

The Florida Department of Transportation (FDOT) commissioned a survey of customer satisfaction factors for six larger Florida transit systems.(R8) As with the TCRP B-11 survey, the FDOT survey sought to identify both existing problems and potential problems. A total of more than 14,500 surveys were returned from the six systems, representing response rates of up to 28%. The surveys covered 22 factors, including hours of service, frequency of service, convenience of routes, on-time performance, travel time, transferring, cost, information availability, vehicle cleanliness, ride comfort, employee courtesy, perception of safety, bus stop locations, and overall satisfaction.

Existing problems of greatest significance to Florida customers were hours of service, routes, and headways. Potential problems of greatest significance were routes and headways, hours of service, bus ride comfort, printed schedules, and safety and cleanliness.

Transit System Size Considerations

In measuring transit quality of service, the size of the city, metropolitan area, "commuter-shed," or transit service area may need to be taken into account. A small city could regard transit service on a route every 30 minutes for 12 hours per day, six days per week to be good. In a large transit system, good service could require service at least every 10 to 15 minutes, 18 hours per day, seven days per week. However, these determinations of "good service" are based as much on passenger demand and the realities of transit operating costs as they are on passengers' perceptions of service quality.

The question naturally arises, should there be different levels of service for different sized areas? From purely a passenger's perspective, which quality of service is based upon, the answer is "no": a 1-hour headway between buses is just as long for a passenger in a small town as it is for a passenger in a large city. Therefore, no distinction has been made in the levels of service presented in Chapter 3 to account for area population. (The consequences of providing a 1-hour headway, though, do vary by city size and are reflected by other measures, such as passenger loads. These consequences will be more severe in a large city than in a small city.)

LOS ranges are not adjusted based on city size.

LOS ranges are not adjusted to reflect differences in city sizes. From an agency's standpoint, though, there are significant differences between small towns and large cities, particularly in passenger demand volumes and available funding levels. If agencies choose to develop service standards based on levels of service, these will likely vary based on community size: a small city agency might wish to provide a seat for every passenger (LOS "C" or better), while a large city agency might allow maximum schedule loads (LOS "E") during peak periods. The service measure and the quality perceived by the passenger for a given LOS is the same in both cases.

The TCQSM does not set national standards.

The TCQSM is not intended to set a national standard on the amount or level of service that should be provided for a given situation. Decisions of this nature are left to the judgment of local agencies, based on community and agency goals and objectives, development and demographic patterns, and available agency resources. The procedures given in Chapter 3 are intended to be tools that agencies can use to evaluate the service they provide or might wish to provide.

This page is intentionally blank.

CHAPTER 3. FIXED-ROUTE TRANSIT SERVICE MEASURES

INTRODUCTION

This chapter presents transit quality of service measures of transit availability and comfort and convenience for fixed-route service provided at transit stops, along route segments and corridors, and throughout a system. The chapter also presents other performance measures that transit operators and planners may want to consider for specific applications. Although each combination of quality of service category and transit system elements has only one service measure, analysts may find it useful to present measures in the form of a transit "report card" to better compare a number of quality of service aspects of various alternatives.

Because route segments contain a series of stops, both stop-level and route-level measures are appropriate to use for routes.

Because of the significant differences in how fixed-route and demand-responsive services operate, and how passengers perceive service quality, separate LOS measures and grading systems are provided for demand-responsive service. These are discussed in Chapter 4. Deviated fixed-route service can be evaluated using the procedures described in this chapter for fixed-route service.

AVAILABILITY—TRANSIT STOPS

From the user's perspective, *service frequency* determines how many times an hour a user has access to the transit mode, assuming that transit service is provided within acceptable walking distance (measured by service coverage) and at the times the user wishes to travel (measured by hours of service). Service frequency also measures the convenience of transit service to choice riders and is one component of overall transit trip time (helping to determine the wait time at a stop).

The service measure used is *average headway,* which is the inverse of the average frequency. For convenience, Exhibit 3-12 lists LOS by both headway and frequency. Although headways are given as continuous ranges for the purposes of determining LOS, passengers find it easier to understand schedules when *clock headways* are used (i.e., headways are evenly divisible into 60), particularly when headways are long. When headways are short, clock headways are less important, as customers know that a transit vehicle will arrive soon. Also, delays due to traffic congestion at certain times of the day may require different scheduled travel times for particular trips, in which case clock headways could not be maintained at all timepoints for those trips.

When clock headways are used, vehicles arrive at the same time each hour.

Service frequency LOS is determined by destination from a given transit stop, as several routes may serve a given stop, but not all may serve a particular destination. Some judgment must be applied to bus stops located near timed transfer centers. There is a considerable difference in service from a passenger's perspective between a bus arriving every 10 minutes and three buses arriving in a row from a nearby transfer center every 30 minutes, even though both scenarios result in six buses per hour serving the stop. In general, buses on separate routes serving the same destination that arrive at a stop within 3 minutes of each other should be counted as one bus for the purposes of determining service frequency LOS.

Calculating an effective headway accounting for pass-ups.

At some locations, pass-ups may be a regular occurrence, particularly for lower-capacity services unable to accommodate peaks in demand, such as some auto ferries, or transit services following special events. In these situations, some or all passengers must wait longer than the scheduled headway before they reach the head of the line and can board a vehicle. To calculate service frequency LOS in this situation, use an effective headway calculated by multiplying the scheduled headway by the number of transit vehicles that arrive before an average passenger can board. For example, if half the peak hour passengers, on average, must wait for a second vehicle, the effective headway would be 1.5 times the scheduled headway.

Exhibit 3-12
Fixed-Route Service Frequency LOS

LOS	Avg. Headway (min)	veh/h	Comments
A	<10	>6	Passengers do not need schedules
B	10-14	5-6	Frequent service, passengers consult schedules
C	15-20	3-4	Maximum desirable time to wait if bus/train missed
D	21-30	2	Service unattractive to choice riders
E	31-60	1	Service available during the hour
F	>60	<1	Service unattractive to all riders

At LOS "A," passengers are assured that a transit vehicle will arrive soon after they arrive at a stop. The delay experienced if a vehicle is missed is low. At LOS "B," service is still relatively frequent, but passengers will consult schedules to minimize their wait time at the transit stop. Service frequencies at LOS "C" still provide a reasonable choice of travel times, but the wait involved if a bus or train is missed becomes long. At LOS "D," service is only available about twice per hour and requires passengers to adjust their routines to fit the transit service provided. The threshold between LOS "E" and "F" is service once per hour; this corresponds to the typical analysis period and to the minimum service frequency applied when determining hours of service LOS. Service at frequencies greater than 1 hour entails highly creative planning or considerable wasted time on the part of passengers.

Other Measures

Other measures that may be important to consider at the transit stop level include those listed below. Further information about these and other measures can be found in *TCRP Report 88*(R17) and in the references identified with specific measures in the following list:

- *Pedestrian crossing difficulty* can be quantified by crossing delay, using the equations given later in the service coverage LOS section.
- *Pedestrian access* can be measured by the pedestrian LOS in the vicinity of the stop. For example, the Florida Department of Transportation uses a pedestrian LOS that accounts for traffic volumes, pedestrian facility type, amount of separation between pedestrians and traffic, and other related factors.(R14)
- *Bicycle access* can be measured by the bicycle LOS in the vicinity of the stop. Researchers(R14,R15) have developed LOS measures that account for traffic volumes, amount of separation between bicycles and traffic, and other related factors.
- For stops associated with a park-and-ride lot, *park-and-ride access* can be measured by the lot occupancy (number of parking spaces occupied, divided by the total number of spaces in the lot). At an occupancy of 95% or higher, the lot is effectively full and unable to serve additional potential passengers.
- *Access for persons with disabilities* can be quantified by examining the stop vicinity (e.g., landing pads, sidewalk widths and condition, grades, curb cuts, etc.) for compliance with the ADA. For example, a stop could be classified as fully, partially, or non-accessible, depending on whether all, most, or only some of the features of the stop vicinity meet the ADA guidelines. ADA access should also consider how frequently ADA-accessible vehicles serve the stop, and—for stations not at-grade—the percentage of time that station elevators are out of service.
- *Passenger loading* affects availability when passengers are unable to board the first vehicle that arrives, due to overcrowding. The passenger loading LOS measures presented later in this chapter can be used—LOS "F" indicates crush loads where additional passengers would be unlikely to board.

AVAILABILITY—ROUTE SEGMENTS/CORRIDORS

"Service span" is a commonly used synonym for hours of service. However, it is measured as the time between the first and last trips of the day, without regard to any gaps in service during that time.

Hours of service, also known as "service span," is simply the number of hours during the day when transit service is provided along a route, a segment of a route, or between two locations. It plays as important a role as frequency and service coverage in determining the availability of transit service to potential users: if transit service is not provided at the time of day a potential passenger needs to take a trip, it does not matter where or how often transit service is provided the rest of the day.

In contrast, hours of service are only counted when service is offered essentially hourly or better.

Hours of service LOS (Exhibit 3-13) is based only on those hours when service is offered at essentially a minimum 1-hour frequency (i.e., service frequency LOS "E" or better). Judgment should be applied to situations where the scheduled headway is slightly longer than 1 hour, due to differences in scheduled departure times as a result of traffic congestion or other factors. For example, a 65-minute headway between two trips can be considered essentially 1-hour service, if the previous and subsequent trips operate at 60-minute or better headways, while a 90-minute service gap to provide an operator lunch break would not be considered hourly service.

Measuring hours of service for peak hour services.

Hours of service can be measured at a given location, or for a particular trip. It may be more appropriate to measure hours of service by trip than by route. For example, an express bus route may operate peak hours only between a park-and-ride lot and the CBD. During off-peak midday hours, the trip might still be possible using a less frequent, slower local bus route. If measured by route, the express service would end up with a low LOS, due to the small number of hours it operates. From a passenger's perspective, though, a trip could be made whenever either the express or local service operates, and hours of service in this case would be best calculated using the combination of the express and local service spans. The differences in service quality between the two routes could be measured by assessing frequency and transit-auto travel time LOS for the same trip during peak and midday periods.

To calculate hours of service, when service is offered at least hourly without interruption, subtract the departure time of the last run from the departure time of the first run and add 1 hour. This additional hour accounts for the last hour when service is provided (for example, trips at 6:00 a.m. and 7:00 a.m. provide service during 2 hours of the day, even though 6:00 subtracted from 7:00 is one). Round down any fractional hours. When service is not operated at least hourly throughout the day, calculate the number of hours of service for each portion of the day when service is provided, and then use the total in determining the LOS.

Exhibit 3-13
Fixed-Route Hours of Service LOS

LOS	Hours of Service	Comments
A	19-24	Night or "owl" service provided
B	17-18	Late evening service provided
C	14-16	Early evening service provided
D	12-13	Daytime service provided
E	4-11	Peak hour service only or limited midday service
F	0-3	Very limited or no service

At LOS "A," service is available for most or all of the day. Workers who do not work traditional 8 to 5 jobs receive service and all riders are assured that they will not be stranded until the next morning if a late-evening transit vehicle is missed. At LOS "B," service is available late into the evening, which allows a range of trip purposes other than commute trips to be served. Transit runs only into the early evening at LOS "C" levels, but still provides some flexibility in one's choice of time for the trip home. Service at LOS "D" levels meets the needs of commuters who do not have to stay late and still provides service during the middle of the day for others. At LOS "E," midday service is limited or non-existent and commuters have a limited choice of travel times. Finally, at LOS "F," transit service is offered only a few hours per day or not at all.

Example Calculations

Peak hour service only. A bus route operates peak hours only, *with no alternative service available at other times.* Trips are provided in each direction at 6:30 a.m., 7:30 a.m., 4:30 p.m. and 5:30 p.m. Service is provided during 2 hours in the morning and 2 hours in the evening, for a total of 4 hours. If service was provided in the peak direction only at the times given, the total hours of service for each direction would be two.

Limited daytime service. A bus route operates hourly between 5:30 a.m. and 8:30 a.m., every 2 hours between 8:30 a.m. and 4:30 p.m., and hourly between 4:30 p.m. and 7:30 p.m. The total hours of service is eight: 8:30 minus 5:30 is 3 hours and add 1 hour; 7:30 minus 4:30 is 3 hours and add 1 hour; the total is 8 hours. Although the bus route operates during the middle of the day, it does not operate at a minimum 1-hour frequency; therefore, this time is not counted.

Early evening service. A bus route operates every 30 minutes between 5:30 a.m. and 8:00 p.m. The total hours of service is 15 (20:00 minus 5:30 is 14.5, add 1 hour, and discard the fractional hour).

Other Measures

The same supplemental measures listed above for transit stops can also be applied to route segments and corridors. Pedestrian and bicycle LOS can be measured by an average LOS weighted by distance. ADA access can be measured in terms of the percentage of stops that are fully accessible, while passenger loading can look at the percentage of stops where pass-ups may occur (i.e., stops with LOS "F" for passenger loading) or the amount of time or distance a particular loading condition occurs.

AVAILABILITY—SYSTEM

Planning Methodology

Introduction

Service coverage is a measure of the area within walking distance of transit service. As with the other availability measures, it does not provide a complete picture of transit availability by itself, but when combined with frequency and hours of service, it helps identify the number of opportunities people have to access transit from different locations. Service coverage is solely an area measure: at the transit stop level, if transit service is provided, obviously coverage exists at that location.

Service coverage LOS requires more data than the other two availability measures.

Since it is an area-wide measure, service coverage LOS takes more time to calculate and requires more information than do the transit stop and route segment/corridor LOS measures. This task can be simplified through the use of a geographic information system (GIS). However, this section also provides a calculation method that does not require GIS software. Both a planning methodology suitable for system-wide analysis and a more detailed methodology suitable for smaller area analysis are provided.

One measure of service coverage is *route miles per square mile* (*route kilometers per square kilometer*). This measure is relatively easy to calculate, but does not address on a system-wide basis how well the areas that generate the most transit trips are being served, nor does it address how well transit service is distributed across a given area.

Another measure would be the *percentage of the system area served.* However, land uses and population and job densities may vary greatly from one system to another, depending on how land uses have developed and how the system's boundaries have been drawn. Urban transit system boundaries might include large tracts of undeveloped land that may be developed in the future, while county-wide systems will likely include large tracts of rural land. Neither area would be expected to generate transit trips in the near term. How the boundaries are drawn will determine how much area is included within the service area, which in turn will affect any area-based performance measures. As a result, service areas, by themselves, are not the best basis for developing service coverage performance measures.

As a compromise, service coverage LOS looks at how much of the area that would typically produce the majority of a system's ridership—that is, the densest areas—are served. Specifically, those areas that may be capable of supporting hourly transit service are addressed.

Service coverage LOS looks at how much of the area likely to produce riders is served.

Service Coverage Area

The planning methodology defines the area covered by a particular route as that area within walking distance of a transit stop. This area is defined as the air distance within 0.25 mile (400 m) of a bus stop or 0.5 mile (800 m) of a busway or rail station. Any location within 0.25 mile (400 m) of the area served by deviated fixed-route bus service is also considered to be covered.

The calculation of the transit service coverage area can be performed relatively easily by GIS software, using the software's buffering feature to draw appropriately sized circles around transit stops. However, if GIS software or accurate bus stop data are not available, this area can be approximated by outlining on a map all of the area within 0.25 mile (400 m) of a bus route. This approximation assumes reasonable bus stop spacings (at least six per mile or four per kilometer). Sections of a route where pedestrian access from the area adjacent to the route is not possible (because of a barrier such as a wall, waterway, roadway, or railroad) should not be included in the service coverage area.

Transit-Supportive Areas

Pushkarev and Zupan(R32) suggest that a household density of 4.5 units per net acre (11 units per net hectare) is a typical minimum residential density for hourly transit service to be feasible. This equates to a density of approximately 3 units per gross acre (7.5 units per gross hectare). (Net acres are often referenced in zoning codes and consider only the area developed for housing or employment. Gross acres are total land areas, which may include streets, parks, water features, and other land not used directly for residential or employment-related development. Gross acres are easier to work with in calculations and therefore are used in this methodology.) Hourly service corresponds to the minimum LOS "E" value for service frequency as well as the minimum frequency used for determining hours of service LOS.

Net acres and gross acres compared.

A TriMet long-range service planning study(R24) found that an employment density of approximately 4 jobs per gross acre (10 jobs per gross hectare) produced the same level of ridership as a household density of 3 units per gross acre (7.5 units per gross hectare). These density values are used in this methodology as the minimum job densities that are capable of supporting hourly transit service.

"Jobs" refers to jobs at worksites.

Areas with a minimum density capable of supporting hourly service are referred to as *transit-supportive areas* in this methodology. For policy reasons, or simply to provide a route connecting two higher-density areas, an agency may choose to—and likely will—cover a larger area than that defined by its transit-supportive areas. However, service coverage LOS is based solely on the percentage of the transit-supportive area covered by transit, as shown in Exhibit 3-14.

Transit-supportive areas.

Exhibit 3-14
Fixed-Route Service Coverage LOS

LOS	% TSA Covered	Comments
A	90.0-100.0%	Virtually all major origins & destinations served
B	80.0-89.9%	Most major origins & destinations served
C	70.0-79.9%	About ¾ of higher-density areas served
D	60.0-69.9%	About two-thirds of higher-density areas served
E	50.0-59.9%	At least ½ of the higher-density areas served
F	<50.0%	Less than ½ of higher-density areas served

Transit-Supportive Area (TSA): The portion of the area being analyzed that has a household density of at least 3 units per gross acre (7.5 units per gross hectare) or an employment density of at least 4 jobs per gross acre (10 jobs per gross hectare).

Covered Area: The area within 0.25 mile (400 m) of local bus service or 0.5 mile (800 m) of a busway or rail station, where pedestrian connections to transit are available from the surrounding area.

TSAs reflect areas that, from a passenger point-of-view, could reasonably have transit service. Agencies that emphasize productivity over access may choose not to serve some areas considered transit-supportive by this methodology.

Service coverage is an all-or-nothing issue for transit riders—either service is available for a particular trip or it is not. As a result, there is no direct correlation between service coverage LOS and what a passenger would experience for a given trip. Rather, service coverage LOS reflects the number of potential trip origins and destinations available to potential passengers. At LOS "A," 90% or more of the TSA has transit service; at LOS "F," less than half of the TSA has service.

Deviating service to increase service coverage results in longer passenger travel times.

This measure is not intended to encourage transit operators to deviate routes substantially simply to cover more area (and thus improve service coverage LOS); should they do so, transit-auto travel time LOS will be negatively affected.

Assessing population and job coverage separately may be worthwhile for some analyses.

For some applications, it may be worthwhile to analyze service coverage LOS separately for residential population (based on only those TSAs that meet the population criterion) and employment (based on the TSAs that meet the employment criterion). This kind of analysis could help identify disconnects in the amount of service provided to potential trip origins compared with potential trip destinations.

Example Calculation—GIS Method

TriMet is the transit service provider for Portland, Oregon, and many of its suburbs. This example shows how to calculate service coverage LOS for TriMet using the planning methodology in GIS.

Data Needs

The following data are used for this calculation:

- Bus stop and light rail station locations from the regional government's GIS database and
- Transportation analysis zone (TAZ) data (households, jobs, and TAZ boundaries) from the regional transportation planning model. Alternatively, census blocks or similar relatively small areas could also have been used.

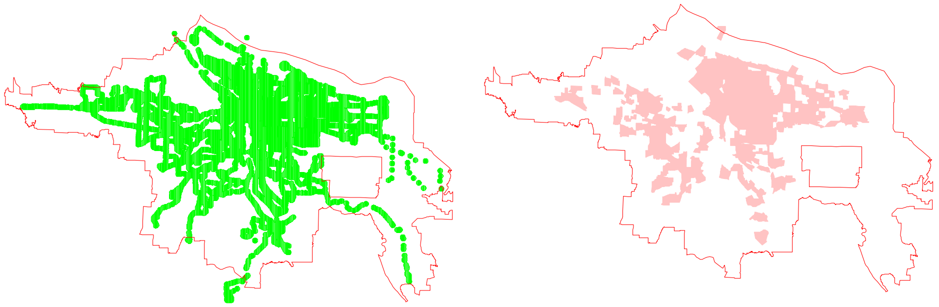
Determine Coverage Area

All of the bus stops are buffered using a 0.25-mile (400-m) radius and all of the light rail stations are buffered using a 0.5-mile (800-m) radius. Inaccessible areas are removed. The resulting 2001-2002 service coverage area is shown in Exhibit 3-15(a) and compared to the TriMet district boundary.

Determine Transit-Supportive Areas

For each TAZ, the number of households is divided by the TAZ area to obtain a household density in households per acre. Each TAZ's job density can be calculated similarly. Following these calculations, TAZs with a household density of 3.0 or more households per acre and/or a job density of 4.0 or more jobs per acre can be readily identified. These TAZs are shown as shaded areas in Exhibit 3-15(b).

Exhibit 3-15
Transit-Supportive Area Compared with Service Area



(a) District Boundary and Areas Served (b) District Boundary and Transit-Supportive Areas

Compare Service Coverage to Transit-Supportive Areas

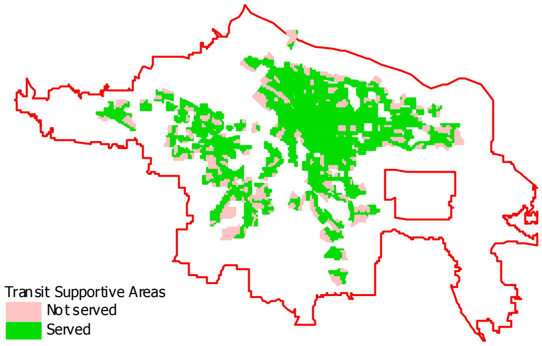
By intersecting the service coverage layer with the TAZ layer, TAZs that are only partially served by transit are divided into two sections: a section completely served by transit and a section completely unserved by transit. Households and jobs can be allocated between the two sections based on the relative areas of the two sections.

Next, all of the transit-supportive TAZs can be selected, and their total area determined, using the GIS software's area calculation function. Finally, all of the transit-supportive TAZ sections served by transit can be selected and their areas added up. Dividing the second area into the first area gives the percentage of the TSA served. Exhibit 3-16 presents numerical results; Exhibit 3-17 compares TriMet's coverage area to its TSA in the form of a map.

Exhibit 3-16
Service Coverage Results

Analysis Area	Area (mi^2)	Households	Jobs	% Area Served	LOS
TriMet District	563.8	458,076	786,713		
Coverage Area	243.1	345,260	664,684		
Transit-Supportive Area	132.9	273,341	639,375		
TSA Served	114.4	244,587	588,072	86.1%	B

Exhibit 3-17
Transit-Supportive Areas Served



How to calculate service coverage LOS without GIS software.

Example Calculation—Manual Method

Required Data

The items listed below are required for calculating service coverage manually:

- A printed map (to scale) of the TAZs, census blocks, or other area type for which household and job data are available, that cover the area being analyzed. The remainder of this example assumes that TAZs are being used from a local regional transportation model.
- Data on the number of households and jobs within each TAZ, in either printed or spreadsheet form.
- A map showing bus routes and busway and rail stations.

Estimate TAZ Areas

A transparent overlay with a printed grid helps in estimating areas. Alternatively, if the TAZ map is available electronically, the software used to develop the map may be able to calculate the area of each TAZ.

Identify Transit-Supportive Areas

Using a computer spreadsheet, or by hand, calculate household and job densities by dividing the number of households and jobs in each TAZ by the TAZ areas estimated. Areas should be converted to hectares or acres as part of this calculation.

Next, identify all TAZs where the household density is at least 3 units/gross acre (7.5 units/gross hectare) or the job density is at least 4 jobs/gross acre (10 jobs/gross hectare). Mark these TAZs on the map.

Identify the Transit Service Area

On the printed map, outline the areas within 0.25 mile (400 m) of bus routes that serve or pass near the transit-supportive TAZs and the areas within 0.5 mile (800 m) of transitway or rail stations within or near the transit-supportive TAZs. The entire system does not need to be outlined, only the portions within and near transit-supportive TAZs. Estimate the percentage (to the nearest 10%) of each transit-supportive TAZ that is covered by transit. Do not include any areas that do not have transit access due to a barrier that blocks pedestrian access, such as a freeway, railroad track, waterway, or wall.

Calculate Level of Service

Add up the areas of the transit-supportive TAZs, using the information developed earlier. This is the total area of the TSA. Next, for each transit-supportive TAZ, multiply its area by the percentage of its area served by transit. The sum of these adjusted areas is the total TSA covered by transit. Finally, divide this result by the total TSA to determine the percentage of the TSA covered by transit. Use Exhibit 3-14 to determine the LOS based on this percentage.

Detailed Methodology

Introduction

Service coverage factors not covered by the planning methodology.

The planning methodology represents a trade-off between ease of calculation and the number of factors included in the calculation. The detailed methodology addresses the following factors that the planning methodology does not address:

- The planning method's use of air distances overestimates the number of people within walking distance of transit service; a lack of pedestrian connectivity, due to topographic barriers or automobile-oriented land use development, reduces an area's access to transit;
- The effect of grades on walking distances is addressed;
- The proportion of older adults in the population, who will generally not walk as far as younger adults, is addressed;
- Transit stop accessibility is addressed (in particular, the difficulty of crossing the street with transit service).

The detailed methodology does not address the following issues. However, means for addressing the first two issues are described in subsequent sections.

- The use of a TSA does not address the extent of service provided to lower-density areas and the number of people that might be provided service in those areas;
- The service coverage provided by park-and-ride lots is not addressed; and
- Other factors than density, such as income, car ownership, and parking costs, also influence transit ridership.

The general analysis procedure is similar to the planning methodology. However, instead of using a set service coverage radius for every stop, each stop's service area is reduced in proportion to the additional time required to climb hills, cross busy streets, wind one's way out of a subdivision, and so on. Each stop ends up with an individual service radius that, in most cases, is smaller than the maximum 0.25 to 0.5 mile (400 to 800 m), and therefore serves a smaller number of people and jobs. This can be expressed mathematically as shown in Equation 3-2:

Equation 3-2

$$r = r_0 f_{sc} f_g f_{pop} f_{px}$$

where:

r = transit stop service radius (mi, m);
r_0 = ideal transit stop service radius (mi, m),
= 0.25 mi (400 m) for bus stops, and 0.5 mi (800 m) for busway and rail stations;
f_{sc} = street connectivity factor;
f_g = grade factor;
f_{pop} = population factor; and
f_{px} = pedestrian crossing factor.

Because the planning and detailed methodologies will produce different results, only one methodology should be applied within a given study area.

Because of the number of factors involved in the detailed methodology, this methodology is best suited for analyzing small areas ranging from the vicinity of an individual stop to a neighborhood. If larger areas, up to the entire system, are desired to be analyzed, developing default values (e.g., a default hourly vehicle volume for an arterial street) for many of the factors is recommended. If the detailed methodology is used, it should be applied consistently throughout the area and not mixed with the planning methodology.

Street Connectivity Factor

This factor reduces a stop's service coverage area in relation to the amount of out-of-direction travel a pedestrian is forced to make to get to a transit stop from the surrounding land uses. In a traditional grid street layout system, there is very little out-of-direction walking required, whereas in a contemporary suburban neighborhood with limited entry points and dead-end streets, a transit stop located only 650 feet (200 m) away in a straight line might be a 15-minute walk away using the subdivision's street system.

Three types of street patterns are defined:(R11)

- *Type 1,* a traditional grid system;
- *Type 2,* a hybrid layout that incorporates elements of both Type 1 and Type 3 street patterns; and
- *Type 3,* a cul-de-sac based street network with limited connectivity.

Exhibit 3-18 illustrates the three types of street patterns. These sketches may be used to estimate the area type surrounding the bus stops under study.

Exhibit 3-18
Street Pattern Types

(a) Type 1—Grid

(b) Type 2—Hybrid

(c) Type 3—Cul-de-Sac

As can be seen from the above sketches, a grid street pattern provides the most direct pedestrian access to transit stops. However, walking distances to and from a transit stop can still be about 42% longer than the corresponding air distance. Stated another way, only about 64% of the area within 0.25-mile (400-m) air distance of a transit stop in a grid street pattern lies within 0.25-mile walking distance of the stop. The amount of coverage provided by the other street patterns is even lower: 54% of the area within a 0.25-mile radius of a transit stop in an average hybrid street pattern lies within 0.25-mile walking distance, and only 28% of the area in an average cul-de-sac street pattern lies within 0.25-mile walking distance.

Using the grid street pattern as the best case, Exhibit 3-19 provides street connectivity factors for the other street patterns. The factor is based on the ratio of each street pattern's area covered to the area covered in a grid network.

Exhibit 3-19
Street Connectivity Factors

Street Pattern Type	Street Connectivity Factor, f_{sc}
Type 1—Grid	1.00
Type 2—Hybrid	0.85
Type 3—Cul-de-Sac	0.45

Using a network connectivity index to determine the street pattern type.

As an alternative to using the sketches, a measure of the network connectivity may be used instead to determine the area type. The *network connectivity index* is the number of links (i.e., street segments between intersections) divided by the number of nodes (i.e., intersections) in a roadway system.(R11) It is assumed for this application that all of the roadways provide for safe pedestrian travel. The index value ranges from about 1.7 for a well-connected grid pattern to approximately 1.2 for a cul-de-sac based suburban pattern. Exhibit 3-20 shows the relationship between the network connectivity index and the street pattern type.

Exhibit 3-20
Relationship Between Network Connectivity Index and Street Pattern Type

Network Connectivity Index	Street Pattern Type
>1.55	Type 1—Grid
1.30-1.55	Type 2—Hybrid
<1.30	Type 3—Cul-de-sac

Grade Factor

As shown in Chapter 1, the horizontal distance that pedestrians are able to travel in a given period of time decreases as the vertical distance climbed increases, particularly when the grade exceeds 5%. The area located within a given walking time of a transit stop decreases in proportion to the square of the reduced horizontal distanced traveled. Based on Exhibit 3-6, Exhibit 3-21 gives reduction factors for the effect of average grades on a given stop's service coverage area.

Exhibit 3-21
Grade Factor

Average Grade	Grade Factor, f_g
0-5%	1.00
6-8%	0.95
9-11%	0.80
12-15%	0.65

This factor assumes that pedestrians will have to walk uphill either coming or going. If the transit route network provides service on parallel streets, such that a person could walk downhill to one route on an outbound trip and downhill from another route back to one's origin on the return trip, use a grade factor of 1.00.

Population Factor

Pedestrian walking speed is highly dependent on the proportion of elderly pedestrians (65 years or older) in the walking population.(R16) The average walking speed of a younger adult is 4.0 ft/s (1.2 m/s), but when elderly pedestrians constitute 20% or more of the pedestrian population, a 3.3 ft/s (1.0 m/s) average speed should be used. For transit stops where 20% or more of the boarding volume consists of elderly pedestrians, a population factor, f_{pop}, of 0.85 should be used to account for the reduced distance traveled during a 5-minute walk.

Pedestrian Crossing Factor

As discussed in Chapter 1, wide, busy streets pose a barrier to pedestrian access to transit stops. The *Highway Capacity Manual*(R16) identifies that pedestrians start to become impatient once pedestrian crossing delay exceeds 30 seconds. Any crossing delay in excess of 30 seconds results in added travel time to reach a transit stop, in addition to the actual walking time. Assuming that the maximum desired travel time is fixed at 5 or 10 minutes (i.e., 0.25 or 0.5 miles, or 400 or 800 meters), excess crossing delay results in shorter maximum walking distances and a reduction in the size of a stop's service coverage area.(R18)

The pedestrian crossing factor reduces transit availability in proportion to the number of people who walk—for example—4 minutes or less to a transit stop, compared to those who walk 5 minutes or less. Using the Edmonton, Alberta, curve from Exhibit 3-5 (representing the approximate mid-point of the reported results), about 85% of transit users walk no more than 0.25 mile (400 m) to access transit, while about 75% of transit users walk no more than 1,000 feet (300 m) to access transit. If excess crossing delays amounted to the time required to walk 320 feet (100 m), then the stop's service area (assumed to be proportional to the number of people served) would be effectively reduced by a factor of 75% divided by 85%, or 0.88.(R18) Taking the square root of this result, in this case 0.94, provides the walking distance reduction that results in that reduced service area.

A best-fit curve was applied to the Edmonton data to develop the following equation for a distance-based pedestrian crossing factor:(R18)

Equation 3-3

$$f_{px} = \sqrt{\left(-0.0005d_{ec}^2 - 0.1157d_{ec} + 100\right)/100}$$

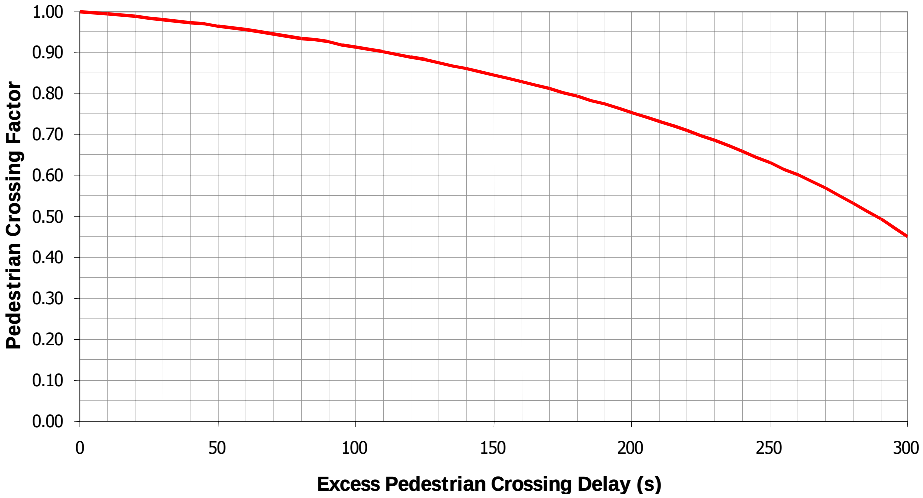
where:

f_{px} = pedestrian crossing factor; and

d_{ec} = pedestrian crossing delay exceeding 30 seconds (s).

Exhibit 3-22 depicts this curve. The factor is 1.00 whenever pedestrian crossing delay on the street with transit service is less than or equal to 30 seconds.

Exhibit 3-22
Pedestrian Crossing Factor



Calculating Pedestrian Crossing Delay

Signalized crossings. At signalized pedestrian crossings, average crossing delay is based on the cycle length and the amount of time available for pedestrians to begin crossing the street, as shown in the following equation:(R16)

Equation 3-4

$$d_p = \frac{0.5(C-g)^2}{C}$$

where:

d_p = average pedestrian delay (s);
C = traffic signal cycle length (s); and
g = effective green time for pedestrians (WALK time + 4 s of flashing DON'T WALK) (s).

Exhibit 3-23 shows typical delays incurred by pedestrians when crossing streets at signalized locations, for various street widths and median types.

Exhibit 3-23
Average Pedestrian Street Crossing Delay: Signalized Crossings

	Transit Street Crossing Distance							
Lanes	**1**	**2U**	**2D**	**3**	**4U**	**4D**	**5**	**6D**
ft	**15**	**24**	**28**	**36**	**48**	**54**	**60**	**78**
m	**4.6**	**7.3**	**8.5**	**11.0**	**14.6**	**16.5**	**18.3**	**23.8**
Assumed cycle length (s)	60	60	60	90	90	120	140	180
Assumed WALK time (s)	7	7	7	7	7	7	7	9
Delay (s)	20	20	20	35	35	50	59	78

SOURCE: Calculated from Equation 3-4, using default cycle length and WALK times shown. WALK time assumed to be the greater of 7 s or 5% of the cycle length.
NOTE: U=undivided, D=divided (with raised median or other pedestrian refuge)

Unsignalized Crossings. At unsignalized pedestrian crossings where pedestrians do not have the right-of-way (or where motorists do not grant pedestrians their legal right-of-way), average crossing delay is based on the crossing distance, average pedestrian walking speed, and traffic volumes (vehicle flow rates). Determining delay is a two-step process. First, the pedestrians' critical gap is determined, which is the shortest gap in traffic (in seconds) that pedestrians can safely use to cross the street. This can be determined from Equation 3-5:

Equation 3-5

$$t_{cg} = \frac{L_x}{S_p} + t_{ps}$$

where:

t_{cg} = pedestrian critical gap (s);
S_p = average pedestrian walking speed (ft/s, m/s);
L_x = crossing distance (ft, m); and
t_{ps} = pedestrian start-up and end clearance time (s).

Where elderly pedestrians make up 20% or less of the pedestrian population, a 4.0 ft/s (1.2 m/s) walking speed can be used; where elderly pedestrians are more numerous, a 3.3 ft/s (1.0 m/s) speed should be used. A default value of 3 seconds for pedestrian start-up and end clearance time may be used.(R16)

The 4.0-second default is not representative of all pedestrians. Field observations of pedestrian speeds may be appropriate in some circumstances.

Once the critical gap is known, Equation 3-6 can be used to determine pedestrian delay at unsignalized crossings where pedestrians do not have the right-of-way:(R16)

Equation 3-6

$$d_p = \frac{1}{v}\left(e^{vt_{cg}} - vt_{cg} - 1\right)$$

where:

d_p = average pedestrian delay (s);
v = vehicular flow rate (veh/s); and
t_{cg} = pedestrian critical gap (s).

In situations where a pedestrian refuge is provided in the middle of the street, and pedestrians tend to use that refuge to cross the street in two stages, delay should be determined individually for each direction of the street crossed, and then summed to determine the total delay. Exhibit 3-24 shows typical values of delay at unsignalized intersections, based on various combinations of lane widths, median types, and traffic volumes. As with signalized intersections, pedestrians start becoming impatient and exhibit risk-taking behavior when delay exceeds 30 seconds.(R16)

Where pedestrians have the right-of-way at an unsignalized crossing, they will experience a minimal amount of delay waiting to make sure that traffic will stop for them before they start to cross the street. This delay is well below the 30-second pedestrian impatience threshold used in Chapter 3 procedures.

Exhibit 3-24
Average Pedestrian Street Crossing Delay (s): Unsignalized Crossings with No Pedestrian Right-of-Way

		Crossing Distance					
Volume (veh/h)	Flow Rate (veh/s)	1 lane 15 ft 4.6 m	2 24 7.3	3 36 11.0	4 48 14.6	5 60 18.3	6 72 22.0
200	0.056	1	3	6	8	13	19
300	0.083	2	4	10	15	24	36
400	0.111	3	6	15	24	40	63
500	0.139	3	9	21	36	63	105
600	0.167	4	12	30	52	97	172
700	0.194	6	15	41	75	147	279
800	0.222	7	20	55	107	223	*
900	0.250	9	25	75	151	*	*
1,000	0.278	11	31	100	214	*	*
1,100	0.306	N/A	39	133	302	*	*
1,200	0.333	N/A	48	178	*	*	*
1,300	0.361	N/A	60	237	*	*	*
1,400	0.389	N/A	74	317	*	*	*
1,500	0.417	N/A	91	*	*	*	*
1,600	0.444	N/A	112	*	*	*	*
1,700	0.472	N/A	137	*	*	*	*
1,800	0.500	N/A	169	*	*	*	*
1,900	0.528	N/A	208	*	*	*	*
2,000	0.556	N/A	256	*	*	*	*

*Delay exceeds 5 minutes, 30 seconds (typical maximum pedestrian walking time to bus stops, plus 30 second pedestrian-impatience threshold).
N/A: not applicable—unlikely to achieve volumes shown with one lane.
SOURCE: Calculated from Equation 3-5 and Equation 3-6, using a pedestrian walking speed of 4.0 ft/s (1.2 m/s) and a pedestrian start-up and end clearance time of 3 seconds.

Other Measures

Researchers have developed more detailed ways of measuring service coverage that may be useful for some types of analyses. Further information about these measures can be found in *TCRP Report 88*(R17) and the references indicated below:

- *Percent people served* and *percent jobs served* are similar to the area-based service coverage measure presented above, but include all people or jobs served not just those living in higher-density areas.
- *Percent person-minutes served (TLOS Indicator)* was developed by the FDOT as a way of measuring service coverage, service frequency, and hours of service in combination. The FDOT provides GIS-based software and spreadsheets to help calculate this measure; the software is capable of evaluating actual walking paths to transit and not just air distances. Because the TCQSM's availability measures and the TLOS Indicator measure the same things, equivalent levels of service can be developed for TLOS Indicator values.(R18)
- The *Transit Service Accessibility Index* is similar to the TLOS Indicator, but looks at the number of trip ends exposed to transit service. The former is a measure of how well service demanded is served, while the latter is a measure of how much service is supplied. Either measure can be used to calculate an *adjusted mode split*—the number of trips made by transit where transit is available as a choice (i.e., in times and at places where transit service is offered), divided by the number of trips made by all modes.(R30)

- The *Local Index of Transit Availability* (LITA) measures the intensity of transit service in an area relative to the area's population and size. The LITA contains three components: frequency (transit vehicles per day), capacity (seat-miles divided by combined residential population and jobs), and route coverage (transit stops per square mile). The measure assesses relative differences in transit availability, rather than providing an absolute measure of the amount of transit availability.(R33)

Guidelines for Assessing Park-and-Ride Service Coverage

This section presents guidelines for including park-and-ride service coverage as part of a system's overall service coverage area. This procedure is not intended to serve as a tool for estimating potential park-and-ride demand; however, the park-and-ride references in Chapter 2 can be used for this purpose.

As was shown in Chapter 2, the area served by park-and-ride lots varies considerably by the type of lot, land uses within its market area, congestion on nearby roadways, and other factors specific to the metropolitan region where the lot is located. However, many of the studies are consistent in finding that approximately one-half of a park-and-ride lot's users start their trip within 2 to 3 miles (3 to 5 km) of the lot. This inner service area is a relatively compact area that can be used to assess a lot's service coverage. The outer service area will provide a similar number of users, but they will be scattered over an area four or more times as large as the inner service area, with the result that park-and-ride users within the lot's outer service area form a much smaller portion of the general population.

This procedure is similar to how bus stop coverage is treated. Approximately 25 to 30% of a bus stop's users will walk more than 0.25 mile (400 m) to a local bus stop, but these users will be spread over a large area and will form a much smaller portion of the general population in that area.

Service coverage LOS for walking should still be reported when park-and-ride service coverage is measured.

For the purposes of assessing service coverage, a 2.5-mile (4-km) radius around larger (100 spaces or more) park-and-ride lots may be used. This area should be added to the walking coverage area determined through either the planning or detailed methodologies described earlier. Because park-and-ride lots usually serve the home end of a trip, and often are designed to serve passengers who do not live in higher-density areas, *percent persons served* may be used as the park-and-ride lot performance measure, with the service area consisting of the transit agency's service area (e.g., a defined county or metropolitan area). When this measure is used, it should be reported in combination with walking service coverage performance.

The 2.5-mile (4-km) radius for urban area park-and-ride lots relates to larger facilities (typically 100 or more spaces), with enhanced transit service. For smaller lots (such as a 25-space shared church lot with only local transit service), a smaller service coverage area might be appropriate. Of course, if a more detailed park-and-ride market assessment related to a particular study or project is conducted, then the results of that study should supercede the method described above.

COMFORT AND CONVENIENCE—TRANSIT STOPS

From the passenger's perspective, passenger loads reflect the comfort level of the on-board vehicle portion of a transit trip—both in terms of being able to find a seat and in overall crowding levels within the vehicle. From a transit operator's perspective, a poor LOS may indicate the need to increase service frequency or vehicle size in order to reduce crowding and provide a more comfortable ride for passengers. A poor passenger load LOS indicates that dwell times will be longer for a given passenger boarding and alighting demand at a transit stop and, as a result, travel times and service reliability will be negatively affected.

Passenger load LOS is based on two measures: *load factor* (passengers per seat), when all passengers can sit, and *standing passenger area,* when some passengers must stand or when a vehicle is designed to accommodate more standees than seated passengers. Passenger load LOS can be measured by time of day (e.g., LOS "D" peak, LOS "B" off-peak) or by the amount of time a certain condition occurs (e.g., some passengers must stand for up to 10 minutes).

When a substantial number of passengers wear or carry objects such as daypacks or briefcases, that increase the space occupied by those passengers, analysts may wish to use the concept of *equivalent passengers,* based on the projected area values given in Exhibit 3-25. For example, a passenger wearing a daypack takes up about twice as much space as a passenger without one. If, on average, 5 of 10 standing passengers wear daypacks, then the space occupied by the standees is the equivalent of 15 unencumbered standing passengers.

Exhibit 3-25
Male Passenger Space Requirements(R4)

These are suggested minimum spaces.

Situation	Projected Area (ft^2)	Projected Area (m^2)
Standing	1.6-2.2	0.15-0.20
... with briefcase	2.7-3.2	0.25-0.30
... with daypack	3.2-3.8	0.30-0.35
... with suitcases	3.8-5.9	0.35-0.55
... with stroller	10.2-12.4	0.95-1.15
... with bicycle (horizontal)	17.2-20.4	1.60-1.90
Holding on to stanchion	2.7	0.25
Minimum seated space	2.7-3.2	0.25-0.30
Tight double seat	3.8 per person	0.35 per person
Comfortable seating	5.9 per person	0.55 per person
Wheelchair space (ADA)	10.0 (30 in x 48 in)	0.93 (0.76 m x 1.22 m)

NOTE: Stroller and bicycle dimensions are based on a review of manufacturer specifications.

The standing passenger area can be measured using a typical vehicle or estimated using the procedure described below. The area next to the vehicle operator, stepwells, interior steps, and wheel wells should not be included as part of the standing area. In addition, a 14-inch (0.36-m) buffer should be left in front of longitudinal seating to account for seated passenger foot room.

When the standing passenger area is not known, it can be estimated as follows:

1. *Calculate the gross interior floor area.* Multiply the vehicle width by the interior vehicle length. For standard buses, the interior vehicle length can be estimated by subtracting 8.5 feet (2.6 m) from the total bus length, as an allowance for the engine compartment and operator area.
2. *Calculate the area occupied by seats and other objects:*
   - Transverse seating: 5.4 ft^2 (0.5 m^2) per seat
   - Longitudinal seating: 4.3 ft^2 (0.4 m^2) per seat
   - Wheelchair position: 10.0 ft^2 (0.95 m^2) per position (use when the wheelchair position is not created by fold-up seats)
   - Rear door: 8.6 ft^2 (0.8 m^2) per door channel
   - Interior aisle stairs: 4.3 ft^2 (0.4 m^2)
   - Low-floor bus wheel well: 10.0 ft^2 (0.95 m^2) each
3. *Calculate the standing passenger area.* Subtract the area calculated in step 2 from the gross interior floor area calculated in step 1.

Exhibit 3-26 provides the LOS thresholds for passenger loads.

Exhibit 3-26
Fixed-Route Passenger Load LOS

LOS	Load Factor (p/seat)	Standing Passenger Area (ft^2/p)	Standing Passenger Area (m^2/p)	Comments
A	0.00-0.50	>10.8†	>1.00†	No passenger need sit next to another
B	0.51-0.75	8.2-10.8†	0.76-1.00†	Passengers can choose where to sit
C	0.76-1.00	5.5-8.1†	0.51-0.75†	All passengers can sit
D	*1.01-1.25**	3.9-5.4	0.36-0.50	Comfortable standee load for design
E	*1.26-1.50**	2.2-3.8	0.20-0.35	Maximum schedule load
F	*>1.50**	<2.2	<0.20	Crush load

*Approximate value for comparison, for vehicles designed to have most passengers seated. LOS is based on area.
†Used for vehicles designed to have most passengers standing.

At LOS "A" load levels, passengers are able to spread out and can use empty seats to store parcels and bags rather than carry them on their laps. At LOS "B," some passengers will have to sit next to others, but others will not. All passengers can still sit at LOS "C," although the choice of seats will be limited. Some passengers will be required to stand at LOS "D" load levels, while at LOS "E," a transit vehicle will be as full as passengers will normally tolerate. LOS "F" represents crush loading levels.

Other Measures

Other measures of passenger comfort at transit stops are listed below. Further information about these measures can be found in *TCRP Report 88*(R17) and in the TCQSM sections identified with particular measures in the following list:

- *Reliability* is discussed in the next section under route segments and corridors, as it tends not to vary between adjacent stops. However, for a passenger waiting at a particular stop, that passenger's perception is that the transit vehicle is late arriving at his or her stop.
- The kinds of *amenities* provided at transit stops are usually a matter of agency policy, based on the number of boarding riders that would benefit from an amenity, along with other factors. Part 7 lists common transit amenities, typical ranges of boarding passengers used by transit systems to warrant their installation, and other factors which should be considered.
- Other aspects of passenger *comfort* are best measured through customer satisfaction surveys and passenger environment surveys.
- *Security* is important to passengers, but can be difficult to quantify at the stop level, as it is often difficult to distinguish between crimes that happen to occur near a transit stop or station and those that occur to persons in the process of making a transit trip.

Customer satisfaction and passenger environment surveys are discussed in Chapter 2.

COMFORT AND CONVENIENCE—ROUTE SEGMENTS/CORRIDORS

Several different measures of reliability are used by transit operators. The most common of these are

- On-time performance,
- Headway adherence (the consistency or "evenness" of the interval between transit vehicles),
- Missed trips, and
- Distance traveled between mechanical breakdowns.

On-time performance is the most widely used reliability measure in the transit industry, is a measure that users can relate to, and encompasses several of the factors listed above that influence transit reliability. However, when vehicles run at frequent intervals, *headway adherence* becomes important to passengers, especially when vehicles arrive in bunches, causing overcrowding on the lead vehicle and longer waits than expected for the vehicles.

On-Time Performance

TCRP Synthesis of Transit Practice 10(R5) reviewed more than 80 agencies' on-time performance standards, as they existed in 1994. A summary of these standards is presented in Exhibit 3-27. Of the surveyed agencies, 42% allowed buses to be more than 5 minutes late and still be considered "on-time," and 24% allowed some early buses to be considered on-time.

Exhibit 3-27
On-Time Performance Standards of Surveyed U.S. Transit Agencies(R5)

	Number of Surveyed Agencies Using Standard	
On-Time % Standard	**Peak**	**Off-Peak**
98-100%	12	14
94-97%	17	29
90-93%	24	20
85-89%	8	7
80-84%	9	4
75-79%	7	4
70-74%	4	3
<70%	2	2

Canadian transit operator on-time performance standards are less lenient than those of their U.S. counterparts. Of the 17 agencies surveyed by the Canadian Urban Transit Association that define an on-time performance standard, 11 use 95% on-time as their standard, with "on-time" defined as being no more than 3 or 4 minutes late. The other six agencies have standards between 80% and 95%, with "on-time" defined as being up to 5 minutes late. Only two of the seventeen agencies allowed early buses.(R7)

Early departures.

From the perspective of a passenger arriving close to the time a transit vehicle is scheduled to depart, an early departure is not on-time; rather, it is equivalent to a vehicle being late by the amount of one headway in terms of when the passenger can board a vehicle. On the other hand, an early arrival towards the end of the route, where no passengers are boarding, would not be seen as a problem by passengers on the bus and would likely be viewed positively.

A review of the on-time performance achieved by three larger transit agencies, conducted as part of the development of the TCQSM Second Edition, found that early running was a significant contributor to non-"on-time" performance (and thus low on-time performance LOS). Data were obtained from automatic vehicle location (AVL) equipment that recorded departure times from timepoints and compared these departure times to the scheduled time. In some cases, more than 50% of the buses that would be considered not on-time (with "on-time" defined as a departure from a timepoint 0 to 5 minutes late) were running early. For two of the three systems, the average early bus was 3 to 4 minutes ahead of schedule.

Exhibit 3-28 shows on-time performance results from these three agencies at the next-to-last timepoint along routes, during the weekday p.m. peak period. Data for agencies #1 and #2 represent a sampling of trips over 1 month; data for agency #3 represents data from all p.m. peak hour trips over 1 week. As can be seen, early running was a major contributor to low on-time performance, even during a time of day when traffic congestion, passenger volumes, and other factors would be expected to cause on-time performance problems.

Exhibit 3-28
Sample On-Time Performances—Weekday P.M. Peak at the Next-to-Last Timepoint

		Systemwide On-Time Performance	
Agency	**Trips Observed**	**Unadjusted**	**Adjusted for Early Departures**
#1—June/July 2001	173	77%	88%
#2—July/August 2001	1,290	74%	86%
#2—October 2001	179	69%	76%
#3—October 2001	5,300	61%	84%

Measure on-time performance at locations of interest to passengers.

On-time performance should be measured at locations of interest to passengers. For example, measuring on-time performance at the next-to-last timepoint may be of more interest than measuring it at the route terminal, if most passengers disembark prior to the end of the route. On the other hand, if the route terminal is a timed-transfer center, on-time performance arriving at that location would be of great interest to passengers. Some agencies measure on-time performance at several timepoints along a route.

Early departures are not considered on-time at stops where passengers board.

On-time performance LOS defines "on-time" as being 0 to 5 minutes late. Whether arrivals or departures should be measured will depend on the situation: departures tend to be more important where passengers are mostly boarding, and arrivals where passengers are mostly disembarking. Early departures should not be considered on-time in locations where passengers are boarding, but early arrivals may be considered on-time at the end of a route or at other locations where passengers are only disembarking. On-time performance measurement can be applied to any transit service operating with a published timetable, but is particularly applicable to services operating with headways longer than 10 minutes. At shorter headways, the evenness of headways between vehicles becomes more important to measure, as vehicle bunching leads to a variety of operating and quality of service problems. Headway adherence LOS is discussed below.

LOS ranges for on-time performance are presented in Exhibit 3-29. On-time performance would typically be measured for a route over a series of days (either over consecutive days or as a monthly sampling of each trip) or as a system-wide value. Note that it takes a minimum of 20 observations to achieve the 5% resolution between LOS grades (more observations may be needed to achieve a particular level of statistical significance). The comments shown for each LOS grade reflect the perspective of a passenger who makes one round-trip by transit each weekday (e.g., 10 boardings per week to and from work, if no transfer is required).

Exhibit 3-29
Fixed-Route On-Time Performance LOS

LOS	On-Time Percentage	Comments*
A	95.0-100.0%	1 late transit vehicle every 2 weeks (no transfer)
B	90.0-94.9%	1 late transit vehicle every week (no transfer)
C	85.0-89.9%	3 late transit vehicles every 2 weeks (no transfer)
D	80.0-84.9%	2 late transit vehicles every week (no transfer)
E	75.0-79.9%	1 late transit vehicle every day (with a transfer)
F	<75.0%	1 late transit vehicle at least daily (with a transfer)

NOTE: Applies to routes with a published timetable, particularly to those with headways longer than 10 minutes.
"On-time" is 0 to 5 minutes late, and can be applied to either arrivals or departures, as appropriate for the situation being measured. Early departures are considered on-time only in locations where no passengers would typically board (e.g., toward the end of a route).
*Individual's perspective, based on 5 round trips per week.

At LOS "A," passengers experience highly reliable service and are assured of arriving at their destination at the scheduled time except under highly unusual circumstances. Service is still very reliable at LOS "B," but an average passenger will experience one late transit vehicle per week. At LOS "C," an average passenger will experience more than one late vehicle per week on average. At LOS "D" and "E," passengers become less and less assured of arriving at the scheduled time, and may choose to take an earlier trip to ensure getting to their destination by their desired time. At LOS "F," the number of late trips is very noticeable to passengers.

Headway Adherence

For transit service operating at headways of 10 minutes or less, headway adherence is used to determine reliability. The measure is based on the coefficient of variation of headways of transit vehicles serving a particular route arriving at a stop, and is calculated as follows:

Equation 3-7

$$c_{vh} = \frac{\text{standard deviation of headway deviations}}{\text{mean scheduled headway}}$$

where:

c_{vh} = coefficient of variation of headways.

Headway deviations are measured as the actual headway minus the scheduled headway. As shown in Exhibit 3-30, the coefficient of variation of headways can be related to the probability P that a given transit vehicle's headway h_i will be off-headway by more than one-half the scheduled headway h. This probability is measured by the area to the right of Z on one tail of a normal distribution curve, where Z in this case is 0.5 divided by c_{vh}. For an illustration of these relationships, see page 4-8.

Exhibit 3-30
Fixed-Route Headway Adherence LOS

LOS	c_{vh}	$P(h_i > 0.5\ h)$	Comments
A	0.00-0.21	≤1%	Service provided like clockwork
B	0.22-0.30	≤10%	Vehicles slightly off headway
C	0.31-0.39	≤20%	Vehicles often off headway
D	0.40-0.52	≤33%	Irregular headways, with some bunching
E	0.53-0.74	≤50%	Frequent bunching
F	≥0.75	>50%	Most vehicles bunched

NOTE: Applies to routes with headways of 10 minutes or less.

At LOS "A," service is provided like clockwork, with very regular headways. At LOS "B," most vehicles are off the scheduled headway by a few minutes, but the probability of being off-headway by more than one-half the scheduled headway is low. At LOS "C," vehicles are often off-headway, with a few headways much longer or shorter than scheduled. Headways between vehicles at LOS "D" levels are quite irregular, with up to one in three vehicles one-half a headway or more off-headway. Bunching occurs frequently at LOS "E," and most vehicles are bunched at LOS "F." The following examples illustrate some of these LOS ranges.

Example Calculations

Example 1. A bus route is scheduled to operate at fixed 10-minute headways. During the peak hour, the actual measured headways between buses are 12, 8, 14, 6, 7, and 13 minutes. The corresponding headway deviations are +2, -2, +4, -4, +3, and -3 minutes. The standard deviation of these values is 3.4 minutes, and the resulting coefficient of variation is 0.34, equivalent to LOS "C."

Example 2. Another bus route is scheduled at 5- to 11-minute headways during the peak period. The following table provides the scheduled headway between buses, the actual headway (based on AVL data), and the corresponding headway deviation.

Scheduled Headway (s)	600	600	600	600	660	600	420	540	540	420	420	420	360	300
Actual Headway (s)	786	906	700	302	616	198	304	918	538	120	308	876	168	134
Headway Deviation (s)	+186	+306	+100	-298	-44	-402	-86	+378	-2	-300	-112	+456	-192	-166

The mean headway is 506 seconds, the standard deviation of the headway deviations is 265 seconds, and the coefficient of variation is 0.52, equivalent to LOS "D."

Other Measures

Other measures of passenger convenience along route segments and corridors are listed below. Further information about these measures can be found in *TCRP Report 88*(R17) and in the references given in the following list:

- *Travel speed* is a useful route segment performance measure, because it reflects how long a trip may take, without depending on the length of a route segment. Transit priority measures, improvements to fare collection procedures, and other similar actions implemented along a route segment will be reflected as improvements in travel speed. The procedures in Parts 4 and 5 can be used to estimate transit travel speeds along a route segment. *TCRP Report 26*(R34) provides suggested LOS ranges based on bus speeds for buses operating on arterial bus lanes.
- MTA-New York City Transit uses *wait assessment* as its measure of headway regularity. The measure is defined as the percentage of transit vehicle arrivals where the actual headway exceeded the scheduled headway by more than 3 minutes. (Headways less than those scheduled are not considered, under the theory that short headways generally result from the previous vehicle's long headway and the vehicle with the long headway is the one that affects passenger service quality, as a result of longer wait times and more crowded conditions on board.)

COMFORT AND CONVENIENCE—SYSTEM

An important factor in a potential transit user's decision to use transit on a regular basis is how much longer the trip will take in comparison with the automobile. Although some transit operators emphasize the "additional free time" aspect of riding transit in their promotional materials—to read, relax, catch up on extra work, etc.—without having to deal with the hassles of rush-hour driving, most people still prefer to drive their own cars unless high out-of-pocket costs (such as parking charges) provide a disincentive, or unless transit travel time is competitive with the automobile.

The level of service measure is *transit-auto travel time*: the door-to-door difference between automobile and transit travel times, including walking, waiting, and transfer times (if applicable) for both modes. It is a measure of how much longer (or in some cases, shorter) a trip will take by transit. The trip length is not as important as the trip time—a 20-mile trip that takes 1 hour longer by transit and a 5-mile trip that takes 1 hour longer both require an extra hour out of one's day—although longer trips have a greater potential for having a greater time differential.

Travel time for transit includes walk time from one's origin to transit (assumed to be an average of 3 minutes), wait time (5 minutes), travel time on-board transit (varies), walk time from transit to one's destination (3 minutes), and any transfer time required (varies). Travel time for automobiles includes travel time in the automobile and time required to park one's car and walk to one's destination (assumed to be an average of 3 minutes). Walk time is based on a maximum 0.25-mile (400-m) walk to transit at 3 mph (5 km/h), which will take about 5 minutes; not all transit users walk the maximum distance.

Smaller cities may find it harder than large cities to achieve high levels of service for this measure. In the San Francisco Bay Area, for example, it is faster to travel between downtown Oakland and downtown San Francisco by BART during the a.m. rush hour than it is to drive alone over the Bay Bridge. On the other hand, for a city with a population less than 50,000, where it is possible to drive virtually anywhere in the city in 10 to 15 minutes, the walk and wait time for transit by itself is nearly as much as the total automobile travel time, and the calculated LOS will suffer as a result. In general, for small cities or for short trips, the total transit travel time will generally be significantly longer than the automobile travel time.

Since transit-auto travel time is a system measure, its data requirements are greater than those for transit stop and route segment measures. This section presents two methods for calculating transit-auto travel time LOS: one uses a transportation planning model and the other is done by hand.

As with many of the other service measures, transit-auto travel time can be measured at different times of the day, for example, at peak and off-peak times. Because peak hour traffic congestion tends to lengthen automobile trip times, the calculated LOS will often be better during peak hours than during the rest of the day. Exhibit 3-31 provides the transit-auto travel time LOS thresholds:

Exhibit 3-31
Fixed-Route Transit-Auto Travel Time LOS

LOS	Travel Time Difference (min)	Comments
A	≤0	Faster by transit than by automobile
B	1-15	About as fast by transit as by automobile
C	16-30	Tolerable for choice riders
D	31-45	Round-trip at least an hour longer by transit
E	46-60	Tedious for all riders; may be best possible in small cities
F	>60	Unacceptable to most riders

Door-to-door travel by transit is faster than by auto at LOS "A." This level of service provides considerable incentive to potential riders to use transit. At LOS "B," the in-vehicle travel times by auto and transit are comparable, but the walk and wait time for transit makes the total trip by transit slightly longer. Riders must spend an extra hour per day using transit at LOS "C" levels and up to 1.5 hours at LOS "D." At LOS "E," individual trips take up to 1 hour longer by transit than by automobile; however, this may be the best possible in small cities where automobile travel times are low. Travel times at LOS "F" levels will be unacceptable to most riders.

Example Calculations

Transportation Planning Model Method

The advantage of using a transportation planning model is that all trips between all zones can be modeled and different kinds of trip types can be compared. Since many urban areas only have a weekday p.m. peak hour model, travel times at other times of the day and week cannot be compared using this method. The transportation model used needs to include networks for both roadways and transit.

Step 1: Calculate travel time differences between zones. Use the transportation planning model to generate (1) a table of automobile travel times between each pair of zones and (2) a table of transit travel times between each pair of zones. Subtract the values in the transit table from the values in the automobile table to obtain travel time differences between each pair of zones.

Step 2: Calculate total person trips between zones. From the model, generate a table of total person trips (both automobile and transit) between each pair of zones.

LOS can be measured as a system average or for individual origin-destination pairs.

Step 3: Calculate the weighted average of travel time differences. For each pair of zones, multiply the travel time difference between the zones by the number of person trips between the zones. Sum all of the resulting values and divide by the total number of person trips that took place. The result is a system-wide weighted average travel time difference, which can then be used with Exhibit 3-31 to calculate a system-wide LOS. The LOS for individual origin-destination pairs can also be calculated.

Manual Method

The manual method is useful in areas without a transportation model or when a faster assessment of travel time LOS is desired. A sampling of about 10 to 15 locations should be used for the analysis. In general, the CBD and 10 to 15 important trip generators should be used, with a balance of residential and employment generators and a balance of geographic locations. Unless there is a heavy reverse-direction volume during the analysis period or the reverse volume is of interest to the analysis (for example, for welfare-to-work applications), estimating peak direction travel times is usually sufficient.

Step 1: Estimate travel times between locations. Analysts may find it useful to sketch two simple network diagrams of the area being studied, one for transit and one for automobiles, and to indicate travel times on the links between locations. Analysts may also find it useful to create a spreadsheet of travel times between locations for use in subsequent steps. During step 1, only travel times between locations and transfer times are considered; access and wait times are not considered. For an analysis of existing conditions, transit travel and transfer times can be derived from published schedules; automobile travel times can be determined by driving the main routes between locations. When a choice of transit routes is available, the fastest route (e.g., an express route) should be selected.

Step 2: Estimate travel time differences between locations. For each pair of locations, subtract the auto travel time from the transit travel time; add transit access, wait, and transfer times; and subtract any auto access time (e.g., walks to or from parking garages).

Step 3: Calculate the level of service. Average the travel time differences of each pair of locations and use the resulting system value with Exhibit 3-31, or calculate point-to-point LOS directly from Exhibit 3-31.

An example of the manual calculation method can be found in the example problems in Chapter 6.

Other Measures

Other measures of passenger convenience along route segments and corridors are listed below. Further information about these measures can be found in *TCRP Report 88*(R17) and in the references identified with particular measures in the following list:

- *Transit/auto travel time ratio* is sometimes used by transit agencies as a service design standard (e.g., a trip by transit should not take longer than twice the time it would take by automobile). This measure can produce large values in smaller cities, where auto travel times are often short relative to transit.
- Rather than compare transit and automobile travel times, the transit *travel time* can be used by itself as a performance measure. The maximum time that passengers will find reasonable will vary, depending on the size of the city or metropolitan area served by transit, and whether travel is occurring during peak or off-peak times.(R10)
- *Safety* measures reflect the probability of being injured while using transit, for example, due to a vehicle crash or a slip and fall. *Security* measures reflect the probability of being a victim of a crime while using transit.

This page is intentionally blank.

CHAPTER 4. DEMAND-RESPONSIVE TRANSIT SERVICE MEASURES

INTRODUCTION

This section describes a quality of service evaluation framework for demand-responsive transportation (DRT). It can also be used for evaluating specialized transportation services, including ADA paratransit. However, it must be recognized that specialized services are, by definition, provided to specific user groups and are not available to the general public. ADA paratransit service, in particular, is heavily regulated, and transit systems must ensure compliance with the federal regulations or face potential legal ramifications. However, for an assessment of service quality from the same perspective of the DRT evaluation framework, the methodology described in this section could be used for ADA paratransit.

Consistent with the evaluation framework for fixed-route transit, the service measures for DRT are provided within two categories: (1) availability and (2) comfort and convenience. Within the two categories, some of the DRT measures parallel those for evaluating fixed-route services. Given the fundamental differences between the two modes, however, the TCQSM presents this separate framework for DRT. Instead of defining LOS on an "A" to "F" scale as with fixed-route transit, a "1" to "8" scale has been established for DRT. This reflects a desired further gradation of LOS thresholds for DRT than could be described on an "A" to "F" scale.

Demand-responsive transit LOS uses a numerical "1" to "8" scale.

There is no DRT equivalent for the "transit supportive area" used in the fixed-route transit framework. Readers interested in estimating demand for rural DRT service are referred to *TCRP Report 3*.(R35)

AVAILABILITY—RESPONSE TIME

Response time is the minimum amount of time a user needs for scheduling and accessing a trip or the minimum advance reservation time. This measure is most appropriate where most of the trips are scheduled each time that the user wants to travel. In other words, it is less appropriate where most of the trips are provided on a standing-order, subscription basis, where riders are picked up on pre-scheduled days at pre-scheduled times and do not need to call in advance for each trip. Nevertheless, the measure could be used where subscription service is provided. For such DRT services, response time could be calculated for the situation when a trip request is first made. Exhibit 3-32 shows the response time associated with each LOS.

Exhibit 3-32
DRT Response Time LOS

LOS	Response Time	Comments
1	Up to ½ hour	Very prompt response; similar to exclusive-ride taxi service
2	More than ½ hour, and up to 2 hours	Prompt response; considered immediate response for DRT service
3	More than 2 hours, but still same day service	Requires planning, but one can still travel the day the trip is requested
4	24 hours in advance; next day service	Requires some advance planning
5	48 hours in advance	Requires more advance planning than next-day service
6	More than 48 hours in advance, and up to 1 week	Requires advance planning
7	More than 1 week in advance, and up to 2 weeks	Requires considerable advance planning, but may still work for important trips needed soon
8	More than 2 weeks, or not able to accommodate trip	Requires significant advance planning, or service is not available at all

DRT service that is provided at LOS "1" is similar to exclusive-ride taxi service, with very prompt response. Such response time is possible where scheduling/ dispatch is provided on a real-time basis, where service is operated by a taxi company, and where there is limited or no shared-riding. DRT service at LOS "2" would have the capacity to provide trips within 2 hours of a user's request for a trip. While not as prompt as LOS "1," it is considered immediate response service for DRT and allows relatively spontaneous trips to be made. At LOS "3," service response is longer than 2 hours but service is still available the same day that a trip is requested. For general public users, this is lesser quality service, but still enables one to travel on the day requested though perhaps not at the exact time desired. With LOS "4" service, trip requests are made the day before service is needed. For many DRT users, this may be satisfactory service as many trips tend to be somewhat pre-planned. Beyond LOS "4," additional advance planning is necessary, until LOS "8," where a trip must be planned more than 2 weeks into the future or, very undesirably from the user's perspective, service is not available at all.

Response time LOS should be based on actual operating experience, rather than stated policy.

Assessment of response time should be based on actual operating experience. It should not be based solely on the stated policy of the DRT system.

To calculate this measure, the DRT provider should look at the minimum amount of time that a user needs to schedule a trip in relation to the response time policy. For example, if the stated policy of the DRT system is that service is provided 24 hours in advance, then the provider should determine if users can systematically schedule a trip the day before the trip is desired. Some portion of users will schedule trips more than 24 hours in advance, but if the policy is 24 hours in advance, then a user should be able to reserve a trip the day before the desired trip.

Information on response time can be obtained from DRT staff that book trips, typically telephone reservationists/schedulers or dispatchers. Another approach is to survey riders to obtain their input and experience with response time.

Using an average for this measure is not appropriate, as some DRT users call far in advance to schedule a trip, even though this may not be necessary. For example, a particular user may call 1 week in advance to schedule an important trip on a DRT system that has 24-hour response time, even though the user could call the day before to get the ride. An average would capture such response times for trips scheduled farther in advance than is necessary and would thus not be representative of actual operations.

AVAILABILITY—SERVICE SPAN

Service span measures the number of hours during the day and days per week that DRT service is available in a particular area. Unlike the similar measure for fixed-route service that measures hours per day of service, the service span measure for DRT incorporates *days* of service in addition to *hours* per day. This is done because in some rural areas DRT service may only be provided selected days per week, or even selected days per month. Incorporation of both hours per day and days per week provides a more complete perspective on the amount of DRT service that is available within a community or larger area. Given that the measure incorporates two factors, it is presented as a matrix.

To use the matrix, first determine how many days per week the DRT service operates. From the column in Exhibit 3-33 that shows the number of days per week, determine the hours per day that service is provided. For DRT systems that operate different hours during the week than during the weekend, a weighted average can be calculated. For example, a DRT system that operates 6 a.m. to 7 p.m. on weekdays and 7 a.m. to 5 p.m. on Saturdays, provides service 6 days per week, for a weighted average of 12.5 hours. This would be LOS "2."

Exhibit 3-33
DRT Service Span LOS

	Days Per Week						
Hours Per Day	**6-7**	**5**	**3 - 4**	**2**	**1**	**0.5***	**< 0.5**
≥16.0	LOS 1	LOS 2	LOS 4	LOS 5	LOS 6	LOS 7	LOS 8
12.0-15.9	LOS 2	LOS 3	LOS 4	LOS 5	LOS 6	LOS 7	LOS 8
9.0-11.9	LOS 3	LOS 4	LOS 4	LOS 6	LOS 6	LOS 7	LOS 8
4.0-8.9	LOS 5	LOS 5	LOS 5	LOS 6	LOS 7	LOS 7	LOS 8
< 4.0	LOS 6	LOS 6	LOS 6	LOS 7	LOS 8	LOS 8	LOS 8

*service at least twice per month

For DRT service availability, there are several key thresholds related to the service span. The first is whether there is any weekend service. In many communities with DRT, service is provided just during the week. This is considered satisfactory service and perfectly acceptable for a majority of users, but does limit trip-making to weekdays only, with no service on Saturdays or Sundays.

A second related threshold considers whether service is available all weekdays. Monday through Friday service is considered standard and is important for users, allowing them to travel throughout the week. DRT service that is available only several weekdays each week cannot be considered particularly high quality from an availability perspective, even though it may be the only financially feasible service in some communities.

A third threshold relates to length of the service day. In smaller communities and rural areas, DRT service is often provided just during the business day, for example, 9 a.m. to 5 p.m. While such a service span allows users to travel by DRT for medical appointments, shopping trips, and other similar trips, a person working a full-time office job could not use the DRT system to travel back and forth to work. Such DRT systems with service hours of less than 9 hours per day are most appropriate as specialized transit programs focused on targeted clienteles.

A fourth threshold relates to whether service is available at least weekly. While service in urban areas and most small communities is provided at least on weekdays or several days per week, some rural areas receive service on less than a weekly basis. This is sometimes referred to as *lifeline* service, allowing the rural residents access to shopping areas and other destinations at least once or several times per month. And while such service may be appreciated by users who are transit dependent, it is very limited quality from the user's perspective in relation to its availability.

The LOS levels shown in Exhibit 3-33 reflect the thresholds identified above, with marked LOS gradations between the thresholds. For example, at LOS "1," DRT service is highly available, with service available 6 or 7 days per week and from early morning hours to very late at night. Such service availability might be typical of an urban ADA paratransit program that provides service during hours comparable to the city's fixed-route transit system. At LOS "2," service is available weekdays and during daytime and at least early evening hours as well. However, service that is available only 4 days per week, even with a long service day, is LOS "4." Service availability less than once per week is LOS "7" or "8." While this amount of service may be the best that can be provided in a rural area given low population densities and limited funding, it is not desirable from the user's perspective.

This measure can also be used to assess any differences in service availability across a transit agency's service area. For example, a transit agency serving a large county that includes several small communities may establish different service spans within different parts of the county. The communities in the county may receive DRT service on a more frequent basis than the outlying rural parts of the county. In such a case, the communities in the county would have a higher LOS on the service span measure than would the rural parts of the county. From the user's perspective, DRT service in the communities is higher quality than that in the rural areas, as the service span is greater.

COMFORT AND CONVENIENCE—RELIABILITY

Reliability of DRT is a critical issue from the user's perspective. Users will want to know: "Will there be a trip for me when I call, or will all the rides be taken?" "Once I book my ride, will the vehicle arrive at the scheduled time?" "Will the driver get me to my destination before my appointment time, or will my trip be too long?"

Because of the nature of DRT, where a user must schedule individual trips, there is more variability in DRT operations than there is for fixed-route service. For fixed-route bus service, a rider simply walks out to a marked bus stop along the published route a few minutes before the published or estimated time that the vehicle will pass by. The rider boards the bus and gets off at the appropriate stop at the published or estimated time.

For DRT service, there are several steps involved in taking a trip, each with reliability issues. The user must call or contact the DRT office to request the particular trip. Depending on available capacity of the DRT system, the user may or may not be able to reserve a trip. If there is capacity, the trip may or may not be available at the exact time the user requests. Once the trip is booked, the user must wait for the vehicle and driver to arrive at the scheduled time (often this is a window of time rather than an exact time). The vehicle and driver may arrive on time (within the window) or late, or there may be times when the vehicle does not arrive at all. Once aboard the vehicle, the user then rides until arrival at the scheduled destination, which will take a varying amount of time depending upon other riders who might be sharing the vehicle and their trip characteristics. If everything goes as scheduled, the user arrives at his or her destination on time.

Given the various steps involved within a DRT trip, reliability is assessed with two measures: *on-time performance* and *trips not served*.

On-Time Performance

On-time performance measures the degree to which DRT vehicles arrive at the scheduled times. The measure is calculated at the pick-up location and, for time-sensitive trips (e.g., medical appointments, work, school, etc.), at the drop-off location as well.

Many DRT systems, particularly those in urban areas, give users a "window of time" that the vehicle will arrive. For example, if a user requests a 10 a.m. pick-up, the scheduler or dispatcher might tell that user that the vehicle can be expected between 9:45 and 10:15 a.m. If the vehicle arrives any time within that 30-minute window, it is considered on time. With the routing variability and shared-ride nature of DRT service, it is difficult to give users an exact time that the vehicle will arrive.

On-time performance is usually measured to ensure that vehicles do not arrive late. However, being *early* can be a problem, too, in that users may feel compelled to hurry outside to meet their vehicle at the pick-up end, and, at the destination end, an early arrival may mean the user gets to an appointment before the building or establishment is even open. Early arrivals may also result in no-shows. When drivers arrive early, they may not find their passengers waiting at the pick-up location because it's too early and then, prematurely, may mark those passengers as no-shows and proceed. Generally, DRT systems require that drivers who arrive early for the pick-up wait at the location until the on-time window begins before starting the "official" waiting time for the passenger, typically up to 5 minutes or sometimes longer depending on the type of DRT system.

Calculating on-time performance is done on a percentage basis for all trips during the defined time period or for a sample of trips over the time period. All trips should be assessed at the pick-up end to determine whether they are within the on-time window. Time-sensitive trips would be assessed at the destination end to see if the vehicle arrived at or before the required time.

The window of time can be determined by the local system. Particularly in larger DRT systems, the on-time window is 30 minutes; however, some DRT systems use a shorter 20-minute or 15-minute window for scheduling trips and assessing timeliness. In some rural areas, DRT systems may have a much longer window—60 minutes, for example. Shorter windows provide a higher service quality to users, as the users' waiting period for service is shorter. Those DRT systems that use a longer window should provide a higher percentage of trips on time, given the longer time frame allowed for arriving at the scheduled locations. Thus, the LOS thresholds given in Exhibit 3-34 may need adjustment depending upon the definition of on-time.

Exhibit 3-34
DRT On-Time Performance LOS

LOS	On-Time Percentage	Comments*
1	97.5-100.0%	1 late trip/month
2	95.0-97.4%	2 late trips/month
3	90.0-94.9%	3-4 late trips/month
4	85.0-89.9%	5-6 late trips/month
5	80.0-84.9%	7-8 late trips/month
6	75.0-79.9%	9-10 late trips/month
7	70.0-74.9%	11-12 late trips/month
8	<70.0%	More than 12 late trips/month

NOTE: Based on 30-minute on-time window.
*Assumes user travels by DRT round trip each weekday for one month, with 20 weekdays/month.

Given the variability of DRT service operations on a day-to-day basis including the unpredictability of dwell times for individual DRT riders, the shared-ride nature of the service, and the vagaries of traffic, particularly in urban areas, achievement of LOS "1" is very high quality service and certainly difficult to achieve in an urban area. In smaller communities, LOS "1" would be more achievable. For a user riding DRT round-trip each weekday for 1 month, LOS "1" would mean no more than one late trip experienced by that user during the month. At LOS "2," 95% of trips are on-time, still high-quality service. At LOS "3," 90% of trips are on-time. While this measure does not assess how late the late trips are, assuming that they are not more than 15 to 30 minutes late, then the DRT service may still be relatively good from the user's perspective. At LOS "4," more trips are outside the on-time window, resulting in less timeliness and reliability for users. For the remaining LOS thresholds, the percentage of trips arriving within the window decreases, until LOS "8," where less than 70% of trips are on-time. For a regular user, riding the DRT system on a daily basis to school, for example, this would mean that in a given month more than 12 trips would be late. This would be very undesirable from that user's perspective.

Trips Not Served: Trips Denied and Missed Trips

Trips not served is a measure that includes two components: (1) trips turned down or denied when requested because of a lack of capacity and (2) missed trips, which are those booked and scheduled but the vehicle does not show up. From a user's perspective, a DRT system is reliable if that user can book a trip when needed and the vehicle shows up when scheduled—in other words, no (or very minimal) trips not served. Conversely, the DRT service is unreliable if the user cannot obtain a trip—either because the trip is denied or because the vehicle never shows up for the scheduled trip. Some DRT providers try to avoid denials by over-accepting trips, which then results in missed trips, as there is inadequate capacity. Other DRT providers may have a higher number of denials in order to guarantee capacity to serve those trips that they do accept, with a resulting minimal number of missed trips. This composite measure of trips not served captures both circumstances—denials and missed trips—which result in the same consequence for the user: a trip not served.

From a DRT provider's perspective, trips not served must be assessed separately from denials. Frequent trip denials indicate that the DRT system does not have enough capacity. Frequent missed trips can stem from a number of causes, including trip scheduling that is too tight, with inadequate time for drivers to carry out their manifest; inexperienced drivers who cannot find pick-up locations; miscommunications between users and schedulers/dispatchers as to where to meet the driver and vehicle, particularly at activity centers or locations with multiple entrances; inadequate number of vehicles due to breakdowns, defects, or other reasons; insufficient number of drivers; or a combination of these factors. Exhibit 3-35 provides the LOS thresholds for trips not served.

Exhibit 3-35
DRT Trips Not Served LOS

LOS	Percent Trips Not Served	Comments*
1	0-1%	No trip denials or missed trips within month
2	>1%-2%	1 denial or missed trip within month
3	>2%-4%	1-2 denials or missed trips within month
4	>4%-6%	2 denials or missed trips within month
5	>6%-8%	3 denials or missed trips within month
6	>8%-10%	4 denials or missed trips within month
7	>10%-12%	5 denials or missed trips within month
8	>12%	More than 5 denials or missed trips within month

NOTE: Trips not served include trip requests denied due to insufficient capacity, and missed trips.
*Assumes user travels by DRT round trip each weekday for one month, with 20 weekdays/month.

At LOS "1," DRT service is very reliable, with no or very isolated denials or missed trips. This is high-quality service, where the DRT system is able to successfully provide capacity for the varying levels of demand throughout the day and ensure effective on–street operations with no or a minimal number of missed trips. LOS "2" service is still quite reliable. From the perspective of a user who travels by DRT each weekday without a standing order ride[1], LOS "2" might entail one denial or missed trip on a monthly basis, depending on the number of weekdays in the month. The percentage of denials/missed trips increases with each LOS threshold. At LOS "8," the user who travels by DRT each weekday would experience more than five denials or missed trips in the month; this is clearly unreliable service from that user's perspective.

COMFORT AND CONVENIENCE—TRAVEL TIME

Travel time is an important measure for DRT users. Some users may compare their DRT travel time to that for a comparable auto trip. Others may compare their DRT trip with a comparable trip on fixed-route service. Still other users may compare DRT travel time with some pre-set length of time, for example, 30 minutes, or perhaps the "usual" travel time for their DRT trips.

A user should expect that travel times on DRT will be somewhat longer than on a private vehicle, due to the shared ride nature of the service, with deviations during the trip for other riders. However, the user also expects that the deviations should not result in a trip that is too lengthy. Defining "too lengthy" will depend on the characteristics of the service area and the type of trip being taken. For example, a DRT trip in a rural area or a regional trip in an urban area might legitimately be 60 to 90 minutes long because of its long length in miles and, in the urban area, because of traffic congestion. However, for a short trip within the community, 60 minutes is excessively long, even with shared riding.

While individual transit systems may set actual numerical values for travel time to assess the quality and performance of their DRT trip travel times (based on their average trip lengths, types of trips, and known service area characteristics), a more

---

[1] Users with standing order rides do not need to call the DRT office for each ride, thus they do not face denials for these rides. However, any type of trip may be a missed trip.

generic measure will compare DRT travel times with other travel choices. This manual's quality of service framework compares DRT travel time with automobile travel time, in a similar way to that for fixed-route transit in Chapter 3.

DRT-Auto Travel Time

This measure assesses the door-to-door difference between DRT and automobile travel times and is parallel to the travel time measure for fixed-route service. Travel time for DRT includes the in-vehicle time for the trip; it does not include the waiting time for the vehicle to arrive (in this regard, the measure is different from its fixed-route counterpart). Travel time for autos includes the travel time in the vehicle, time to park the vehicle, and time to walk to one's destination, which is the same calculation as that used for the fixed-route transit measure. LOS thresholds for this measure are given in Exhibit 3-36.

Exhibit 3-36
DRT-Auto Travel Time LOS

LOS	Travel Time Difference (min)	Comments
1	≤0	The same or slightly faster by DRT as by automobile
2	1-10	Just about the same or slightly longer by DRT
3	11-20	Somewhat longer by DRT
4	21-30	Satisfactory service
5	31-40	Up to 40 minutes longer by DRT than by automobile
6	41-50	May be tolerable for users who are transit-dependent
7	51-60	May indicate a lot of shared riding or long dwell times
8	>60	From most users' perspectives, this is "too lengthy"

At the highest LOS, average DRT trips are comparable to those by private automobile. This is very high quality service from a user's perspective, as it indicates no shared riding. At LOS "2," DRT trips are just about the same or slightly longer than the same trip by private car. At LOS "3," DRT trips are somewhat longer, and at the LOS "4," DRT trips are up to 30 minutes longer than by automobile. Such trips, however, may still be considered satisfactory as the users are picked up at their residences and dropped off directly at their destinations. Travel time differences continue to increase with each LOS threshold, until LOS "8," where DRT service is more than 1 hour longer than the comparable trip by automobile. For most users, this would be undesirable.

A high LOS may be undesirable from a DRT provider's perspective.

It should be noted that these LOS thresholds at the higher quality levels are quite different from the DRT provider's perspective. A DRT provider wants shared riding to improve efficiency and productivity. If trips consistently have the same or similar travel time as trips by auto, it indicates that the scheduling/dispatch function is failing to group rides. One of the skills for scheduling/dispatching is balancing the degree of shared riding with travel times for individual riders.

Calculation of the measure is done in a similar way as that for fixed-route transit as described in Chapter 3. To determine the difference in travel time, both the DRT travel time and auto travel time need to be calculated.

To calculate DRT travel time, select a sample of about 10 to 15 origin and destination pairs, reflecting various neighborhoods throughout the community or service area and common destinations, perhaps a frequented shopping mall and major medical facility. With actual operating data on trip travel times from driver manifests, dispatcher records, or Mobile Data Terminals (MDTs) if available, calculate average travel times for a sample of users between the selected origin-destination pairs.

For auto travel time, it is suggested that the manual method described in Chapter 3 be employed. This straightforward method involves simply driving the main route between the selected origin-destination pairs. Any auto access time at the origin or destination end must also be added into the auto travel time to ensure measurement of door-to-door travel time. This access time is assumed to be 3 minutes.

With the average travel times for both DRT and auto between the selected locations, the next step involves calculating the time difference between the two modes for each origin-destination pair. Then, average the travel time differences to compute the average travel time difference between DRT and private auto. Use this average time difference to determine the LOS as indicated in Exhibit 3-36.

CHAPTER 5. REFERENCES

1. Abkowitz, Mark and John Tozzi, "Research Contributions to Managing Transit Service Reliability," *Journal of Advanced Transportation,* Vol. 21, No. 1 (1987).
2. American Public Transportation Association, Transit Vehicle Data Book, Washington, DC (2001).
3. Atkinson, W.G. (editor), *Canadian Transit Handbook,* Third Edition, Canadian Urban Transit Association, Toronto (1993).
4. Batelle Institute, *Recommendations en vie de l'amènagement d'une installation de transport compte tenu de donnèes anthropomètriques et des limites physiologiques de l'homme,* Geneva, Switzerland (1973).
5. Benn, Howard P., *TCRP Synthesis of Transit Practice 10: Bus Route Evaluation Standards,* TRB, National Academy Press, Washington, DC (1995). http://gulliver.trb.org/publications/tcrp/tsyn10.pdf
6. Bolger, Don, David Colquhoun, and John Morrall, "Planning of Park-and-Ride Facilities for the Calgary Light Rail Transit System," *Proceedings of the Conference on Light Rail Transit,* Calgary, Alberta (1992).
7. Canadian Urban Transit Association, *A Review of Canadian Transit Service Standards,* Toronto, Ontario (2001).
8. Cleland, Francis, Dennis Hinebaugh, and Joel R. Rey, "Transit Customer Satisfaction Index for Florida Transit Properties," *Technical Memorandum No. 3: Results and Analysis of Florida Transit Properties,* Center for Urban Transportation Research, University of South Florida, Tampa (1997).
9. Danaher, Alan, Tom Parkinson, Paul Ryus, and Lewis Nowlin, "TCRP A-15 Development of Transit Capacity and Quality of Service Principles, Practices, and Procedures," *Appendix to Interim Report: Literature Review,* available on loan from the Transit Cooperative Research Program, TRB, National Research Council, Washington, DC (1997).
10. Dowling, Richard G. and Steven B. Colman, "Performance and Level of Service Measures for Corridor and Areawide Analyses," *NCHRP 3-55(2a) Issue Paper* (unpublished), Dowling Associates, Oakland, CA (1998).
11. Ewing, Reid, *Best Development Practices,* APA Planners Press, Chicago, IL (1996).
12. Federal Highway Administration, "Implementing Bicycle Improvements at the Local Level," *Publication FHWA-98-105,* U.S. Department of Transportation, Washington, DC (1998). http://www.fhwa.dot.gov/safety/fourthlevel/pdf/LocalBike.pdf
13. Florida Department of Transportation, Public Transit Office, *State Park-and-Ride Lot Program Planning Manual*, Tallahassee, FL (1996, portions updated 2001).
14. Florida Department of Transportation, Systems Planning Office, *2002 Quality/ Level of Service Handbook,* Tallahassee, FL (2002). http://www.dot.state.fl.us/planning/systems/sm/los/pdfs/QLOS2002Novcd.pdf
15. Harkey, D.L, "Development of the Bicycle Compatibility Index: A Level of Service Concept", *FHWA RD-98-072,* McLean, VA (1988). http://www.hsrc.unc.edu/research/pedbike/bci/index.html
16. *Highway Capacity Manual.* TRB, National Research Council, Washington, DC (2000).

17. Kittelson & Associates, Inc., Urbitran, Inc., LKC Consulting Services, Inc., MORPACE International, Inc., Queensland University of Technology, and Yuko Nakanishi, *TCRP Report 88: A Guidebook for Developing a Transit Performance-Measurement System,* TRB, Washington, DC (2003). http://gulliver.trb.org/publications/tcrp/tcrp_report_88/Guidebook.pdf
18. Kittelson & Associates, Inc. and URS, Inc., *Transit Level of Service (TLOS) Software User's Guide, Version 3.1,* Florida Department of Transportation, Public Transit Office, Tallahassee, FL (2001). http://www.dot.state.fl.us/transit/Pages/TLOS%20Software%20Users%20Guide.pdf
19. KJS Associates, *MAG Park-and-Ride Site Selection Study,* Maricopa Association of Governments, Phoenix, AZ (2001). http://www.mag.maricopa.gov/project.cms?item=735
20. Lam, W. and J. Morrall, "Bus Passenger Walking Distances and Waiting Times: A Summer-Winter Comparison," *Transportation Quarterly,* Vol. 36, No. 3 (1982).
21. Levinson, Herbert S., "Supervision Strategies for Improved Reliability of Bus Routes," *NCTRP Synthesis of Transit Practice 15,* TRB, National Research Council, Washington, DC (1991).
22. MORPACE International, Inc., and Cambridge Systematics, Inc., *TCRP Report 47: A Handbook for Measuring Customer Satisfaction and Service Quality,* TRB, National Academy Press, Washington, DC (1999). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_47-a.pdf
23. Municipal Planning Association, "Transit: A Part of the Pittsburgh Plan," Report No. 3, Pittsburgh, PA (1923).
24. Nelson\Nygaard Consulting Associates, *Tri-Met Primary Transit Network Phase II Report,* Portland, OR (1997).
25. North Central Texas Council of Governments, *Estimating the Service Area for Park-and-Ride Operations*, Arlington, TX (1979).
26. O'Sullivan, Sean and John Morrall. Walking Distances to and from Light-Rail Transit Stations. In *Transportation Research Record 1538,* TRB, National Research Council, Washington, DC (1996).
27. Parsons Brinckerhoff Quade & Douglas, Inc., *Calibration of the Mode Choice Models for the Minneapolis-St. Paul Region,* prepared for the Metropolitan Council, Minneapolis, MN (1993).
28. Parsons Brinckerhoff Quade & Douglas, Inc., *Park and Ride Demand Estimation Study: Final Report and Users Manual*, King County Department of Metropolitan Services, Seattle, WA (1995).
29. Peterson, S.G., "Walking Distances to Bus Stops in Washington, D.C.," *Traffic Engineering,* Vol. 39, No. 3 (1968).
30. Polzin, Steven E., Ram M. Pendyala, and Sachin Navari. Development of Time-of-Day–Based Transit Accessibility Analysis Tool. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1799*, TRB, National Research Council, Washington, DC (2002).
31. Pratt, Richard H., *TCRP Web Document 12: Traveler Response to Transportation System Changes: Interim Handbook,* TRB, Washington, DC (2000). http://gulliver.trb.org/publications/tcrp/tcrp_webdoc_12.pdf
32. Pushkarev, Boris and Jeffrey M. Zupan, *Public Transportation and Land Use Policy,* Indiana University Press, Bloomington, IN (1977).

33. Rood, Timothy, "Local Index of Transit Availability: Riverside County, California Case Study Report," Local Government Commission, Sacramento, CA (1997).
34. St. Jacques, Kevin and Herbert S. Levinson, *TCRP Report 26: Operational Analysis of Bus Lanes on Arterials,* TRB, National Academy Press, Washington, DC (1997). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_26-a.pdf
35. SG Associates, Inc., Leigh, Scott & Cleary, Inc., and C.M. Research, Inc., *TCRP Report 3: Workbook for Estimating Demand for Rural Passenger Transportation,* TRB, National Academy Press, Washington, DC (1995). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_03-a.pdf
36. Shortreed, J.H. and D. Maynes, "Calibration of a Transit Demand Model for Kitchener Waterloo," *Project Report WRI 606-11,* Ontario Ministry of Transportation and Communications, Toronto (1977).
37. Spillar, Robert J., "Park-and-Ride Planning and Design Guidelines," *Parsons Brinckerhoff Monograph 11,* Parsons Brinckerhoff Quade & Douglas, Inc., New York, NY (1997).
38. Strathman, James G., Thomas J. Kimpel, and Steve Callas, "Headway Deviation Effects on Bus Passenger Loads: Analysis of Tri-Met's Archived AVL-APC Data," *Report TNW2003-01,* TransNow, Seattle, WA (January 2003). http://www.transnow.org/publication/Reports/TNW2003-01.pdf
39. Strathman, James G., Thomas J. Kimpel, Kenneth J. Dueker, Richard L. Gerhart, and Steve Callas, "Evaluation of Transit Operations: Data Applications of Tri-Met's Automated Bus Dispatching System," *Report TNW2001-04,* TransNow, Seattle, WA (February 2001). http://www.transnow.org/publication/Reports/TNW2001-04.pdf
40. Texas Transportation Institute, *TCRP Report 19: Guidelines for the Location and Design of Bus Stops,* TRB, National Academy Press, Washington, DC (1996). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_19-a.pdf
41. Weinstein, Aaron and Rhonda Albom. Securing Objective Data on the Quality of the Passenger Environment for Transit Riders—Redesign of the Passenger Environment Measurement System for the Bay Area Rapid Transit District. In *Transportation Research Record 1618,* TRB, National Research Council, Washington, DC (1998).

This page is intentionally blank.

CHAPTER 6. EXAMPLE PROBLEMS

1. Service availability (frequency, hours of service, service coverage—GIS method)
2. Service coverage (manual method)
3. Passenger loading
4. Reliability
5. Transit-auto travel time
6. Service coverage (detailed method)
7. Demand-responsive transit

Example Problem 1

The Situation

Riverbank, population 23,000, is an outer suburb of Anytown. The city is currently in the process of updating its long-range transportation plan and expects to grow significantly in the future. As part of this process, Riverbank wishes to evaluate the quality of existing transit service from an availability perspective and also to compare the location of transit service with where housing and jobs are planned 20 years from now. By doing so, Riverbank hopes to better coordinate its planning with that of the regional transit agency that serves this region of 1.5 million people.

The Questions

1. What is the frequency LOS for trips within the city and to major destinations outside the city?
2. What is the hours of service LOS within the city?
3. What is the service coverage LOS now, and what will it be 20 years from now with no changes to the current route structure?

The Facts

Exhibit 3-37 provides a map of the city, showing the location of bus routes and stops. Major barriers to travel within the city include two freeways and a river, as shown on the map.

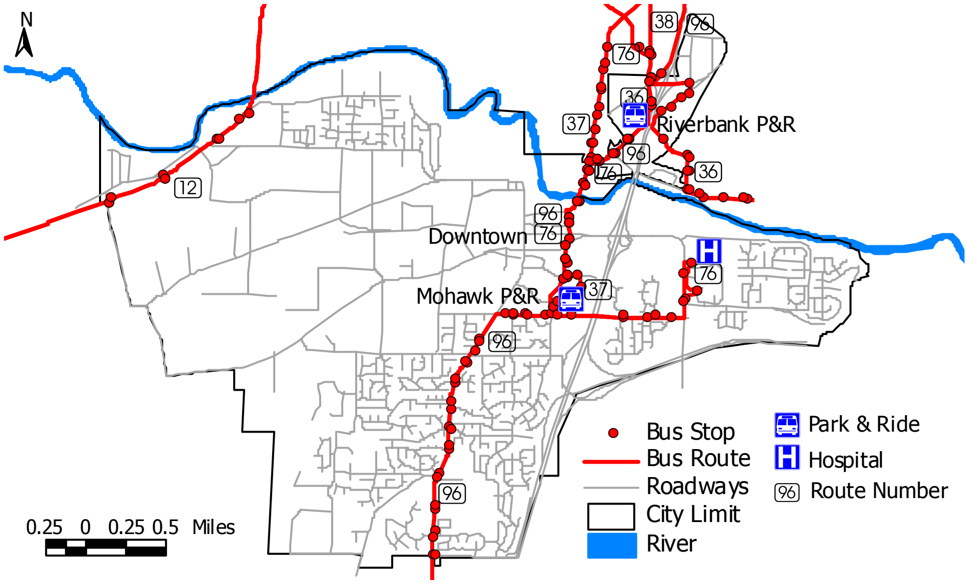
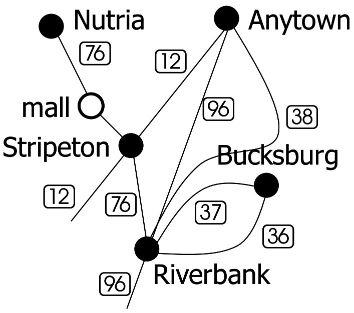


Exhibit 3-37
City Map

The following routes serve the city:

- *Route 12* provides all-day service north to the inner suburb of Stripeton, where it connects with Route 76, and continues north to downtown Anytown, where connections can be made to the regional light rail system.
- *Route 36* provides service from the Riverbank park-and-ride to downtown Bucksburg. It only runs every 2 hours during the midday. It has a timed transfer with Route 76 at the park-and-ride.
- *Route 37* provides service from the Mohawk park-and-ride through downtown Riverbank and continues east to downtown Bucksburg. It only



runs every 2 hours during the midday. Between Route 37 and the combination of Routes 36 and 76, it is possible to travel midday between downtown Riverbank and downtown Bucksburg once per hour. During the a.m. peak period, Routes 36 and 37 run every 30 minutes each, but depart and arrive within 3 minutes of each other.

- *Route 38* provides peak hour service to areas north of Bucksburg, continuing to downtown Anytown.
- *Route 76* is a cross-region route that provides service into the evening. It serves the hospital, downtown, and both park-and-rides. It continues to Stripeton (connecting with Route 12), a regional shopping mall, and the inner suburb of Nutria, where it connects with the regional light rail system. During midday hours, the only connection between downtown Riverbank and downtown Anytown is the combination of Routes 76 and 12.
- *Route 96* provides frequent peak hour service between the Mohawk park-and-ride, downtown Riverbank, and the Riverbank park-and-ride, and then travels non-stop on a freeway to downtown Anytown. Every other trip begins just south of Riverbank.

Travel times to downtown Bucksburg are similar via Routes 36 and 37. Travel times from the Riverbank park-and-ride to downtown Anytown are 27 minutes via Route 96 and 50 minutes via the combination of Routes 76 and 12. Because of the considerable difference in travel times and the frequency of service, travelers to Anytown only use Route 96 during peak hours. During the evening, reverse-commute travelers to Anytown will use either the combination of Routes 76 and 12, or Route 96, depending on which will get them to their destination sooner.

Exhibit 3-38 gives the times of the first and last departures from the city for each route and the frequencies of each route from Riverbank for different time periods.

Exhibit 3-38
Bus Route Schedule Data

			Headway (min)				
Route	**First Trip**	**Last Trip**	**AM Peak**	**Midday**	**PM Peak**	**Evening**	**Night**
12	5:09 am	11:38 pm	10	15	10	30	60
36	5:54 am	6:29 pm	30	120	30	--	--
37	6:58 am	5:06 pm	30	120	40	--	--
38	5:59 am	5:34 pm	30	--	30	--	--
76	5:48 am	9:42 pm	30	30	30	60	--
96*	5:20 am	8:34 pm	7-8	--	7-8	60	--
96	5:51 am	8:26 pm	15	--	15	60	--

*from Mohawk park-and-ride north
-- = no service, AM peak = first trip to 9:00 am, midday = 9:00 am to 4:00 pm, PM peak = 4:00 pm to 6:00 pm, evening = 6:00 pm to 9:30 pm, night = after 9:30 pm

Exhibit 3-39 shows the locations of the transportation analysis zones (TAZs) covering Riverbank, which were obtained from the regional transportation planning model. Exhibit 3-40 provides year 2000 and year 2020 household and employment numbers for each TAZ, along with their areas.

Exhibit 3-39
TAZ Locations

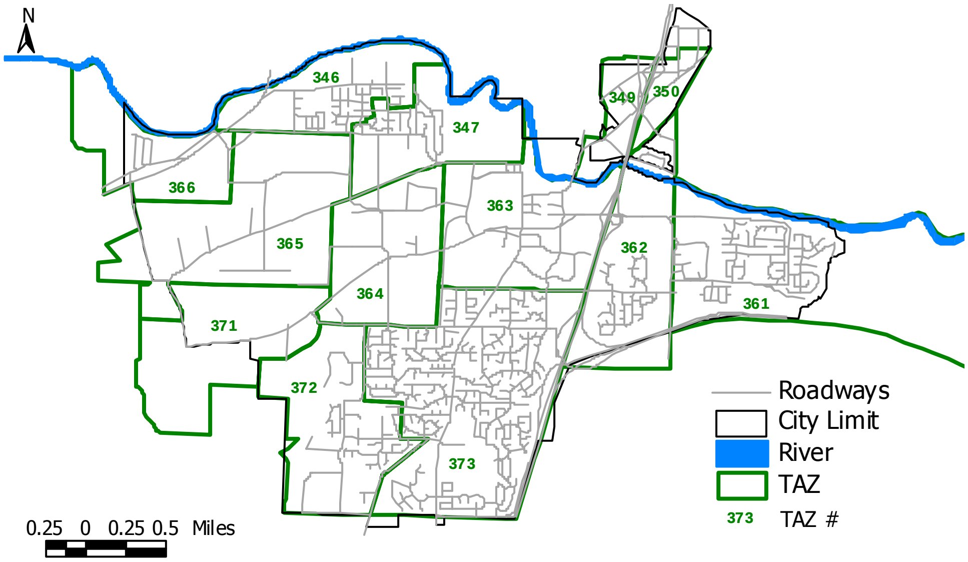


Exhibit 3-40
Population and Employment Data

TAZ	Area (acres)	Year 2000 HH	Year 2000 Jobs	Year 2020 HH	Year 2020 Jobs
346	331.9	506	58	990	676
347	362.3	334	365	1,199	1,204
349	143.9	88	1,346	216	1,524
350	90.8	9	1,203	27	1,415
361	1,203.6	938	472	1,593	844
362	462.8	1,391	1,151	1,864	1,595
363	549.0	854	5,112	2,291	7,572
364	432.0	181	3,022	181	4,373
365	747.3	19	1,518	19	5,361
366	334.4	154	205	516	905
371	500.1	9	375	17	1,344
372	505.0	180	885	826	1,569
373	1,008.3	2,582	580	2,991	891

NOTE: HH = households

Outline of Solution

Service Frequency

Service frequency LOS is determined between pairs of locations. For each pair, determine how often during 1 hour one can make a trip between those locations. The data provided give headways for each route; if a trip requires taking more than one route, the longest headway will control how often a trip can be made. (For example, if the first bus runs every 15 minutes, but connects to a bus that runs every 60 minutes, one can only arrive at the destination once per hour.) Similarly, if there is a choice of more than one set of routes to make a trip, all the possible choices should be looked at in combination (however, remember that departures within 3 minutes of each other are counted as a single opportunity to make a trip).

Hours of Service

Hours of service LOS is determined for individual routes or combinations of routes using the same street. For routes that provide service at least once per hour throughout the day, hours of service will be based on the time of the first and last departures. For routes that operate peak hours only, or have longer-than-hourly service during parts of the day, only those hours where service is provided at least once per hour will be counted.

Service Coverage

Service coverage LOS requires three basic steps: (1) determining the area served by the city's bus routes, (2) determining which portions of the city are "transit-supportive," and (3) determining how much of the TSAs are served by transit.

Solution

Service Frequency

For the purposes of this example, use the trip origins and destinations listed below and evaluate LOS for the a.m. peak and midday hours. A long-range transportation plan would likely look at a greater variety of origins and destinations, as well as other time periods, such as nights and weekends.

Origins

- Downtown Riverbank
- Southern Riverbank (along Route 96 south of the Mohawk park-and-ride)
- Northwestern Riverbank (along Route 12)

Destinations

- Downtown Riverbank
- Hospital
- Downtown Bucksburg
- Downtown Anytown
- Regional mall

From downtown Riverbank during the a.m. peak period, service to the hospital is provided every 30 minutes via Route 76 (LOS "D"), to Anytown every 7 to 8 minutes via Route 96 (LOS "A"), and to the regional mall every 30 minutes via Route 76 (LOS "D"). Travelers to downtown Bucksburg have a choice of routes, but since they leave within 3 minutes of each other, a trip can only be made once every 30 minutes regardless of the route chosen (LOS "D").

From southern Riverbank during the a.m. peak, Route 96 runs every 15 minutes to downtown Riverbank and downtown Anytown (LOS "C"). To reach the other destinations, travelers must transfer to routes that run every 30 minutes; thus, those trips can only be made every 30 minutes (LOS "D").

From northwest Riverbank, Route 12 runs every 10 minutes during the a.m. peak to downtown Riverbank (LOS "B"). Travel to downtown Riverbank, the hospital, and the regional mall requires a transfer to Route 76, which only runs every 30 minutes (LOS "D"). Travel to Bucksburg requires two transfers, with the longest headway involved in the trip being 30 minutes (LOS "D").

Exhibit 3-41 summarizes the results for midday. There is no midday service in the southern portion of Riverbank, thus the LOS from that area is "F" during the midday. Although the individual routes connecting Riverbank to Bucksburg run every 2 hours during the midday, they are scheduled so that a trip is possible once per hour using one route or the other. Travel from northwest Riverbank to Bucksburg involves travel on Route 12 (15-minute service), Route 76 (30-minute service), and Routes 36 or 37 (combined 60-minute service). The longest headway involved in the trip is 60 minutes, thus the LOS for the entire trip is "E."

Exhibit 3-41
Midday Service Frequency LOS Results

	Destinations				
Origins	**Downtown Riverbank**	**Hospital**	**Downtown Bucksburg**	**Downtown Anytown**	**Regional Mall**
Downtown	NA	30/LOS D	60/LOS E	30/LOS D	30/LOS D
South	--/LOS F	--/LOS F	--/LOS F	--/LOS F	--/LOS F
Northwest	30/LOS D	30/LOS D	60/LOS E	15/LOS C	30/LOS D

NOTE: headways in minutes.
NA = not applicable, -- = no service

Hours of Service

Hours of service can be determined by route. However, for a city with a simple route structure such as Riverbank, the process can be shortened by dividing the city into areas that receive similar amounts of service. For Riverbank, these are:

- The area between the park-and-rides, including downtown, which are served by Routes 37, 76, and all Route 96 runs;
- The hospital area, which is served only by Route 76;
- Southern Riverbank, which is served only by some Route 96 runs;
- Northwest Riverbank, which is served only by Route 12; and
- The northeast corner of Riverbank, across the freeway from the park-and-ride, which is served only by Route 36.

The downtown area receives service at least hourly throughout the day, from 5:20 a.m. (the first Route 96 run) to 9:42 p.m. (the last Route 76 run). After converting these times to a 24-hour clock, subtracting 0520h from 2142h results in a difference of 16 hours, 22 minutes. Adding 1 hour to the result and dropping the fractional hour gives a total hours of service of 17 hours, or LOS “B.”

Southern Riverbank does not have service midday. Hourly-or-better service is provided between 5:51 a.m. and 9:00 a.m. (4 hours of service), and between 4:00 p.m. and 8:26 p.m. (5 hours of service), for a total of 9 hours of service, or LOS “E”.

Although northeast Riverbank has midday service, it is only provided every 2 hours, and thus does not count toward hours of service. Hourly-or-better service is provided between 5:54 a.m. and 9:00 a.m. (4 hours of service), and between 4:00 pm. and 6:00 p.m. (3 hours of service), for a total of 7 hours of service, or LOS “E.”

Similarly, the hospital area receives 17 hours of service (LOS “B”), while northwest Riverbank receives 19 hours of service (LOS “A”). Exhibit 3-42 shows these results in the form of a map.

Service Coverage

The GIS planning method of calculating service coverage will be used for this example. For an example that applies the manual method, see Example Problem 2. For an example that applies the detailed method, see Example Problem 5.

As Riverbank only receives bus service, a 0.25-mile (400-m) buffer is created around each bus stop, representing the area served by each bus stop. If desired, these buffers can be created by route, so that the resulting map can also be used to display hours of service LOS. The buffers should be clipped in areas where service coverage would not extend across a barrier. In the case of Riverbank, the river and the two freeways form barriers which need to be considered. The results are shown in Exhibit 3-42 (for clarity, areas served by transit that are outside the city limits are not shown). All shaded areas are considered to receive service; the darkness of the shading indicates the hours of service LOS provided to each area, as calculated from the previous step.

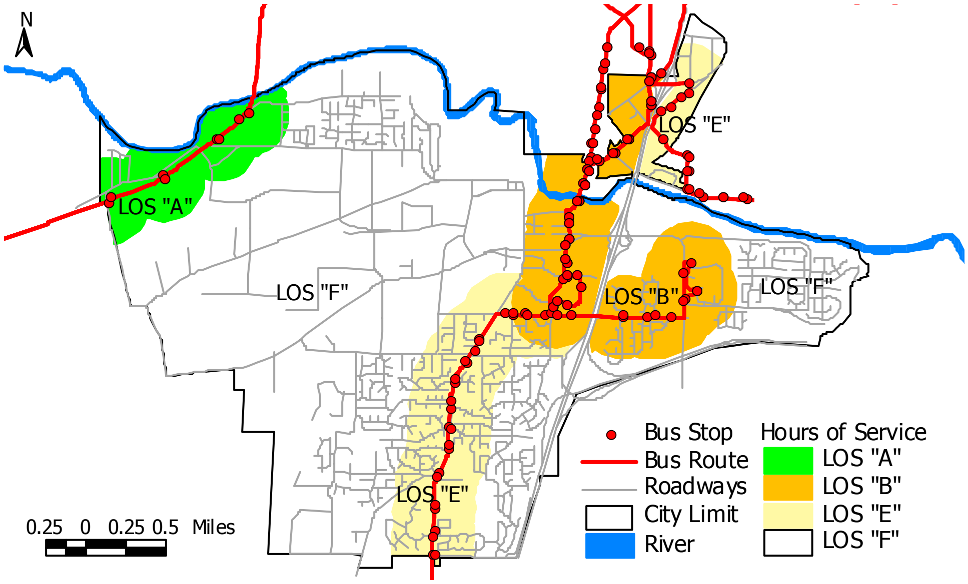


Exhibit 3-42
Service Coverage Area and Hours of Service LOS

All shaded areas are considered to be served by transit. Areas served by transit outside the city limits are not shown.

Next, each TAZ is evaluated to determine whether it meets the criteria for being "transit-supportive" (a household density of 3 households or more per acre or a job density of 4 jobs or more per acre). Household density is calculated by dividing the TAZ's households (given in Exhibit 3-40) by its area in acres. Job density is calculated similarly. For example, the year 2000 household density of TAZ 362 is 1,391 households, divided by 482.8 acres, or 2.88 households per acre. This is slightly below the criterion for TAZ 362 to be a TSA. Results for all TAZs are given in Exhibit 3-43.

Exhibit 3-43
Household and Job Densities

	Year 2000			Year 2020		
TAZ	**HH Density**	**Job Density**	**TSA?**	**HH Density**	**Job Density**	**TSA?**
346	1.52	0.17		2.98	2.04	
347	0.92	3.31		1.01	3.32	
349	0.61	9.35	✓	1.50	10.59	✓
350	0.10	13.25	✓	0.30	15.58	✓
361	0.78	0.39		1.32	0.70	
362	2.88	2.38		3.86	3.30	✓
363	1.56	9.31	✓	4.17	13.79	✓
364	0.42	7.00	✓	0.42	10.12	✓
365	0.03	2.03		0.03	7.17	✓
366	2.17	0.61		1.54	2.71	
371	0.02	0.75		0.03	2.69	
372	0.36	1.75		1.64	3.11	
373	2.56	0.58		2.97	0.88	

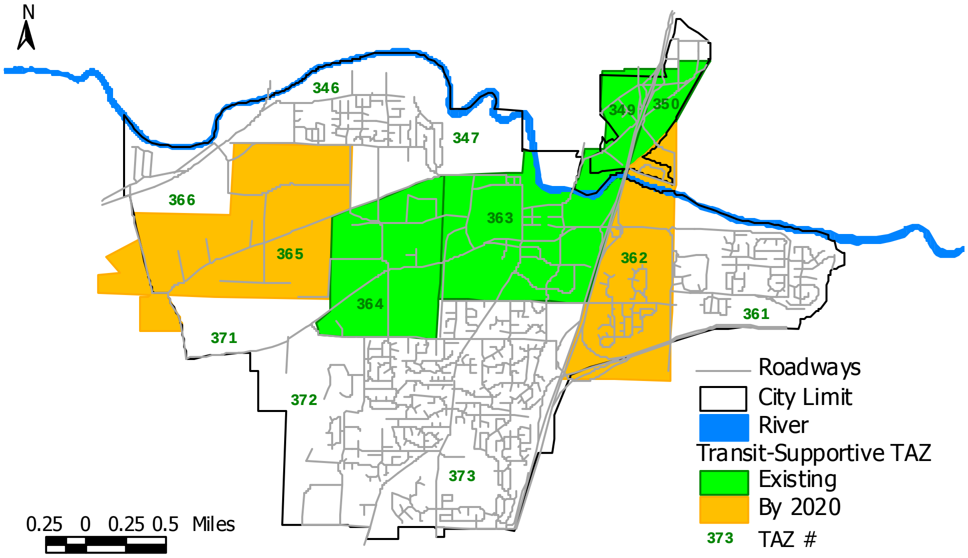
NOTE: HH = households, TSA = transit-supportive area
Densities in households/acre and jobs/acre.

A local transportation plan might wish to go into more detail to identify potential TSAs. For example, TAZs could be subdivided to remove undeveloped areas. This would have the effect of increasing the density in the developed areas. Also, TAZs could be subdivided based on zoning or comprehensive plan designations, so that households were only assigned to areas zoned for residential development, for example. A further refinement would be to assign more households to areas designated for multi-family housing. Any of these steps would provide greater understanding of the sections of the city that could support hourly transit service, and it is likely that TAZs 346 and 373 would turn out to be transit-supportive in the future if these steps were taken. However, for simplicity, this example will use the basic planning methodology outlined in Chapter 3.

A more detailed analysis could look at where particular land use types are located within a TAZ.

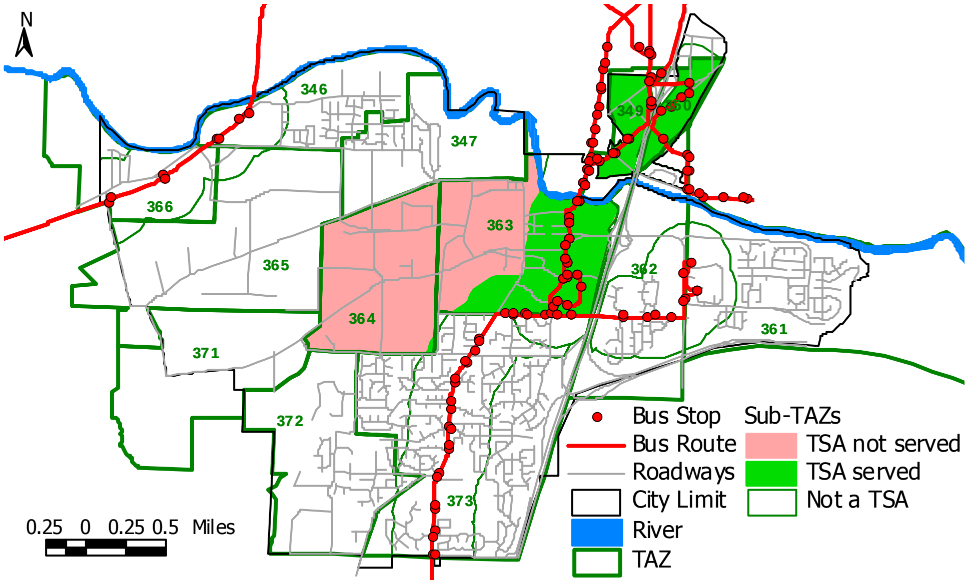
Exhibit 3-44 shows the locations of the transit-supportive TAZs.

Exhibit 3-44
Transit-Supportive TAZs



Next, the buffers indicating the areas receiving transit service are intersected with the TAZs. The result is that TAZs are subdivided into smaller sub-TAZs, each of which is either entirely within the transit service coverage area or entirely outside the transit service coverage area. Exhibit 3-45 shows the results of this process for Riverbank, for existing conditions. Of the four transit-supportive TAZs, all of TAZs 349 and 350 are served, about one-half of TAZ 363 is served, and almost none of TAZ 364 is served.

Exhibit 3-45
Year 2000 Transit-Supportive Areas Served



NOTE: TAZ = transportation analysis zone, TSA = transit-supportive area

Finally, the area of the portion of the TSAs that are served is divided into the total area of the TSAs. The resulting percentage is used to calculate the service coverage LOS. In this case, from Exhibit 3-46, dividing the area served (540.1 acres) into the total TSA (1,215.7 acres) results in 44%, or LOS “F.”

Exhibit 3-46
Service Coverage LOS Calculation

Transit-Supportive TAZ	Area (acres)	Area Served (acres)
349	143.9	143.9
350	90.8	90.8
363	549.0	302.6
364	432.0	2.8
Total	1,215.7	540.1

The Results

The service provided to Riverbank is not unusual for a low-density suburb: as most of the residential areas cannot support hourly transit service, much of the service is focused around park-and-ride lots, serving the commuter market. During peak hours, the park-and-ride and downtown Riverbank areas receive excellent service into downtown Anytown, but receive fairly infrequent service to other destinations. Those residential areas that do receive service generally only have service during peak periods; most residential areas cannot make midday transit trips to downtown Riverbank, the hospital, or other destinations.

The service coverage analysis indicates that a large area with sufficient employees to support transit service is not receiving service, and that this area will be even bigger by the year 2020.

Example Problem 2

The Situation

As part of an overall review of its service, a transit agency wants to evaluate its service coverage area. The agency provides fixed-route bus service to a city of 125,000 people. Its service area includes two universities, a community college, and numerous government offices scattered about the city. Although the agency has access to regional transportation planning model data maintained by the local metropolitan planning organization (MPO), it does not have access to GIS software.

The Questions

Where are the city's TSAs, and how well are they being served?

The Facts

- The MPO's model contains population and employment figures at the TAZ level. The TAZ map is available in an electronic form that allows the areas of each TAZ to be calculated.
- Census data for the area indicate an average household size of 2.5 people.

Outline of Solution

Under the manual calculation method, the TSA is identified first. (See Example Problem 1 for an example using GIS software.) Next, the coverage area of the routes serving the transit-supportive TAZs is identified. Third, the approximate percentage of each transit-supportive TAZ served by transit is identified. Finally, the percentage of the total TSA served by transit is calculated to determine LOS.

Steps

1. Develop a spreadsheet from the data used for the transportation model, listing population, jobs, and area for each TAZ. Convert population to households by dividing by the average household size, in this case, 2.5. Calculate household density for each TAZ by dividing the number of households by the TAZ's area (in acres); calculate job density similarly. A TAZ is transit-supportive if the household density is at least 3 households per acre, or the job density is at least 4 jobs per acre. Exhibit 3-47 illustrates this process for two TAZs:

Exhibit 3-47
Example Transit-Supportive Area Determination

TAZ	Pop	Jobs	Area (ft^2)	Households	Area (acres)	HH Density	Job Density	TSA?
255	1,134	308	10,941,788	453.6	251.2	1.81	1.23	
399	345	852	5,355,176	138.0	122.9	1.12	6.93	✓

NOTE: TAZ = transportation analysis zone, Pop = population, HH = households

In this example, TAZ 255 is not transit-supportive, but TAZ 399 is. Exhibit 3-48 illustrates the locations of all of the transit-supportive TAZs identified through this process. There are 174 transit-supportive TAZs in all.

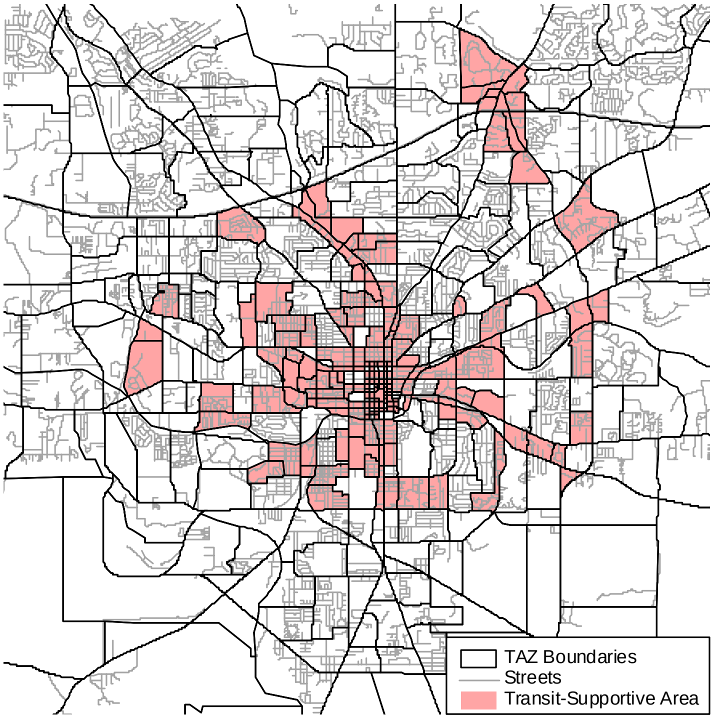


Exhibit 3-48
Transit-Supportive Area Locations

2. For the transit-supportive TAZs identified in step 1, draw the location of the bus routes serving those TAZs, and draw 0.25-mile (400-m) buffers around each route, excluding any areas known not to have pedestrian access. This process is illustrated in Exhibit 3-49.

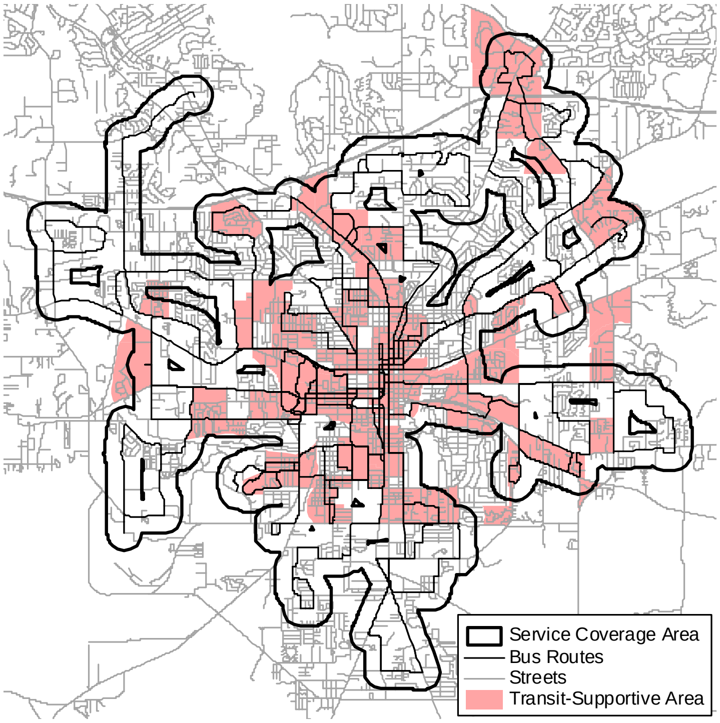
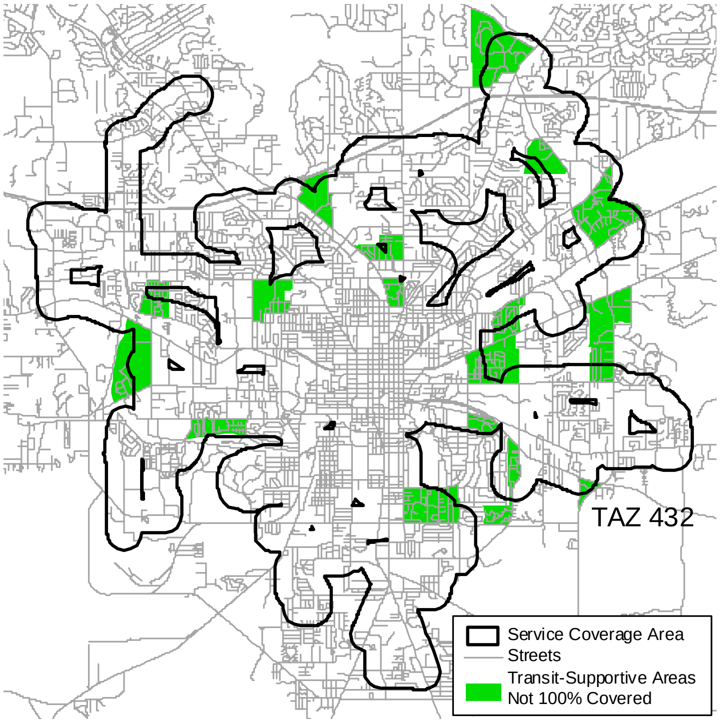


Exhibit 3-49
Bus Route Buffers

3. Twenty-four of the 174 transit-supportive TAZs are only partially served by transit, as depicted in Exhibit 3-50. Estimate the percentage of the area of each of these TAZs that is served by transit, to within 10%. For example, TAZ 432 is about 50% served by transit.

Exhibit 3-50
Partially Served TAZs



4. Divide the TSA served by transit by the total area of the TSAs to determine the percentage of the TSA served, and the resulting service coverage LOS.

The Results

The total TSA is 12.6 square miles, and 10.8 square miles of it is served by transit. As a result, 86% of this system's TSA is served, corresponding to LOS "B." The portions of the city that can support at least hourly bus service receive, for the most part, at least some service during the day. For policy reasons or simply to connect two higher-density areas, most agencies will serve a considerably larger area than the TSA.

Example Problem 3

The Situation

After receiving customer complaints about excessive crowding on one of its heavily used bus lines, a transit agency reviews its automatic passenger counter (APC) data from the previous month to determine whether its passenger loading policy is being exceeded. Not all of the agency's buses are APC-equipped; instead, buses with APCs are assigned such that each run is sampled at least once per month.

The Question

Is the agency loading policy being exceeded on a regular basis?

The Facts

- During the a.m. peak hour (7:00 to 8:00 a.m.) in the inbound direction, 13 buses are scheduled. Scheduled headways range from 3 to 6 minutes (an average of 4 to 5 minutes), and each run is scheduled to take 47 minutes from beginning to end.
- The agency's loading standard for peak periods is that no bus should exceed its maximum schedule load (LOS "E").
- The buses assigned to this line are 40 feet long and 8 feet wide, with single-channel front and rear doors, and 41 seats (20 transverse, 21 longitudinal).
- The data available for the analysis consist of 13 sets of weekday boardings and alightings by stop, one set for each inbound trip made during the a.m. peak hour during the month in question.

Outline of Solution

LOS for standees is based on the area available to each standing passenger. Dividing this area by the threshold between LOS "E" and "F" (2.2 ft^2 per passenger, from Exhibit 3-26) gives the maximum number of standees allowed by policy.

One can determine the passenger load on each bus from the APC data. This load is the load arriving at the stop, minus the count of passengers getting off, plus the count of passengers getting on. By repeating this process for all stops, one can determine for each sampled run whether the maximum number of standees was exceeded at any given stop. However, because the data represent only one weekday trip made on a given run during the month, one cannot tell whether or not each sampled run is representative of typical conditions for that run.

As an alternative, one can average the results together for the peak hour, and then apply an appropriate peak hour factor to determine whether the maximum number of standees was exceeded during the peak 15 minutes (i.e., the most crowded 3 or 4 buses out of the 13 that operate during the hour).

Steps

1. First, determine the maximum number of standees at LOS "E," given the interior configuration of the agency's buses. The gross interior floor area is estimated by subtracting 8.5 feet from the bus length (an allowance for the engine compartment and the operator's area), and multiplying the result by the bus width. In this case, (40-8.5)*8 is 252 square feet.

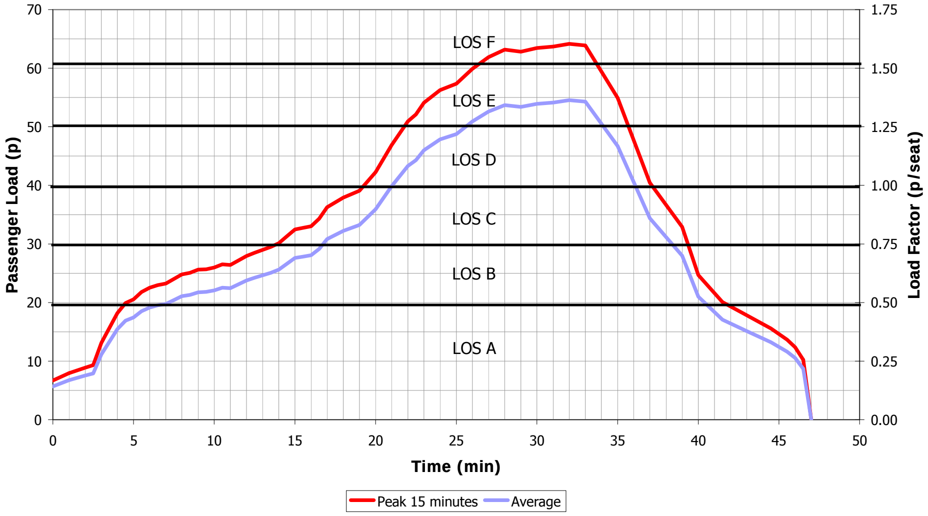
   Next, subtract the area occupied by seats and other objects to determine the net interior floor area available for standees:

Gross interior floor area	252.0 square feet
20 transverse seats at 5.4 square feet each	-108.0 square feet
21 longitudinal seats at 4.3 square feet each	-90.3 square feet
single-channel rear door at 8.6 square feet per channel	-8.6 square feet
Net interior floor area	45.1 square feet

Dividing the net interior floor area (45.1 ft^2) by the minimum space per passenger at LOS "E" (2.2 ft^2/p) gives the maximum number of standees for a maximum schedule load: 20 passengers. Adding this result to the number of seats on the bus gives the maximum schedule load: 61 passengers.

2. The average load at each stop, calculated from the APC data, is plotted against the scheduled departure time from each stop. Plotting load against time helps to visualize how long particular loading conditions occur. Exhibit 3-51 shows the results. As can be seen from the lower curve, an average of 55 passengers are carried at the maximum load section, meeting the standard. However, this result assumes that all passengers are evenly distributed among the buses throughout the hour, which is unlikely to happen.

Exhibit 3-51
Passenger Load Example



Peak hour factors are discussed in Part 4, Bus Transit Capacity.

3. To estimate the average load during the peak 15 minutes, divide the average load for the hour by an appropriate peak hour factor (PHF). Peak hour factors for buses typically range from 0.60 to 0.95, with 0.75 recommended as a default in the absence of other information. However, because the line's schedule already reflects some variations in loading (i.e., the scheduled headways vary from 3 to 6 minutes), a higher PHF is appropriate. Using a PHF of 0.85 produces the upper curve on the graph. It can be seen that the agency loading standard will be exceeded for an average of 6 to 7 minutes at a time on the most heavily loaded three or four buses during the hour.

The Results

Based on this analysis, it appears likely that the agency's loading standard is exceeded on some runs during the a.m. peak hour. As the standard is not exceeded by much, adjusting the headways to even out the loads between buses (thus raising the PHF) might be sufficient to meet the standard. However, some variation in loads would always be expected, resulting from variations in running times due to traffic and other factors. The graph also indicates that standees are present for 15 minutes on average (from the threshold between LOS "C" and "D") and that the first standee would often have to stand for at least 12 minutes before a substantial number of passengers began to get off the bus.

Example Problem 4

The Situation

As part of its 5-year planning process, a transit agency adopted a customer charter expressing a commitment to improving the quality of service provided to its customers. One of the agency's adopted goals is to improve the reliability of the service it provides. As a first step, the agency is reviewing the on-time performance of some of its more popular routes to determine how good a job the agency is currently doing and to determine whether there are areas where it can work to improve performance. This example looks at the evaluation conducted at one timepoint along one of these routes.

The Questions

- What is the on-time performance LOS currently provided, as an average for the day, and during the a.m. peak, midday, and p.m. peak periods?
- Some afternoon buses are scheduled at 10-minute headways, between 3:52 p.m. and 5:02 p.m. What is the headway adherence LOS during that period?
- If needed, what are some areas of improvement to focus on?

The Facts

- The a.m. peak is defined for this route as departures prior to 9:00 a.m., midday is defined as departures from 9:00 a.m. to 3:30 p.m., and the p.m. peak is defined as departures after 3:30 p.m.
- Exhibit 3-52 shows scheduled and actual departure times on the day that data were collected:

Exhibit 3-52
Bus Departure Time Data

A.M. Peak		Midday		P.M. Peak	
Scheduled	**Actual**	**Scheduled**	**Actual**	**Scheduled**	**Actual**
5:06 am	5:06 am	9:06 am	9:06 am	3:52 pm	3:52 pm
5:37 am	5:38 am	9:22 am	9:21 am	4:02 pm	4:05 pm
5:52 am	5:52 am	9:38 am	9:38 am	4:12 pm	4:13 pm
6:06 am	6:07 am	9:54 am	9:56 am	4:22 pm	4:29 pm
6:20 am	6:20 am	10:09 am	10:09 am	4:32 pm	4:32 pm
6:32 am	6:34 am	10:24 am	10:25 am	4:42 pm	4:47 pm
6:47 am	6:48 am	10:39 am	10:39 am	4:52 pm	4:48 pm
7:01 am	7:04 am	10:57 am	10:59 am	5:02 pm	5:02 pm
7:16 am	7:22 am	11:12 am	11:11 am	5:13 pm	5:15 pm
7:32 am	7:38 am	11:25 am	11:25 am	5:26 pm	5:30 pm
7:47 am	7:51 am	11:40 am	11:40 am	5:41 pm	5:46 pm
8:02 am	8:06 am	11:54 am	11:52 am	5:57 pm	6:01 pm
8:17 am	8:20 am	12:09 pm	12:09 pm	6:15 pm	6:17 pm
8:33 am	8:35 am	12:24 pm	12:24 pm	6:33 pm	6:36 pm
8:50 am	8:50 am	12:39 pm	12:40 pm	6:49 pm	6:50 pm
		12:54 pm	12:53 pm	7:06 pm	7:08 pm
		1:10 pm	1:11 pm	7:21 pm	7:23 pm
		1:26 pm	1:25 pm	7:36 pm	7:36 pm
		1:42 pm	1:40 pm		
		1:57 pm	1:58 pm		
		2:12 pm	2:12 pm		
		2:27 pm	2:25 pm		
		2:39 pm	2:41 pm		
		2:49 pm	2:52 pm		
		3:01 pm	3:02 pm		
		3:15 pm	3:15 pm		
		3:30 pm	3:31 pm		

Outline of Solution

A bus is considered "on-time" if it departs no more than 5 minutes after the scheduled time and is not early. By comparing each departure's scheduled and actual departure times, each departure can be classified as "early" (actual departure time before the schedule departure time), "on-time" (actual departure is 0 to 5 minutes after the scheduled time), or "late" (actual departure is more than 5 minutes after the scheduled time). Dividing the number of on-time departures by the total number of departures gives the on-time percentage, which in turn gives the LOS.

Headway adherence LOS will be calculated for the departures between 3:52 and 5:02 p.m. The process here is to first calculate the headway deviation for each departure (the number of minutes the actual headway deviated from the scheduled headway, which is 10 minutes). Next, the coefficient of variation of headways is calculated and the corresponding LOS determined. (Because these frequent departures are scheduled, include them in both the on-time percentage calculation and the headway adherence calculation.)

Steps

1. For each departure, determine whether it is on-time, early, or late. For example, the scheduled 6:47 a.m. departure actually left at 6:48 p.m., which is considered on-time; the scheduled 7:32 a.m. departure left at 7:38 a.m., which is considered late; and the scheduled 1:42 p.m. departure left at 1:40 p.m., which is considered early.

   During the a.m. peak period, the scheduled 7:16 a.m. and 7:32 a.m. departures were late, while the other 13 departures were on-time. The corresponding on-time percentage, 13/15, is 87%, or LOS "C."

   During the midday period, the scheduled 9:22 a.m., 11:12 a.m., 11:54 a.m., 12:54 p.m., 1:26 p.m., 1:42 p.m., and 2:27 p.m. departures all left early, while the other 20 departures were on-time. The on-time percentage in this case, 20/27, is 74%, or LOS "F."

   During the p.m. peak period, the scheduled 4:22 p.m. departure was late and the scheduled 4:52 p.m. departure was early, while the other 16 departures were on time. The corresponding on-time percentage, 16/18, is 89%, or LOS "C." For the day as a whole, 49 of 60 buses were on time (82%), equivalent to LOS "D."

2. The headways between the buses scheduled to depart between 3:52 and 5:02 p.m. are 13, 8, 16, 3, 15, 1, and 14 minutes. The corresponding headway deviations are +3, -2, +6, -7, +5, -9, and +4 minutes. The sum of these values (Σx_i) is 0 and the square of the sum ($(\Sigma x_i)^2$) is 0. The sum of the squares of the values (Σx_i^2) is 220 (e.g., $3^2 + (-2)^2 + \ldots + (4)^2$). There are 7 observations, so use the sample standard deviation:

   $$s = \sqrt{\frac{\sum x_i^2 - \frac{\left(\sum x_i\right)^2}{n}}{n-1}} = \sqrt{\frac{220 - \frac{0}{7}}{6}} = 6.06$$

   The coefficient of variation of headways is the standard deviation divided by the average scheduled headway, 6.06 / 10, or 0.61, equivalent to LOS "E." As can be seen from Exhibit 3-52, several buses arrived bunched together.

The Results

An obvious way to improve on-time performance at this location is to control early running. If the early trips were eliminated, on-time performance for the day would increase to 93%, equivalent to LOS "B." Another area to focus on is maintaining the evenness of the interval between the buses scheduled at 10-minute headways. Because several buses were bunched, it is likely that the lead bus in each case experienced overcrowding, while the following bus had unused capacity.

Example Problem 5

The Situation

As part of a regional study of traffic congestion, the Anytown MPO wishes to compare existing travel times by transit and auto to help determine where transit service improvements or transit priority measures may be needed to help make transit service more competitive with the automobile.

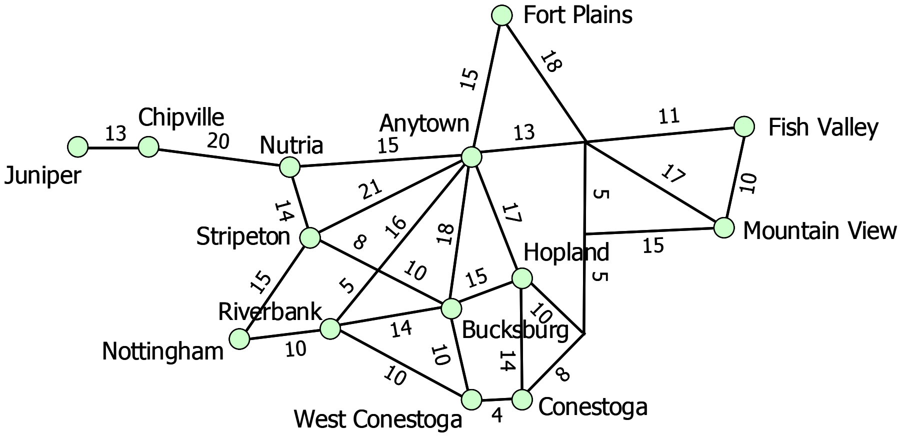
The Question

What are comparative travel times by transit and auto between city centers in the region during the a.m. peak hour, and what is the corresponding LOS?

The Facts

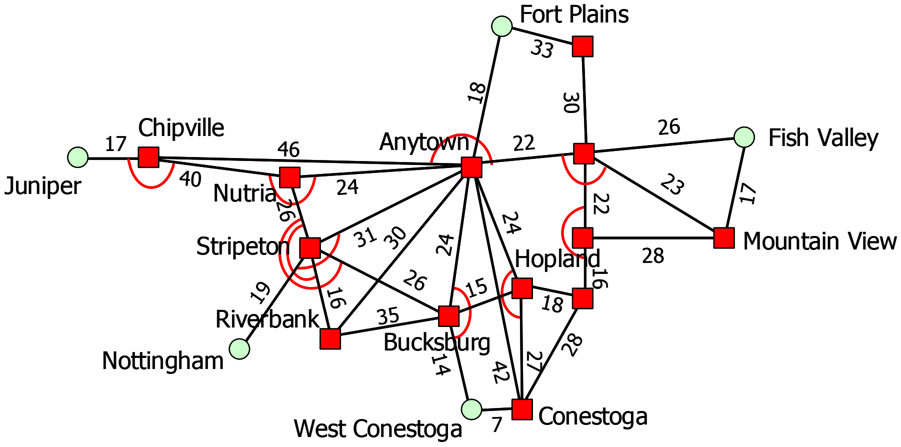
Travel time data for key regional roadways were collected by driving each of the links several times during the a.m. peak hour. The average results of these travel time runs are shown in Exhibit 3-53, giving peak direction travel times in minutes.

Exhibit 3-53
Auto Travel Times



Current scheduled peak direction transit travel times are shown in Exhibit 3-54. Transfers occur at locations marked by squares. "Bypasses" shown on the map indicate trips where no transfer needs to be made.

Exhibit 3-54
Transit Travel Times



The following additional information is known:

- Passengers average 3 minutes of walking at each end of their trip.
- Wait time for transit is assumed to be 5 minutes at the start of a trip.
- Each transfer is assumed to add 10 minutes to a trip.
- Auto trips to Anytown add 5 minutes on average for parking in garages, and 3 minutes average walk time from garages to offices.
- Plentiful free parking is available at all work locations outside Anytown.
- Congestion in central Nutria adds 5 minutes to access the freeway system from Nutria by car.

Outline of Solution

Door-to-door travel times will be calculated between each location, first by automobile, and then by transit. These times include actual in-vehicle time, from the maps on the preceding page, plus the adjustments listed above for access to and from each mode. The transit-auto travel time difference will be calculated by subtracting the auto time from the transit time, and the LOS determined from the result.

Steps

1. Determine the door-to-door peak direction auto travel time between each pair of locations. For example, from Chipville to Anytown, this time includes 35 minutes of in-vehicle time (tracing a path from the map), plus 5 minutes parking time, plus 3 minutes walking time, for a total of 43 minutes. The other results, in minutes are listed below:

	Nutria	Jun	Mtn V	Chip	Buck	Hop	Con	Fish V	Not	Str	Riv	Ft P	W Con
Any	28	56	38	43	26	25	39	32	39	29	29	23	36
Nutria		38	50	25	37	37	46	44	34	19	32	35	42
Jun			78	13	65	65	74	72	62	47	60	63	70
Mtn V				65	42	30	28	10	52	51	42	35	32
Chip					52	52	61	59	49	34	47	50	57
Buck						15	14	42	24	18	14	33	10
Hop							14	31	39	33	29	32	18
Con								29	24	27	14	36	4
Fish V									55	45	45	29	33
Not										15	10	46	20
Str											13	36	23
Riv												36	10
Ft P													40

2. Determine the door-to-door peak direction transit travel time between each pair of locations. For example, from Fish Valley to Anytown, this time includes 48 minutes of in-vehicle time (tracing a path from the map), a total of 6 minutes of walking time at both ends of the trip, 5 minutes wait time at the start of the trip, and 10 minutes of transfer time, for a total of 69 minutes. The other results, in minutes, are listed below:

	Nutria	Jun	Mtn V	Chip	Buck	Hop	Con	Fish V	Not	Str	Riv	Ft P	W Con
Any	35	84	56	57	35	35	53	69	61	42	41	29	49
Nutria		68	90	51	63	69	76	103	66	37	53	63	83
Jun			129	28	118	118	136	142	133	104	120	112	132
Mtn V				102	90	90	103	28	116	97	96	84	104
Chip					91	91	109	115	116	87	97	85	105
Buck						26	32	103	66	37	46	63	25
Hop							38	103	91	62	71	63	50
Con								121	97	68	77	81	18
Fish V									129	110	109	97	117
Not										30	56	89	90
Str											27	70	61
Riv												69	70
Ft P													77

3. Subtract the auto travel times from the transit travel times. For example, the auto travel time from Chipville to Anytown is 43 minutes, the transit travel time is 57 minutes, and the difference is 14 minutes, equivalent to LO S "B." The results, in minutes and LOS, for all trip combinations are shown below:

	Nutria	Jun	Mtn V	Chip	Buck	Hop	Con	Fish V	Not	Str	Riv	Ft P	W Con
Any	7	28	18	14	9	10	14	37	22	13	12	6	13
Nutria		30	40	26	26	32	30	59	32	18	21	28	41
Jun			51	15	53	53	62	70	71	57	60	49	62
Mtn V				37	48	60	75	18	64	46	54	49	72
Chip					39	39	48	56	67	53	50	35	48
Buck						11	18	61	42	19	32	30	15
Hop							24	72	52	29	42	31	32
Con								92	73	41	63	45	14
Fish V									74	65	64	68	84
Not										15	46	43	70
Str											14	34	38
Riv												33	60
Ft P													37

	Nutria	Jun	Mtn V	Chip	Buck	Hop	Con	Fish V	Not	Str	Riv	Ft P	W Con
Any	B	C	C	B	B	B	B	D	C	B	B	B	B
Nutria		C	D	C	C	D	C	E	D	C	C	C	D
Jun			E	B	E	E	F	F	F	E	E	E	F
Mtn V				D	E	E	F	C	F	E	E	E	F
Chip					D	D	E	E	F	E	E	D	E
Buck						B	C	F	D	C	D	C	B
Hop							C	F	E	C	D	D	D
Con								F	F	D	F	D	B
Fish V									F	F	F	F	F
Not										B	E	D	F
Str											B	D	D
Riv												D	E
Ft P													D

The Results

The radial route pattern serving Anytown provides good levels of service (LOS "B" or "C") from everywhere within the metro area except Fish Valley. Service between suburbs is generally poor, as is often the case with a radial pattern, although some suburbs (e.g., Nutria) have relatively good service. Because of the high number of transfers involved, transit travel times from Fish Valley are very high compared with the automobile, making transit an unattractive option for potential riders.

Possible service improvements to consider include:

- Provide express service from distant suburbs to Anytown to reduce travel times.
- Expand cross-town routes between suburbs where demand warrants.
- Decrease the number of transfers required or improve timed transfers to reduce the average wait time when transferring between routes.
- Establish transit priority measures on high-volume routes serving Anytown to make travel times even more competitive with the automobile.

Naturally, the potential demand for the service improvements would need to be taken into consideration, along with the cost of those improvements.

Example Problem 6

The Situation

The Marbleton Transit Authority has developed a good working relationship with the City of Marbleton, and the city routinely gives extra priority to public works projects, such as sidewalk and pedestrian crossing improvements that provide transit benefits. The two agencies are currently evaluating Route 29, which runs parallel to an elevated freeway, to see what kinds of improvements, if any, might provide better access to transit.

The Question

What is Route 29's service coverage area, compared with the ideal?

The Facts

Exhibit 3-55 shows a map of the study area. Exhibit 3-56 lists the traffic volumes and geometric characteristics (street width and median type) for the streets used by the route. There are two traffic signals in the area: one at the intersection of Spring Park Road and Spring Glen Road, which has a 90-second cycle length, and one at the intersection of Barnes Road and University Boulevard, which has a 180-second cycle length. All of the streets are undivided, although Barnes Road South has a two-way left-turn lane, so that pedestrians have to cross the equivalent of three lanes. The area is flat, and the senior population forms less than 20% of the total area population.

Exhibit 3-55
Study Area Map

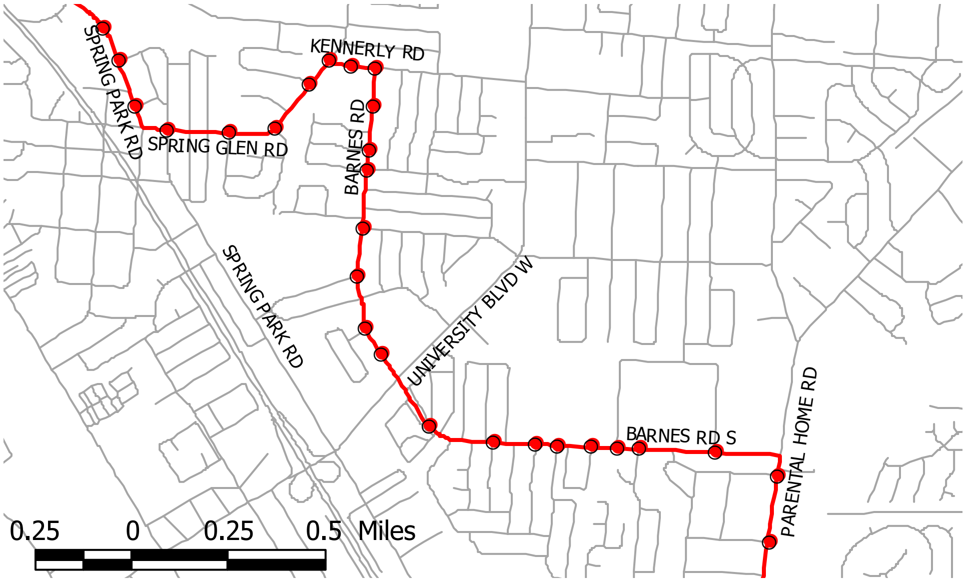


Exhibit 3-56
Street Data

Street Name	Peak Hour Traffic Volume (veh/h)	Street Width (lanes)
Spring Park Road	350	2
Spring Glen Road	1,150	2
Kennerly Road	500	2
Barnes Road North	550	2
Barnes Road South	1,000	3
Parental Home Road	1,300	2

Outline of Solution

The detailed service coverage method will be used to identify the effective area served by each bus stop, accounting for the street pattern, the difficulty pedestrians have crossing streets, and any other applicable factors. The relative contribution of each factor to the reduction in coverage area will be determined. Finally, the size of the reduced service coverage area will be compared with the size of the ideal service coverage area.

Steps

1. The TCQSM uses 0.25 mile as the ideal radius served by a local bus stop. Equation 3-2 will be used to determine the reduction in this radius due to the following four factors: street connectivity factor, grade (terrain), population characteristics, and pedestrian crossing difficulty.
2. Comparing the map of the study area with the street pattern types depicted in Exhibit 3-18, it appears that the street pattern most closely resembles the Type 2 (hybrid) pattern. The street network does not form a grid; yet, there is some connectivity provided and relatively few dead-end streets and culs-de-sac. From Exhibit 3-19, the street connectivity factor for a Type 2 pattern is 0.85.
3. The area is flat, so the grade factor is 1.00.
4. Less than 20% of the area's population is elderly; therefore, the population factor is 1.00.
5. To determine the pedestrian crossing factor, first find out how much delay pedestrians encounter while crossing streets. For example, Barnes Road South has a traffic volume of 1,000 vehicles per hour and a three-lane width. From Exhibit 3-24, the average pedestrian delay is 100 seconds. Subtracting 30 seconds from this result gives the amount of excess pedestrian delay at this location—70 seconds. The results for all unsignalized crossings are listed below:

Street Name	Average Pedestrian Delay (s/ped)	Excess Pedestrian Delay (s/ped)
Spring Park Road	5	0
Spring Glen Road	44	14
Kennerly Road	9	0
Barnes Road North	10	0
Barnes Road South	100	70
Parental Home Road	60	30

For the two signalized intersections, Equation 3-4 should be used. In the absence of other information, we will use an effective green time of 11 seconds (7 seconds of WALK time, plus four seconds of flashing DON'T WALK). At the Spring Park/Spring Glen intersection, the traffic signal cycle length is 90 seconds. Applying this information to Equation 3-4 gives the following average pedestrian delay, in seconds:

$$d_p = \frac{0.5(C-g)^2}{C} = \frac{0.5(90-11)^2}{90} = 35\,\mathrm{s}$$

The excess delay is 30 seconds less, or 5 seconds. Performing the same calculation for the Barnes/University intersection produces an average pedestrian crossing delay of 80 seconds and an excess delay of 50 seconds.

6. Next, we will apply Equation 3-3 to determine the pedestrian crossing factor. Using Barnes Road South as an example, with 70 seconds of excess delay, the pedestrian factor is:

$$f_{px} = \sqrt{\left(-0.0005d_{ec}^2 - 0.1157d_{ec} + 100\right)/100}$$

$$f_{px} = \sqrt{\left(-0.0005(70)^2 - 0.1157(70) + 100\right)/100}$$

$$f_{px} = 0.95$$

   Although this factor may seem small, keep in mind that the area served is reduced in proportion to the square of the radius. The square of 0.95 is 0.90; thus the area served by stops along Barnes Road South is reduced by 10% from the ideal. This reduction is equivalent to one LOS grade if the area is transit-supportive.

   The other pedestrian crossing factors are as follows:

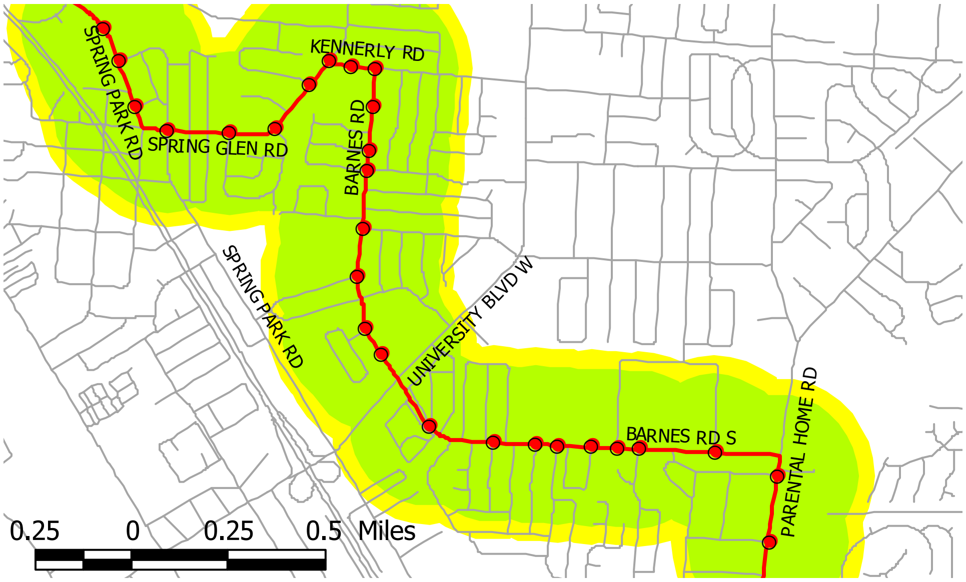
   - Spring Park Road: 1.00
   - Spring Glen Road (signalized intersection): 1.00
   - Spring Glen Road (unsignalized intersections): 0.99
   - Kennerly Road: 1.00
   - Barnes Road North (signalized intersection): 0.96
   - Barnes Road North (unsignalized intersections): 1.00
   - Parental Home Road: 0.98

7. The last step is to calculate each stop's service radius, by multiplying 0.25 miles by the four factors. The results are as follows:

Street Name	**Combined Factors**	**Adjusted Radius (mi)**
Spring Park Road	0.85	0.213
Spring Glen Road-signalized	0.85	0.213
Spring Glen Road-unsignalized	0.84	0.210
Kennerly Road	0.85	0.213
Barnes Road North-signalized	0.82	0.205
Barnes Road North-unsignalized	0.85	0.213
Barnes Road South	0.81	0.203
Parental Home Road	0.83	0.208

8. In GIS, each stop can be buffered by the adjusted radius and the resulting service coverage area compared with the ideal area developed using a 0.25-mile radius. (No adjustment was made where the buffer crosses the freeway, as access underneath the elevated freeway is possible, as shown on the map.) The results are shown in Exhibit 3-57. The inner shaded area shows the adjusted service coverage area, while the outer shaded area shows the ideal area. Although visually the two areas do not seem that much different, in reality, the reduced area is 18% smaller than the ideal area. This difference is approximately equal to two LOS grades if the area is transit-supportive.

Exhibit 3-57
Reduced Service Coverage Area



The Results

The adjusted service coverage area is 18% smaller than the ideal service coverage area. Based on the relationships developed in Part 3 between average walking distances to transit and the number of people served, this result indicates that 18% fewer people are assumed to be served by this section of the route due to less-than-ideal street network patterns and street crossing delays.

In this example, the biggest impact on service coverage was due to the street pattern. Because this area is already developed, there is not much that can be done in the short term to improve pedestrian connectivity. (Longer term, zoning provisions to require more pedestrian connectivity as land redevelops could be considered.) However, lessons learned in this area could be applied in areas of Marbleton that have yet to be developed and that could be developed with better pedestrian connections.

In terms of pedestrian crossing difficulty, Barnes Road South and Parental Home Road are the most difficult to cross, with average delays of 60 to 100 seconds. From a delay standpoint, extra priority to pedestrian improvements could be considered here (other factors, such as safety—for example, due to high vehicle speeds or poor sight distances—should also be considered when prioritizing improvements).

Example Problem 7

The Situation

The operator of general public demand-responsive transit services in Livingston County wants to evaluate how well they provide service to their users. In particular, an agency goal is to ensure that every passenger with a time-sensitive appointment (e.g., a medical appointment or a school or work trip) is delivered to his or her destination no later than the scheduled time.

The Question

What is the agency's LOS for availability and for reliability in delivering passengers to their destination?

The Facts

Exhibit 3-58 shows a map of the county, while Exhibit 3-59 shows service and population statistics for its communities. Dial-a-ride service is available Monday through Friday in the county seat, Chillicothe. The southwestern portion of the county receives service once per week, while the northeastern portion of the county receives service twice per month. The van will deviate up to 5 miles from the route to pick up and drop off passengers on services from the outer parts of the county into Chillicothe.

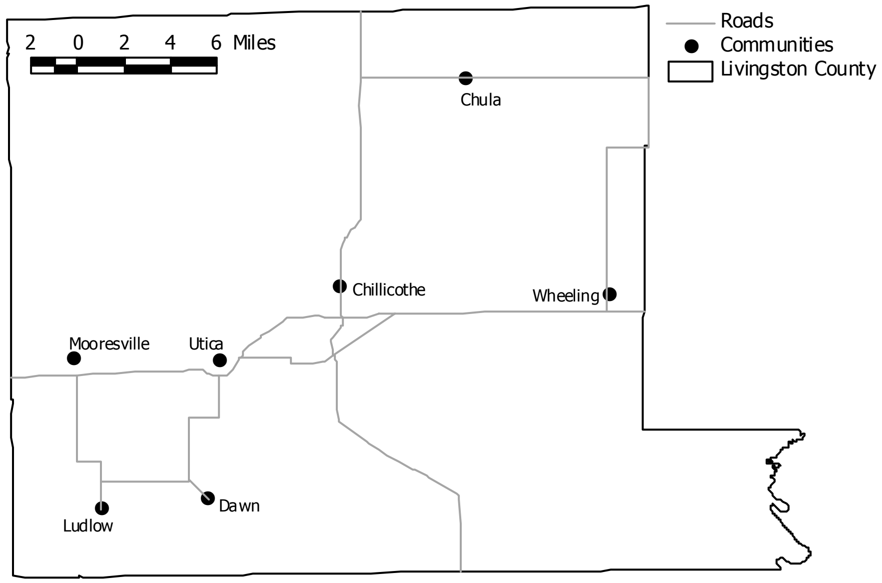


Exhibit 3-58
Livingston County

Exhibit 3-59
Livingston County Service Data

Location	Population	Days Served	Service Hours
Chillicothe	8,799	weekdays	6 am to 6 pm
Chula	183	first & third Thursdays	8 am to 5 pm
Dawn	25	Fridays	8 am to 5 pm
Ludlow	147	Fridays	8 am to 5 pm
Mooresville	100	Fridays	8 am to 5 pm
Utica	299	Fridays	8 am to 5 pm
Wheeling	284	first & third Thursdays	8 am to 5 pm
remainder of county	4,755	same as nearest community, if within 5 miles of the route	

Passengers outside Chillicothe must call no later than the day before to reserve a ride. At present, enough capacity is available to accommodate all passengers who request a ride a day in advance. Passengers within Chillicothe can call the same day for service, although the majority of trips are standing orders. A review of response times for requests for immediate service within Chillicothe found that nearly all could be served within 30 minutes.

Exhibit 3-60 compares scheduled and actual drop-off times for time-sensitive trips within Chillicothe on 2 days.

Exhibit 3-60
Arrival Time Data for Time-Sensitive Trips

Day 1		Day 2	
Scheduled	Actual	Scheduled	Actual
7:00 am	6:30 am	6:45 am	6:35 am
7:00 am	6:35 am	8:00 am	7:40 am
8:00 am	7:45 am	8:30 am	8:25 am
8:00 am	7:45 am	8:30 am	8:30 am
8:00 am	7:45 am	8:30 am	8:45 am
9:00 am	8:45 am	9:00 am	8:50 am
9:00 am	8:45 am	9:00 am	8:55 am
9:00 am	8:55 am	9:30 am	9:25 am
10:00 am	9:55 am	10:15 am	10:05 am
11:00 am	10:45 am	10:30 am	10:10 am
11:00 am	10:55 am	1:15 pm	1:15 pm
12:00 pm	11:35 am	1:30 pm	1:35 pm
1:00 pm	12:45 pm	1:45 pm	1:35 pm
3:00 pm	2:50 pm	2:00 pm	1:40 pm
3:00 pm	2:50 pm	2:15 pm	2:00 pm
4:00 pm	3:30 pm	2:30 pm	2:20 pm
		4:00 pm	3:50 pm

Outline of Solution

All of the information required to answer the questions has been provided. Response time LOS can be determined from the dispatcher's records of call-in times and the drivers' records of pick-up times. Service span LOS can be determined from the published schedule. On-time performance LOS can be determined from the drivers' records of scheduled and actual drop-off times.

Steps

1. Exhibit 3-32 will be used to determine response time LOS. Within Chillicothe, the average passenger requesting immediate service can be picked up within 30 minutes, which equates to LOS "1." For service from other communities, the agency policy is to reserve a ride no later than the day before. Since there is adequate capacity to meet all trip requests (i.e., no capacity constraints), the LOS for these areas is "4."
2. Exhibit 3-33 will be used to calculate service span LOS. Within Chillicothe, service is available 5 days per week, 12 hours per day, equivalent to LOS "3." The southwestern portion of the county receives service once per week, for 9 hours per day, equivalent to LOS "6." The northeastern portion of the county receives service twice per month, for 9 hours per day, equivalent to LOS "7." The remainder of the county has no service to Chillicothe and thus is at LOS "8." Exhibit 3-61 shows the results in the form of a map.

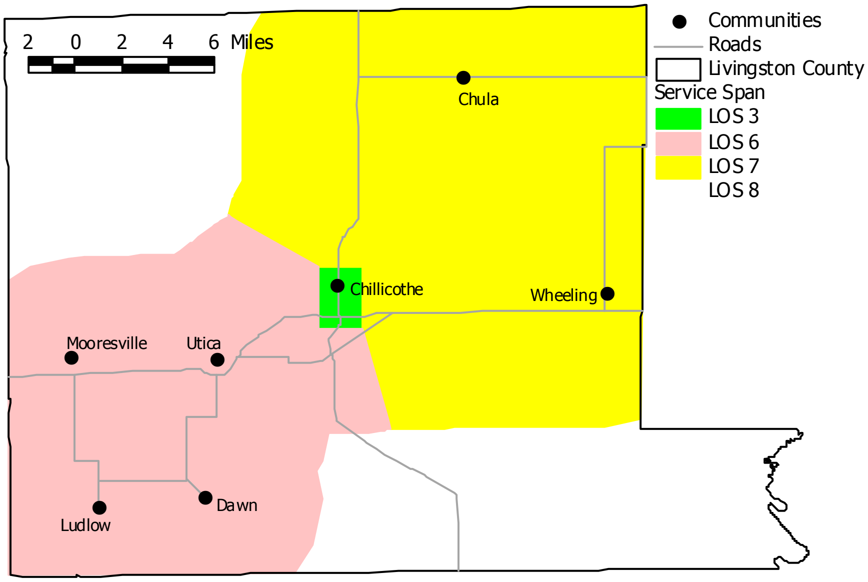


Exhibit 3-61
Service Span LOS Results

The results can also be expressed in terms of the number of people who receive service, as shown in Exhibit 3-62. The southwestern route serves about 30% of the county, while the northeastern route serves about 40% of the county. Assuming that the rural population is spread evenly about the county, the number of county residents living outside communities who receive service can be estimated.

Exhibit 3-62
Livingston County Service Data

LOS	Locations	Population	% of County Pop.
3	Chillicothe	8,799	60%
6	Dawn Ludlow Mooresville Utica rural SW county	1,998	14%
7	Chula Wheeling rural NE county	2,186	15%
8	rural NW & SE county	1,609	11%

3. Of the 33 time-sensitive trips studied, only twice did the passenger arrive after the scheduled time (Day 2, an 8:45 a.m. arrival for an 8:30 a.m. appointment, and a 1:35 p.m. arrival for a 1:30 p.m. appointment). The resulting on-time percentage is 93.9%, which is equivalent to LOS "3," from Exhibit 3-34.

The Results

Residents of Chillicothe have very good DRT service: service is available for one-half of the day on weekdays, and those riders who need immediate service are able to get it. About three-quarters of the county's residents outside Chillicothe have some service, with one-half of those people having access to at least weekly service. About one-quarter of the county's residents have no access to transit service.

The LOS "3" for on-time performance indicates that the agency is doing a relatively good job at getting its customers to their time-sensitive appointments on time.

This page is intentionally blank.

APPENDIX A: EXHIBITS IN METRIC UNITS

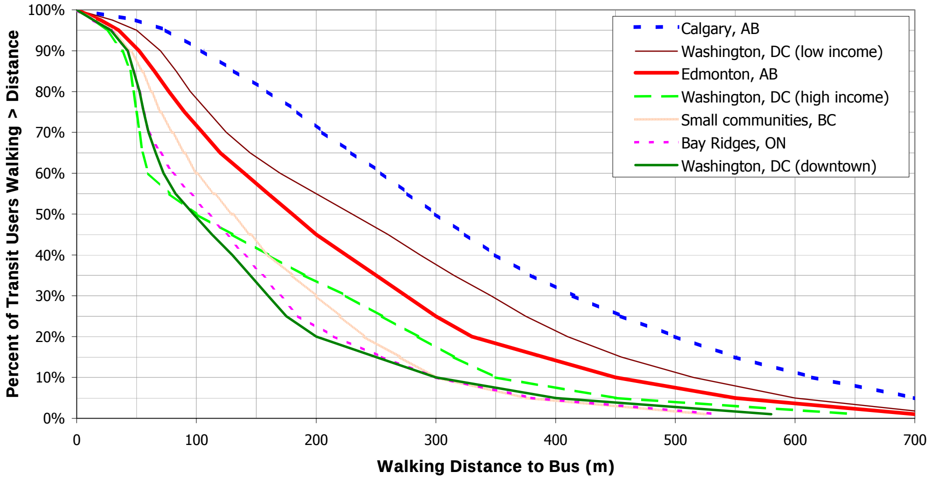


Exhibit 3-5m
Walking Distance to Bus Stops(R3,R20,R29,R36)

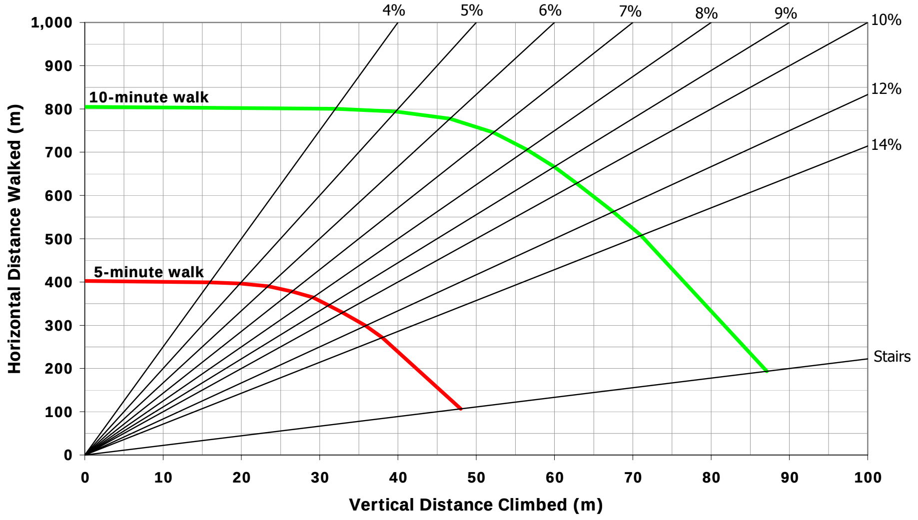


Exhibit 3-6m
Effect of Grade on Distance Walked(R23)

This page is intentionally blank.

PART 4
BUS TRANSIT CAPACITY

CONTENTS

LIST OF EXHIBITS

This page is intentionally blank.

CHAPTER 1. BUS CAPACITY FUNDAMENTALS

OVERVIEW

Bus capacity is a complex topic: it deals with the movement of both people and vehicles, depends on the size of the buses used and how often they operate, and reflects the interaction between passenger traffic concentrations and vehicle flow. It also depends on the operating policy of the service provider, which normally specifies service frequencies and allowable passenger loadings. Ultimately, the capacities of bus routes, bus lanes, and bus terminals, in terms of persons carried, are generally limited by (1) the ability of stops or loading areas to pick up and discharge passengers, (2) the number of vehicles operated, and (3) the distribution of boardings and alightings along a route.

Organization of Part 4.

Part 4 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents methods for calculating bus capacity and speed for a variety of facility and operating types.

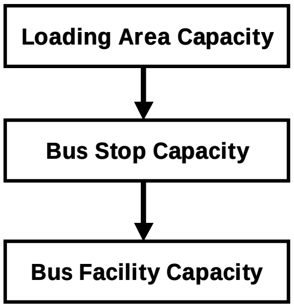
- *Chapter 1* introduces the basic factors that determine bus capacity.
- *Chapter 2* discusses transit preferential treatments and operating measures that influence bus performance.
- *Chapter 3* presents planning applications that can be used to determine the effects of transit priority measures.
- *Chapters 4 through 6* discuss busways, freeway HOV lanes, arterial street bus lanes, and operations in mixed traffic.
- *Chapter 7* presents issues related to demand-responsive transportation.
- *Chapter 8* contains the references used within this part of the manual.
- *Chapter 9* presents example problems that apply Part 4 procedures to “real world” situations.
- *Appendix A* provides substitute exhibits in metric units for Part 4 exhibits that use U.S. customary units.
- *Appendix B* provides a standardized procedure for collecting bus dwell time data in the field.
- *Appendix C* presents information of interest to users of the *Highway Capacity Manual* on determining bus effects on adjacent lane vehicle capacity.
- *Appendix D* provides planning-level graphs applying the bus stop and lane capacity procedures presented in this part of the TCQSM.
- *Appendix E* discusses the effects of bus bunching on bus capacity.

Exhibits also appearing in Appendix A are indicated by a margin note such as this.

CAPACITY CALCULATION PROCESS

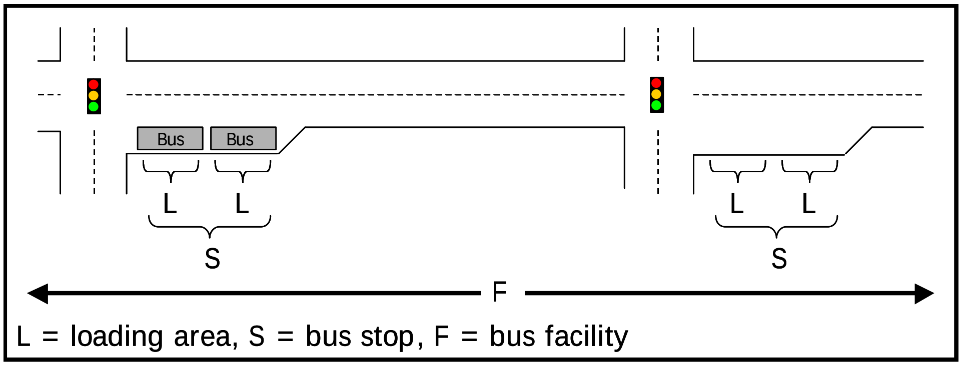
Bus capacity is calculated for three key locations:

1. *Bus loading areas (berths)* are curbside spaces where a single bus can stop to load and unload passengers.
2. *Bus stops* are formed from one or more loading areas, depending on how many buses can use the stop simultaneously.
3. *Bus facilities* are roadways used by buses and may contain multiple bus stops along their length.



Bus stop capacity is dependent on the individual capacities of the loading areas that form the bus stop. Similarly, a bus facility’s capacity will be constrained by the capacity of the *critical stop* along the facility, which is typically the stop with the highest passenger volumes and the longest dwell time. Exhibit 4-1 shows the relationships of loading areas, stops, and facilities.

Exhibit 4-1
Bus Loading Areas, Stops, and Facilities



Loading Areas

The bus capacity of a loading area is dependent on the following factors:

Dwell time plus clearance time equals the average time a given bus occupies a loading area.

- *Dwell time*—the average amount of time a bus is stopped at the curb to serve passenger movements, including the time required to open and close the doors;
- *Clearance time*—the minimum time required for one bus to accelerate out of and clear the loading area and the next bus to pull into the loading area, including any time spent waiting for a gap in traffic;
- *Dwell time variability*—the consistency (or lack thereof) of dwell times among buses using the loading area; and
- *Failure rate*—the probability that one bus will arrive at a loading area, only to find another bus already occupying it.

Dwell time variability and failure rate account for longer-than-average dwells so that one bus typically does not delay the one behind it.

The combination of dwell time and clearance time gives the average amount of time an individual bus occupies the loading area. The combination of dwell time variability and a design failure rate provides an additional margin of time to ensure that most buses will be able to immediately use the loading area upon arriving. Adding these two combinations together produces the minimum headway between buses required to avoid interference between buses. Dividing this headway into the number of seconds in an hour gives the number of buses per hour that can use the stop—the *loading area capacity.*

Bus Stops

The bus capacity of a bus stop is based on the following:

- *Number of loading areas provided*—two loading areas will be able to accommodate more buses than a single loading area, but not necessarily two times as many;
- *Loading area design*—how the loading areas are designed determines how much extra capacity each additional loading area will provide; and
- *Traffic control*—traffic signals may constrain the number of buses that can leave (or enter) a stop during a given period of time. If a bus is ready to leave a stop, but a red traffic signal prevents it from doing so, the bus will occupy the stop longer, and the bus stop capacity will be lower as a result.

Traffic signals limit when buses are able to enter or exit stops located nearby, and thus they constrain capacity.

Bus Facilities

The capacity of an on-street bus facility is based on the following:

- *Critical bus stop capacity*—the bus stop with the lowest capacity along the facility will constrain how many buses can pass through it. This bus stop is usually the stop with the longest dwell time, but heavy right-turning traffic volumes at near-side bus stops or a traffic signal that provides only a short period of green time for the bus facility can also be constraints.
- *Operational procedures*—bus route design that spreads bus stopping activity over a group of stops (*skip-stops*), rather than having all buses stop at the same set of stops, can greatly increase the capacity of an on-street facility.

The bus stop with the lowest capacity—the "critical stop"—constrains facility capacity.

The capacity of freeway high-occupancy vehicle (HOV) lanes, where buses do not stop along the lanes, is generally not an issue. The number of buses that can use an HOV lane will be constrained by the capacity of a bus terminal or on-street facility before or after the lane. When an HOV lane is shared with a large number of other vehicles, the *Highway Capacity Manual* can be used to determine the total number of vehicles or passenger car equivalents that can use the lane before it becomes congested.

The number of buses that can use non-stop facilities such as HOV lanes is usually constrained by on-street facilities or off-street terminals elsewhere.

Person Capacity

The maximum number of people that can be transported through the facility during a given time period can be determined from the following:

- *Bus capacity of the facility*—the number of buses that can use the facility during a given period of time;
- *Maximum schedule load of the buses using the facility*—the maximum number of people aboard each bus using the facility; and
- *Passenger demand characteristics*—not all of the offered capacity will be used, as passengers will arrive at uneven rates, and service should be designed so as not to pass up any passengers. A *peak hour factor* is used to reduce the *theoretical* capacity (i.e., the number of buses per hour multiplied by the number of people per bus) to a *person capacity* that can be achieved on a sustained basis day after day.

Once the maximum number of buses that can use a facility in a given time is known, the number of people that can be transported by those buses can be readily calculated.

LOADING AREA BUS CAPACITY

Dwell Time

The capacity of individual loading areas is fundamental to determining the capacities of bus stops and facilities. In turn, the average dwell times at loading areas are fundamental to determining the capacities of those areas.

Dwell time is the most important component of loading area, bus stop, and facility capacity.

Dwell times may be governed by boarding demand (e.g., in the p.m. peak period when relatively empty buses arrive at a heavily used stop), by alighting demand (e.g., in the a.m. peak period at the same location), or by total interchanging passenger demand (e.g., at a major transfer point). In all cases, dwell time is proportional to the boarding and/or alighting volumes and the amount of time required to serve each passenger.

There are five main factors that influence dwell time. Two of these relate to passenger demand, while the other three relate to passenger service times:

- *Passenger Demand and Loading.* The number of people passing through the *highest-volume* door is a key factor in how long it will take for all passengers to be served. The proportion of alighting to boarding passengers through the busiest door also affects how long it takes all passenger movements to occur.

The highest-volume door generally determines how long it takes to serve all boarding or alighting passengers.

- *Bus Stop Spacing.* The smaller the number of stops, the greater the number of passengers boarding at a given stop. A balance is required between providing too few stops, each with relatively high dwell times and relatively long passenger walk times, and providing too many stops (which reduce overall travel speeds due to the time lost in accelerating, decelerating, and possibly waiting for a traffic signal every time a stop is made).

Fare payment method strongly influences dwell time.

- *Fare Payment Procedures.* The average time to pay a fare is a major influence on the time required to serve each boarding passenger. Some types of fare-payment procedures allow passengers to board through more than one door at busy stops, thus allowing all passengers to be served more quickly.

Passengers stopping to ask bus operators questions also impacts dwell time, particularly for tourist-oriented services. Providing information at stops about how to ride and places to go can help.

- *Vehicle Types.* Having to ascend or descend steps while getting on and off the bus increases the amount of time required to serve each passenger.
- *In-Vehicle Circulation.* When standees are present on a bus, it takes more time for boarding passengers to clear the farebox area, as other passengers must move to the back of the bus.

Wheelchair and bicycle boarding times may also need to be considered when calculating dwell time, but are accounted for by dwell time variability when they occur infrequently.

Dwell time can also be affected by the time required for wheelchair loading and securement and for bicyclists to use bus-mounted bicycle racks. However, unless these activities occur regularly at a given stop, they can be treated as random events that are addressed by dwell time variability (i.e., a wheelchair loading will result in a longer-than-average dwell time when it occurs, but these events happen rarely).

A double-stream (two-channel) door is wide enough to allow two passengers to use it at the same time.

Combinations of these factors can substantially reduce dwell times. In the late 1990s, Denver's 16th Street Mall shuttle operation maintained 75-second peak headways with scheduled 12.5-second dwell times, despite high peak passenger loads on its 70-passenger buses.[1] This was accomplished through a combination of fare-free service, few seats (passenger travel distances are short), low-floor buses, and three double-stream doors on the buses.

Estimating Dwell Time

Three methods can be used to estimate bus dwell times:

1. *Field measurements*—best for evaluating an existing bus route;
2. *Default values*—suitable for future planning when reliable estimates of future passenger boarding and alighting volumes are unavailable; and
3. *Calculation*—suitable for estimating dwell times when passenger boarding and alighting counts or estimates are available.

Method 1: Field Measurements

Best for evaluating existing bus routes. See Appendix B for details.

The most accurate way to determine bus dwell times at a stop is to measure them directly. An average (mean) dwell time and its standard deviation can be determined from a series of observations. Appendix B presents a standardized methodology for measuring bus dwell times in the field.

Method 2: Default Values

Suitable for future planning when reliable passenger estimates are unavailable.

If field data or passenger counts are unavailable for a bus stop, the following representative values can be used to estimate dwell time at the critical (busiest) stop: 60 seconds at a downtown stop, transit center, major on-line transfer point, or major park-and-ride stop; 30 seconds at a major outlying stop; and 15 seconds at a typical outlying stop.(R26)

---

[1] Denver's Regional Transit District (RTD) began using 116-passenger hybrid electric/ compressed natural gas buses in 1999 to accommodate growing passenger demand for this service.

Method 3: Calculation

This method requires that passenger counts or estimates be available, categorized by the number of boarding and alighting passengers.

Suitable when passenger counts or estimates are available.

Step 1: Obtain hourly passenger volume estimates. These estimates are required only for the highest-volume stops. When skip-stop operations are used (see Chapter 2), estimates are needed for the highest-volume stops in each skip-stop sequence.

Step 2: Adjust hourly passenger volumes for peak passenger volumes. Equation 4-1 shows the peak hour factor (PHF) calculation method. Typical peak hour factors range from 0.60 to 0.95 for transit lines.(R18,R40) In the absence of other information, 0.75 may be used as a default PHF for bus service where the schedule is not adjusted to accommodate peaks in demand (e.g., when clock headways are used). When headways are adjusted to serve predictable peaks in demand, a PHF of 0.85 may be used as a default. A PHF close to 1.0 may well indicate system overload (underservicing) and reveal the potential for more service. If buses operate at longer than 15-minute headways, the denominator of Equation 4-1 should be adjusted appropriately (e.g., $3P_{20}$ for 20-minute headways). Equation 4-2 adjusts hourly passenger volumes to reflect peak-within-the-peak conditions.

Peak hour factors are used (1) to develop equivalent hourly volumes based on peak 15-minute demands, and (2) adjust person capacities to reflect variations in passenger demand over the course of an hour.

Equation 4-1

$$PHF = \frac{P_h}{4P_{15}}$$

Equation 4-2

$$P_{15} = \frac{P_h}{4(PHF)}$$

where:

PHF = peak hour factor;

P_h = passenger volume during the peak hour (p); and

P_{15} = passenger volume during the peak 15 minutes (p).

Peak hour factors range from 0.25 (all passenger demand occurs during a single 15-minute period in an hour) to 1.00 (demand is constant throughout the hour).

Step 3: Determine the base passenger service time. Exhibit 4-2 can be used to estimate these times for typical situations where only one direction of passengers uses a door at a time and all passengers board through a single door. When passengers may board through multiple doors (for example, free shuttles, proof-of-payment or pay-on-exit fare collection, or boarding from a fare-paid area), Exhibit 4-3 can be used instead to estimate these times. Note that having two doors available for boarding does not halve the average passenger boarding time, although it provides a significant improvement.

Exhibit 4-2
Passenger Service Times with Single-Channel Passenger Movement

	Passenger Service Time (s/p)	
Situation	**Observed Range**	**Suggested Default**
	BOARDING	
Pre-payment*	2.25-2.75	2.5
Single ticket or token	3.4-3.6	3.5
Exact change	3.6-4.3	4.0
Swipe or dip card	4.2	4.2
Smart card	3.0-3.7	3.5
	ALIGHTING	
Front door	2.6-3.7	3.3
Rear door	1.4-2.7	2.1

*includes no fare, bus pass, free transfer, and pay-on-exit
Add 0.5 s/p to boarding times when standees are present.
Subtract 0.5 s/p from boarding times and alighting times on low-floor buses.

Comparing relative service times of different fare payment methods can be used to estimate the dwell time impacts of changing the payment method.

Exhibit 4-3
Passenger Service Times with Multiple-Channel Passenger Movement(R5,R20,R23,R24)

Available Door Channels	Default Passenger Service Time (s/p)		
	Boarding*	**Front Alighting**	**Rear Alighting**
1	2.5	3.3	2.1
2	1.5	1.8	1.2
3	1.1	1.5	0.9
4	0.9	1.1	0.7
6	0.6	0.7	0.5

*Assumes no on-board fare payment required

Increase boarding times by 20% when standees are present. For low-floor buses, reduce boarding times by 20%, front alighting times by 15%, and rear alighting times by 25%.

Passenger service times increase when significant two-way passenger flow occurs through a door.

Step 4: Adjust the passenger service times for heavy two-flow through a single door channel. When 25 to 50% of the passenger flow through a single door channel is in the opposite direction of the main flow of passengers, increase both the boarding and alighting passenger service times by 20% (0.5 seconds for a single door channel) to account for passenger congestion at the door.(R40)

Step 5: Calculate the dwell time. The dwell time is the time required to serve passengers at the busiest door, plus the time required to open and close the doors. A value of 2 to 5 seconds for door opening and closing is reasonable for normal operations.(R5,R25)

Equation 4-3

$$t_d = P_a t_a + P_b t_b + t_{oc}$$

where:

t_d = average dwell time (s);
P_a = alighting passengers per bus through the busiest door (p);
t_a = alighting passenger service time (s/p);
P_b = boarding passengers per bus through the busiest door (p);
t_b = boarding passenger service time (s/p); and
t_{oc} = door opening and closing time (s).

Impact of Wheelchair Movements on Dwell Time

All new transit buses in the United States are equipped with wheelchair lifts or ramps. When a lift is in use, the door is blocked from use by other passengers. Typical wheelchair lift cycle times are 60 to 200 seconds, while the ramps used in low-floor buses reduce the cycle times to 30 to 60 seconds (including the time required to secure the wheelchair inside the bus). The higher cycle times relate to a small minority of inexperienced or severely disadvantaged users. When wheelchair users regularly use a particular bus stop, the wheelchair lift time should be incorporated into the average dwell time. When wheelchair movements are rare, their impact on dwell time is accounted for by dwell time variability, discussed later in this chapter.

Impact of Bicycles on Dwell Time

A growing number of transit systems provide folding bicycle racks on buses. When no bicycles are loaded, the racks typically fold upright against the front of the bus. (Some systems also use rear-mounted racks, and a very few allow bikes on board on certain long-distance routes.) When bicycles are loaded, passengers deploy the bicycle rack and load their bicycles into one of the available loading positions (typically two are provided). The process takes approximately 20 to 30 seconds. When bicycle rack usage at a stop is frequent enough to warrant special treatment, average bus dwell time is determined using the greater of the passenger service time or the bicycle loading/unloading time.

Clearance Time

The time required for a bus to start up and travel its own length is fixed; re-entry delay is dependent on traffic volumes in the curb lane.

Once a bus closes its doors and prepares to depart a stop, there is an additional period of time, known as the *clearance time,* when the loading area is not yet available for use by the next bus. Part of this time is fixed, consisting of the time for a bus to start up and travel its own length, clearing the stop. When buses stop in the traffic lane (*on-line*), this is the only component of clearance time.

When buses stop out of traffic (*off-line*), there is another component to clearance time: the time required for a suitable gap in traffic to allow the bus to re-enter the street. This *re-entry delay* depends on the traffic volume in the curb lane and increases as traffic volumes increase. The delay also depends on the influence of upstream traffic signals, which may create long gaps in traffic, followed by periods of time when a constant stream of cars passes the stop. Some states have laws requiring motorists to yield to buses re-entering a roadway; depending on how well motorists comply with these laws, the re-entry delay can be reduced or even eliminated.

Many transit agencies avoid using off-line stops on busy streets in order to avoid this re-entry delay. However, many roadway agencies prefer off-line stops to avoid delays to other traffic and to reduce the potential for rear-end collisions between other vehicles and stopped buses. Exhibit 4-4 illustrates on-line and off-line stops, and the problem of re-entry delay at off-line stops.

Exhibit 4-4
On-Line and Off-Line Loading Areas

(a) On-Line (Portland, Oregon)

(b) Off-Line (Albuquerque)

Estimating Clearance Time

Various studies have examined the components of clearance time, with total clearance times ranging from 9 to 20 seconds.(R40) The time required for a bus to start up and travel its own length to clear a stop is about 10 seconds.(R36,R38) At off-line stops, re-entry delay can be measured in the field or estimated from Exhibit 4-5. Note that this exhibit applies only to random vehicle arrivals. If the flow of traffic past the bus stop is affected by a nearby upstream signal, or if buses must wait for a queue from a downstream signal to clear before they can re-enter the street, the *Highway Capacity Manual* or simulation can be used to estimate the average interval between acceptable gaps (assumed to be 7 seconds in the absence of other information).

Some states have passed laws requiring vehicles to yield to buses signaling to re-enter the street, which can eliminate re-entry delay. These laws are discussed in Chapter 2.

Exhibit 4-5
Average Bus Re-Entry Delay (Random Vehicle Arrivals)

Adjacent Lane Mixed Traffic Volume (veh/h)	Average Re-Entry Delay (s)
100	1
200	2
300	3
400	4
500	5
600	6
700	8
800	10
900	12
1,000	15

SOURCE: Computed using HCM 2000 unsignalized intersection methodology (minor street right turn at a stop sign), assuming a critical gap of 7 seconds and random vehicle arrivals. Delay based on 12 buses stopping per hour.

Exhibit 4-5 applies only to off-line stops where buses must yield to other traffic when re-entering a street, and only when the stop is located away from the influence of a signalized intersection.

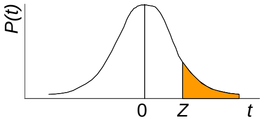
Dwell Time Variability

Coefficient of variation of dwell times.

Not all buses stop for the same amount of time at a stop, depending on fluctuations in passenger demand between buses and between routes. The effect of variability in bus dwell times on bus capacity is reflected by the *coefficient of variation of dwell times* (c_v), which is the standard deviation of dwell times divided by the average (mean) dwell time. When c_v is zero, all dwell times are the same. When c_v is 1.0, the standard deviation of dwell times is as large as the mean dwell time, meaning that approximately one in three buses will have a dwell time twice as large as the average dwell time.

Based on field observations of bus dwell times in several U.S. cities,$^{(R36)}$ c_v typically ranges from 0.4 to 0.8, with 0.6 recommended as an appropriate value in the absence of field data. Dwell time variability is influenced by the same factors that affect dwell time.

Standard normal distribution.



If a series of dwell time observations were to be plotted, they would form a normal distribution similar to the one shown to the left. A narrower distribution with a higher peak would indicate less variability, while a wider distribution with a lower peak would indicate greater variability.

Bus loading area capacity is maximized when a bus is available to move into a loading area as soon as the previous bus vacates it. However, this condition is undesirable for several reasons: (1) bus travel speeds are reduced, due to the time spent waiting for a loading area to become available, (2) bus schedule reliability suffers because of the additional delays, and (3) buses block traffic in the street for longer periods of time. Consequently, bus capacity analysis incorporates the concept of a *failure rate* that sets how often a bus should arrive at a stop only to find all loading areas occupied.

Failure rate.

Operating margin.

The failure rate is used in combination with dwell time variability and the average dwell time to provide an *operating margin* that is added to the dwell time and the clearance time to make sure that failures do not happen more often than the desired rate. In effect, the operating margin is the maximum amount of time that an individual bus dwell time can exceed the average without creating the likelihood of a bus stop failure when the number of buses scheduled to use the stop approaches its capacity. The lower the desired failure rate, the greater the operating margin and schedule reliability, and the lower the loading area capacity. Conversely, the greater the allowed failure rate, the lower the operating margin and schedule reliability, and the greater the loading area capacity.

Standard normal variable *Z*.

From statistics, the area under and to the right of a given point Z on a normal distribution curve (such as the shaded area in the diagram above) represents the probability that any given bus's dwell time will be longer than that amount. The dwell time value t_i corresponding to Z is incorporated in Equation 4-4:

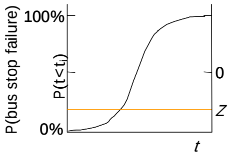
Equation 4-4

$$Z = \frac{t_{om}}{s} = \frac{t_i - t_d}{s}$$

where:

Z = standard normal variable corresponding to a desired failure rate;
s = standard deviation of dwell times;
t_{om} = operating margin (s);
t_d = average dwell time (s); and
t_i = dwell time value that will not be exceeded more often than the desired failure rate.

Probability of bus stop failure.



Rearranging Equation 4-4 provides the operating margin required to achieve a particular design failure rate, when a loading area operates close to capacity:

Equation 4-5

$$t_{om} = sZ = c_v t_d Z$$

where:

c_v = coefficient of variation of dwell times.

Exhibit 4-6 provides values for *Z* corresponding to different failure rates.

Exhibit 4-6
Values of *Z* Associated with Given Failure Rates(R36)

Failure Rate	*Z*
1.0%	2.330
2.5%	1.960
5.0%	1.645
7.5%	1.440
10.0%	1.280
15.0%	1.040
20.0%	0.840
25.0%	0.675
30.0%	0.525
50.0%	0.000

Suggested design failure rates.

In downtown areas, design failure rates of 7.5 to 15% are recommended for estimating capacity. This represents a trade-off between maintaining bus travel speeds and achieving the higher capacities required in downtown areas. The upper limit, 15%, represents bus stop failure (queues forming behind the bus stop) for about 10 minutes out of the hour. It also represents the point where bus travel speeds begin to drop rapidly. Simulation indicates that bus speeds at a 15% failure rate are about 20% lower than when scheduled bus volumes are well below capacity.(R36)

Bus travel speeds drop rapidly above a 15% failure rate.

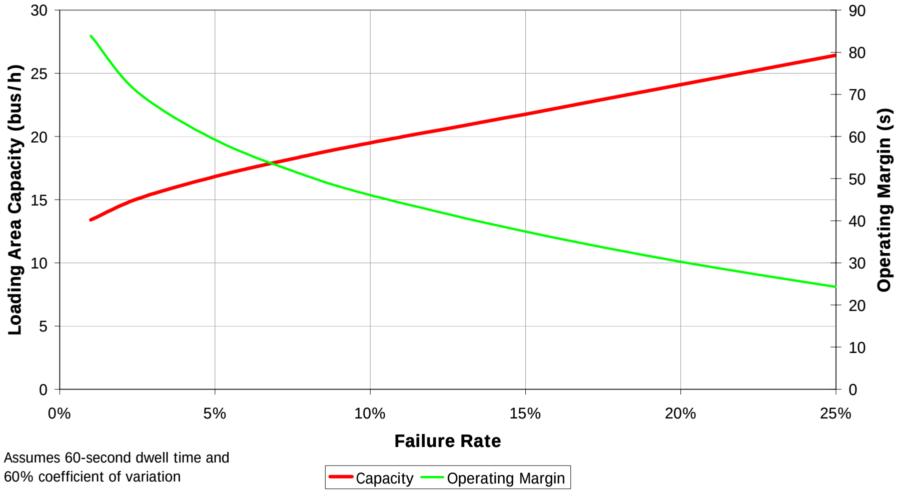
Outside downtown areas, a design failure rate of 2.5% is recommended whenever possible, particularly when off-line stops are provided, as queues will block a travel lane whenever a bus stop failure occurs. However, failure rates up to 7.5% are acceptable.(R36)

Capacity is maximized at a 25% failure rate. Lower failure rates are recommended to balance capacity and schedule reliability.

Capacity is effectively reached at a failure rate of 25%. Mathematically, capacity would be maximized at a 50% failure rate; however, achieving this would require precise control of bus headways, with the only variable being the passenger boarding volumes on a given bus, something not likely to be achieved in practice. More likely, bus interference would be so prevalent that not all of the scheduled buses would be able to serve a given stop during the course of an hour. Further, bus speeds would be extremely low at a 50% failure rate, resulting in poor service quality for passengers.

Exhibit 4-7 illustrates the relationships between failure rate, operating margin, and loading area bus capacity.

Exhibit 4-7
Illustrative Relationships Between Failure Rate, Operating Margin, and Loading Area Bus Capacity



Assumes 60-second dwell time and 60% coefficient of variation

Traffic Signal Timing

A traffic signal located in the vicinity of a bus stop and its loading areas will serve to meter the number of buses that can enter or exit the stop. For example, at a far-side stop (or a mid-block stop downstream from a traffic signal), buses can only enter the stop during the portion of the hour when the signal is green for the street that the stop is located on. The lower the green time provided to the street, the lower the capacity. Similarly, at a near-side stop, a bus may finish loading passengers but have to wait for the signal to turn green before leaving the stop. As a result, the bus occupies the stop longer than if it would have if it could have left immediately, and capacity is lower as a result. Due to the nature of bus operations, shorter cycle lengths offer more opportunities for buses to move through the signal. At unsignalized locations well away from the influence of upstream traffic signals, buses can enter and exit stops immediately, subject to traffic conditions (accounted for by clearance time), with no impact on capacity.

The *g/C* ratio for a given traffic signal approach will depend mainly on the traffic volumes on that approach, the presence or absence of protected left-turn phasing (i.e., left-turn arrows), and policy decisions on which movements to prioritize.

The *g/C* ratio is 1.00 at unsignalized locations well away from the influence of upstream traffic signals.

The effect of traffic signals on capacity is accounted for by the *green time ratio* (*g/C ratio*), which is the average amount of green time for the traffic movement used by buses, divided by the length of the traffic signal cycle (the time required to serve all movements). For example, if traffic moving parallel to a particular bus stop receives a green signal for an average of 54 seconds, and the total cycle length is 120 seconds, the g/C ratio at that stop is 54 divided by 120, or 0.45. The g/C ratio at unsignalized locations well away from the influence of traffic signals is 1.00, because bus access to the stop or its loading areas is not metered by a signal.

As will be seen below, the g/C ratio affects the capacity equation in two ways. First, the equation numerator is adjusted—it becomes 3,600(g/C)—reflecting the portion of the hour when buses can enter far-side or mid-block stops, or leave near-side stops. Second, the dwell time in the equation denominator is adjusted—it becomes $t_d(g/C)$—reflecting the portion of dwell occurring during the street's green phase. Dwell time that occurs during the red phase does not impact capacity, as the bus would not have been able to enter or leave the stop during the red phase. The net effect is that capacity is increased as the amount of green time provided is increased.

Calculation Procedure

The capacity of a loading area in buses per hour, B_l, is:(R36)

Equation 4-6

$$B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + t_{om}} = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

where:

B_l = loading area bus capacity (bus/h);
3,600 = number of seconds in 1 hour;
g/C = green time ratio (the ratio of effective green time to total traffic signal cycle length, equals 1.0 for unsignalized streets and bus facilities);
t_c = clearance time (s);
t_d = average (mean) dwell time (s);
t_{om} = operating margin (s);
Z = standard normal variable corresponding to a desired failure rate; and
c_v = coefficient of variation of dwell times.

Exhibit 4-8 presents the estimated maximum number of buses that can use a bus loading area, based on a 25% failure rate, a 60% coefficient of variation of dwell times, no traffic signal in the vicinity, and the combinations of dwell times and clearance times shown. Planning graphs presenting results based on various assumptions are provided in Appendix D.

Exhibit 4-8
Estimated Maximum Capacity of Loading Areas (bus/h)

Dwell Time (s)	Clearance Time 10 s	Clearance Time 15 s
15	116	100
30	69	63
45	49	46
60	38	36
75	31	30
90	26	25
105	23	22
120	20	20

NOTE: Assumes 25% failure rate, 60% coefficient of variation of dwell times, and *g/C* = 1.0.

These are maximum capacities. The planning graphs in Appendix D show lower design capacities based on the recommended failure rate for different locations.

BUS STOP VEHICLE CAPACITY

Design and Location Considerations

A bus stop is a location where buses stop to load and unload passengers and consists of one or more loading areas. Bus stop vehicle capacity is related to the vehicle capacity of the individual loading areas at the stop, the number of loading areas provided, and the design of the loading areas. In addition, nearby traffic signals may meter the number of buses into or out of the stop.

External factors and passenger needs may constrain the size of bus stops.

The number of loading areas provided should be sufficient to accommodate the number of buses scheduled to use the stop. However, block lengths, driveway locations, and/or the need to maintain on-street parking may constrain the size of the bus stop. In addition, having more than three loading areas at a stop can potentially be confusing to passengers, as they will not know where to wait for a bus, and can lead to longer dwell times, when passengers must walk to the back of the queue of buses to board.

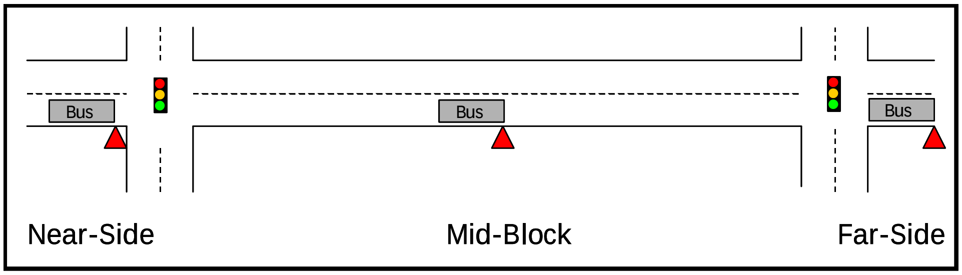
Off-line bus stops trade potentially higher capacity for potentially greater delays.

Off-line bus stops (i.e., where the bus stops out of the flow of traffic) provide a higher bus capacity relative to on-line stops, when four or more loading areas are provided. On-line bus stops provide a higher bus capacity when one or two loading areas are provided. The two types of stops provide similar capacities when three loading areas are provided. Because of the delays incurred when buses try to merge back into traffic and the cumulative effect of those delays on running speeds and travel time, many agencies tend to avoid using off-line stops, except when the speed limit on the street is relatively high (e.g., greater than 40 to 45 mph or 60 to 70 km/h).

The three typical on-street bus stop locations are near-side, far-side, and mid-block.

On-street bus stops are typically located curbside in one of three locations: (1) *near-side,* where the bus stops immediately prior to an intersection, (2) *far-side,* where the bus stops immediately after an intersection, and (3) *mid-block,* where the bus stops in the middle of the block between intersections. Under certain circumstances, such as when buses share a stop with streetcars running in the center of the street, or when a median busway exists, a bus stop may be located on a boarding island within the street rather than curbside. Boarding islands are discussed further in Chapter 2. Exhibit 4-9 depicts typical on-street bus stop locations.

Exhibit 4-9
On-Street Bus Stop Locations



Freeway bus stops.

Special bus stops are sometimes located along freeway rights-of-way, usually at interchanges or on parallel frontage roads. Examples include stops in Marin County, California, and in Seattle, where they are known as "flyer stops." These stops are used to reduce bus travel times by eliminating delays associated with exiting and re-entering freeways. Freeway stops should be located away from the main travel lanes and adequate acceleration and deceleration lanes should be provided. To be successful, attractive and well-designed pedestrian access to the stop is essential.(R7)

Off-street bus stop design is discussed in Part 7.

Off-street bus stops, such as transit centers and intermodal terminals, are often designed based on factors other than capacity, including accommodating driver layovers and separating a large number of routes so passengers can easily find their desired buses. Part 7 describes off-street bus stop design in more detail.

Far-side stops have the most beneficial effect on bus stop vehicle capacity, but other factors must also be considered when siting bus stops.

Bus stop location influences vehicle capacity, particularly when other vehicles can make right turns from the curb lane (which is typical, except for certain kinds of exclusive bus lanes and when a one-way street grid is used). Far-side stops have the least effect on capacity (as long as buses are able to avoid right-turn queues on the approach to the intersection), followed by mid-block stops, and near-side stops.

However, vehicle capacity is not the only factor which must be considered when selecting a bus stop location. Potential conflicts with other vehicles operating on the street, transfer opportunities, passenger walking distances, locations of passenger generators, signal timing, driveway locations, physical obstructions, and the potential for implementing transit preferential measures must also be considered.

For example, near-side stops are often preferable when curb parking is allowed, since buses may use the intersection area—where cars would not be parking in any event—to re-enter the moving traffic lane. Near-side stops are desirable where buses make a right turn, while far-side stops are desirable where buses make left turns. At intersections with one-way streets, both traffic and transfer opportunities may need to be considered. If traffic on the one-way street moves from left to right, for example, right-turning traffic volumes might suggest a far-side stop, while providing a convenient transfer to routes on the cross street might suggest a near-side stop.

Mid-block stops are typically only used at major passenger generators or where insufficient space exists at adjacent intersections.(R7) How passengers will cross the street to get to or from a mid-block bus stop must be carefully considered.

Exhibit 4-10 compares the advantages and disadvantages of each kind of bus stop location. Additional guidelines for the spacing, location, and geometric design of bus stops are given in *TCRP Report 19*.(R43) These guidelines must be carefully applied to ensure both good traffic and transit operations.

Bus Stop Effectiveness

It seems logical that the more loading areas that are available at a bus stop, the greater the bus stop's capacity will be, because more buses will be able to load and unload passengers simultaneously. However, some designs are more efficient than others at adding capacity.

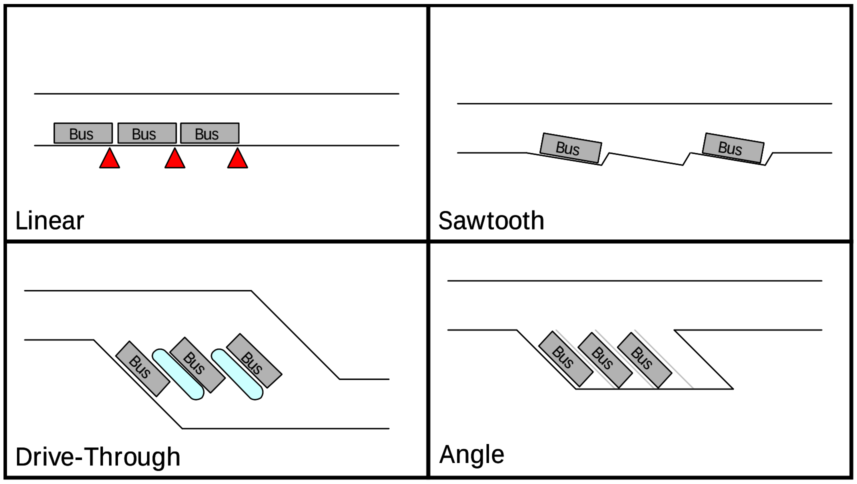
Off-street loading areas fall into the four general categories depicted in Exhibit 4-11: linear, sawtooth, drive-through, and angle. The latter three categories are *non-linear loading areas,* and their designs allow buses to pull in and out of loading areas independently of each other. Non-linear designs are *fully effective*: doubling the number of loading areas doubles the stop's total bus capacity. The full effectiveness results from buses being able to move independently of each other. In addition, buses are typically assigned to a particular loading area when non-linear designs are used, and there is no delay incurred with passengers walking down the line of buses when their bus arrives behind several others. Non-linear designs are rarely seen at on-street locations, except at on-street transit centers.

Exhibit 4-10
On-Street Bus Stop Location Comparison[R43]

Advantages and disadvantages of near-side, far-side, and mid-block stops.

Location	Advantages	Disadvantages
Far-Side	• Minimizes conflicts between right-turning vehicles and buses • Provides additional right-turn capacity by making curb lane available for traffic. • Minimizes sight distance problems on intersection approaches • May encourage pedestrians to cross behind the bus, depending on distance from intersection • Creates shorter deceleration distances for buses, since the intersection can be used to decelerate • Buses can take advantage of gaps in traffic flow created at signalized intersections • Facilitates bus signal priority operation, as buses can pass through intersection before stopping	• Could result in traffic queued into intersection when a bus stops in the travel lane • May obscure sight distance for crossing vehicles • May increase sight distance problems for crossing pedestrians • Can cause a bus to stop far side after stopping for a red light, interfering with both bus operations and all other traffic • May increase the number of rear-end crashes since drivers may not expect buses to stop again after stopping at a red light
Near-Side	• Minimizes interferences when traffic is heavy on the far side of the intersection • Allows passengers to access buses close to crosswalk • Intersection width available for bus to pull away from the curb • Eliminates potential for double stopping • Allows passengers to board and alight while bus stopped for red light • Allows driver to look for oncoming traffic, including other buses with potential passengers	• Increases conflicts with right-turning vehicles • May result in stopped buses obscuring curbside traffic control devices and crossing pedestrians • May cause sight distance to be obscured for side street vehicles stopped to the right of the bus • Increases sight distance problems for crossing pedestrians • Complicates bus signal priority operation, may reduce effectiveness or require a special queue-jump signal if the stop is located in the parking lane or a right-turn lane
Mid-Block	• Minimizes sight distance problems for vehicles and pedestrians • May result in passenger waiting areas experiencing less pedestrian congestion.	• Requires additional distance for no-parking restrictions • Encourages passengers to cross street mid-block (jaywalking) • Increases walking distance for passengers crossing at intersections

Exhibit 4-11
Bus Stop Design Types



Linear bus stops are partially effective—each additional loading area adds less capacity than the loading area before it.

The vast majority of on-street stops are *linear* stops, where the first bus to arrive occupies the first loading area, the second bus occupies the second loading area, and so on. Each additional linear loading area provided at a stop will be less effective than the one before it for three reasons:

1. The rear loading areas will be used less often than the first loading area.
2. Not knowing which loading area their bus will stop at, passengers may have to walk down the line of buses to get to a bus that stops at one of the rear loading areas. This walking takes more time than if the bus stopped where the passengers were already waiting. As a result, for the same boarding volume, the dwell time of buses using the rear loading areas will be longer than the dwell time of buses using the front loading areas.
3. Depending on how closely buses stop behind the bus in front, and the buses' ability to pass each other, a bus may not be able to leave its loading area until the bus in front of it departs.

Bus platoons.

The incremental increase in capacity provided by each additional loading area at a bus stop depends on whether the loading areas are located on-line or off-line, as well as on the arrival characteristics of the buses using the stop. Field observations indicate that linear loading areas are used more efficiently when buses enter and exit them as *platoons*. These are groups of 2 to 3 buses with similar dwell times (or, at least, dwell times short enough to be completed by the time a traffic signal turns green) that travel down the street together. Platoons can be formed by upstream traffic signals or by intentionally scheduling groups of buses to leave the start of a route together. (This requires a staging area near the locations where most passengers will board.)

Sawtooth and other non-linear designs are more effective than linear loading areas when four or five loading areas are required.

Exhibit 4-12 provides efficiency factors for off-line loading areas, on-line loading areas used by platooned buses, and on-line loading areas used by randomly arriving buses. The off-line loading area efficiency factors given in Exhibit 4-12 are based on experience at the Port Authority of New York and New Jersey's Midtown Bus Terminal.(R27) The on-line loading efficiency factors are based on simulation(R37) and European experience.(R22) The exhibit suggests that four or five on-line linear loading areas have the equivalent effectiveness of no more than three loading areas. Note that to provide two "effective" on-line loading areas, *three* physical loading areas would need to be provided, since partial loading areas are never built. Once again, it should be noted that Exhibit 4-12 applies only to *linear* loading areas. All other types of multiple loading areas are 100% efficient—the number of effective loading areas equals the number of physical loading areas.

Exhibit 4-12
Efficiency of Multiple Linear Loading Areas at Bus Stops(R25,R27,R28)

	On-Line Loading Areas				**Off-Line Loading Areas**	
	Random Arrivals		**Platooned Arrivals**		**All Arrivals**	
Loading Area #	**Efficiency %**	**Cumulative # of Effective Loading Areas**	**Efficiency %**	**Cumulative # of Effective Loading Areas**	**Efficiency %**	**Cumulative # of Effective Loading Areas**
1	100	1.00	100	1.00	100	1.00
2	75	1.75	85	1.85	85	1.85
3	70	2.45	80	2.65	80	2.65
4	20	2.65	25	2.90	65	3.25
5	10	2.75	10	3.00	50	3.75

NOTE: On-line values assume that buses do not overtake each other.

Capacity is added more effectively by decreasing average dwell times than by adding linear loading areas.

Exhibit 4-13 provides an illustration of the diminishing effect on total bus stop capacity of adding additional linear loading areas. It shows on-line bus stop capacity for selected dwell times and g/C ratios, based on a 10-second clearance time and random arrivals. *Increasing the number of linear loading areas has a much smaller effect on changes in capacity than reducing dwell times.* Note that for dwell times greater than 60 seconds, the differences between a g/C of 0.5 and 1.0 are small.

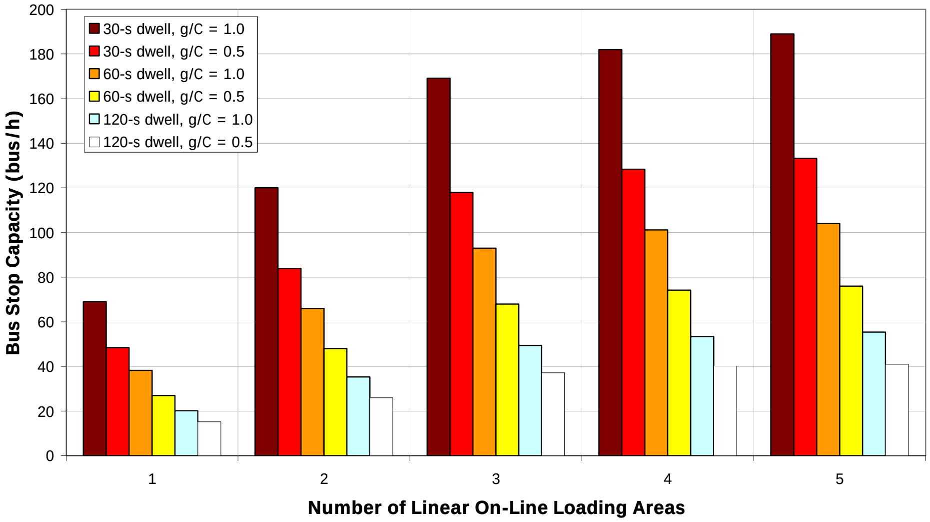


Exhibit 4-13
Relative Contributions of Dwell Time, *g*/*C* Ratio, and Number of Loading Areas to Bus Stop Capacity

NOTE: Based on 10-second clearance time, 25% failure rate, 60% coefficient of variation of dwell times, and random bus arrivals at on-line stops.

Calculation Procedure

The capacity of a bus stop in buses per hour, B_s, is:(R36)

Equation 4-7

$$B_s = N_{el} B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

where:

B_s = bus stop bus capacity (bus/h);
B_l = individual loading area bus capacity (bus/h);
N_{el} = number of effective loading areas, from Exhibit 4-12;
3,600 = number of seconds in 1 hour;
g/C = green time ratio (the ratio of effective green time to total traffic signal cycle length, equals 1.0 for unsignalized streets and bus facilities);
t_c = clearance time (s);
t_d = average (mean) dwell time (s);
Z = standard normal variable corresponding to a desired failure rate; and
c_v = coefficient of variation of dwell times.

Exhibit 4-14 provides estimated maximum capacities of on-line linear bus stops, for various numbers of loading areas, dwell times, and *g*/*C* ratios. Planning graphs showing bus stop capacities for other situations are provided in Appendix D.

Exhibit 4-14
Estimated Maximum Capacity of On-Line Linear Bus Stops (bus/h)

	Number of On-Line Linear Loading Areas									
Dwell	**1**		**2**		**3**		**4**		**5**	
Time (s)	***g*/*C* 0.50**	***g*/*C* 1.00**	***g*/*C* 0.50**	***g*/*C* 1.00**	***g*/*C* 0.50**	***g*/*C* 1.00**	***g*/*C* 0.50**	***g*/*C* 1.00**	***g*/*C* 0.50**	***g*/*C* 1.00**
30	48	69	84	120	118	169	128	182	133	189
60	27	38	48	66	68	93	74	101	76	104
90	19	26	34	46	48	64	52	69	54	72
120	15	20	26	35	37	49	40	53	41	55

NOTE: Assumes 10-second clearance time, 25% failure rate, 60% coefficient of variation of dwell times, and random bus arrivals. To obtain the vehicle capacity of non-linear on-line bus stops, multiply the one-loading-area values shown by the number of loading areas provided.

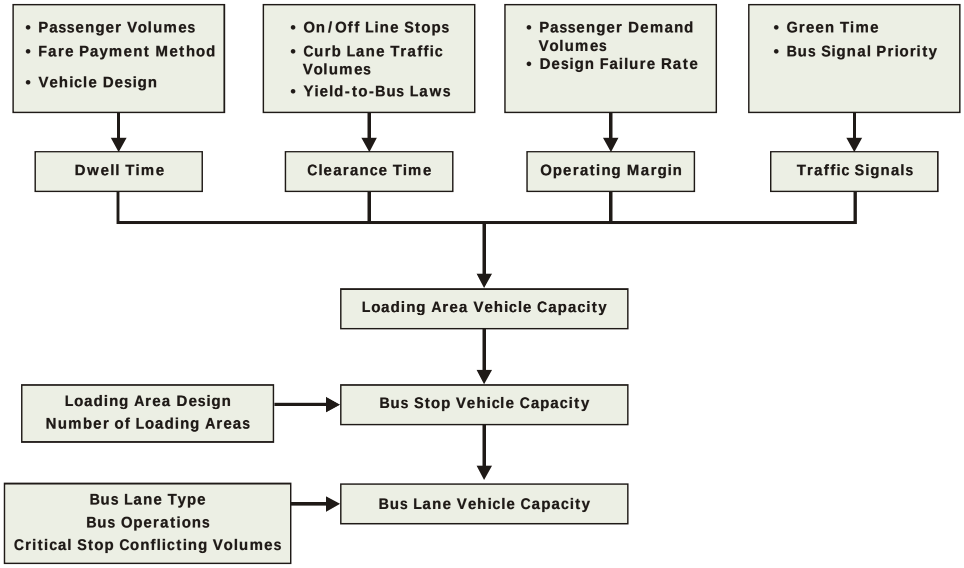
BUS FACILITY CONCEPTS

Bus facility capacity is greatly dependent on the exclusivity of the facility—the less interference that buses have from other traffic, the greater the capacity. Specific procedures for calculating bus facility capacity are presented in the facility-specific Chapters 4 through 6, covering grade-separated busways and freeway arterial HOV lanes, arterial street bus lanes, and mixed traffic lanes, respectively.

Where buses make no stops along a facility, bus capacity will be constrained by (1) the capacity of other facilities before or after the non-stop section, or (2) the capacity of a terminal or transit center where the buses end up. For all other facility types, the facility capacity is determined largely by the capacity of the *critical bus stop*—the bus stop that produces the longest headways between buses. Typically, this is the stop with the longest dwell times, but could also be, for example, a far-side stop after a signalized left turn (with relatively low green time provided to the left turn), or a near-side stop with heavy right-turn volumes.

Facility-specific factors will also influence bus facility capacity. For example, Exhibit 4-15 illustrates the factors that ultimately determine the bus capacity of an arterial street bus lane.

Exhibit 4-15
Capacity Factors for Exclusive Bus Lanes



PERSON CAPACITY

Once a facility's bus capacity is known, it is relatively straightforward to determine its person capacity. However, as Exhibit 4-16 illustrates, in addition to the factors shown in Exhibit 4-15 relating to bus capacity, there are several other factors that must be considered when calculating person capacity.

Loading Diversity

How passenger demand is distributed spatially along a route and how it is distributed over time during the analysis period affect the number of boarding passengers that can be carried. The spatial aspect of passenger demand, in particular, is why person capacity must be stated for a maximum load section and not for a route or street as a whole.

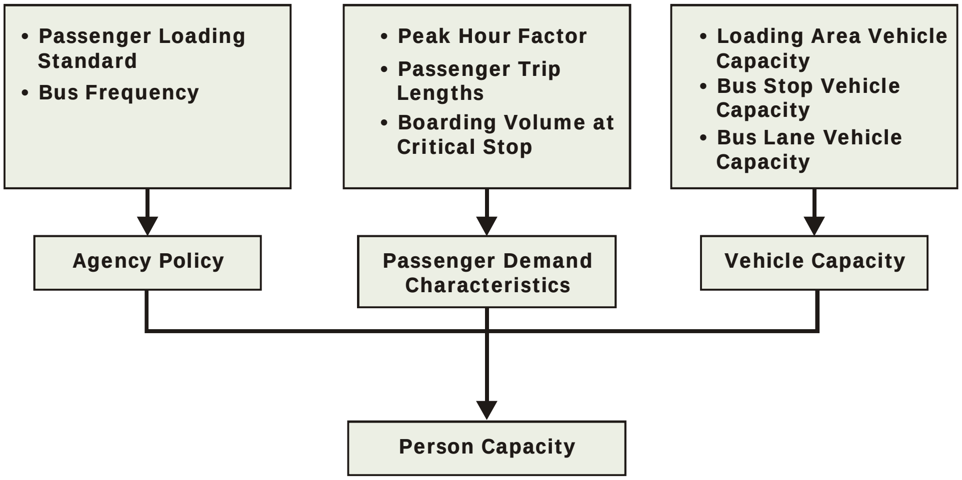


Exhibit 4-16
Person Capacity Factors

Over the course of an hour, passenger demand will fluctuate. The *peak hour factor*, shown in Equation 4-1, reflects passenger demand volumes over (typically) a 15-minute period during a peak hour. A bus system should be designed to provide sufficient capacity to accommodate this peak passenger demand. However, since this peak demand is not sustained over the entire hour and since not every bus will experience the same peak loadings, the achievable person capacity during the hour will be less than that calculated using peak-within-the-peak demand volumes.

The average *passenger trip length* affects how many passengers may board a bus as it travels its route. If trip lengths tend to be long (passengers board near the start of the route and alight near the end of the route), buses on that route will not board as many passengers as a route where passengers board and alight at many locations. However, the total number of passengers on board buses on each route at their respective maximum load points may be quite similar.

The *distribution of boarding passengers* among bus stops affects the dwell time at each stop. If passenger boardings are concentrated at one stop, the facility’s bus capacity will be lower, since that stop’s dwell time will control the bus capacity (and, in turn, the person capacity) of the entire facility. Both the potential bus capacity and person capacity at the maximum load point are greater when passenger boarding volumes are evenly distributed among stops.

Operator Policy

Increasing the maximum schedule load increases person capacity, but decreases quality of service.

Two factors directly under the control of a transit agency are the *maximum schedule passenger load* allowed on buses (set by a combination of agency policy and agency vehicle purchasing decisions) and the *service frequency*. Maximum schedule load is synonymous with “capacity,” assuming a reasonable number of standees. It represents the upper limit for scheduling purposes. Maximum schedule loads are typically 125 to 150% of a bus’s seating capacity, for example 54 to 64 passengers on a typical 40-foot (12-meter) bus.

Crush loads.

Crush loads, typically loads above 150% of a bus’s seating capacity, subject standees and other passengers to unreasonable discomfort. Such loads are unacceptable to passengers. Crush loads prevent circulation of passengers at intermediate stops and so induce delay and reduce vehicle capacity. Although crush loading represents the theoretically offered capacity, it cannot be sustained on every bus for any given period, and it exceeds the maximum utilized capacity. *Therefore, crush loads should not be used for transit capacity calculations.* Note, however, that when maximum schedule loads are used, some buses will experience crush loading, due to the peaking characteristics of passenger demand.

An agency whose policy requires all passengers to be seated will have a lower potential person capacity for a given number of buses than an agency whose policy allows some standees or an agency that purchases longer buses. The bus frequency determines how many passengers can actually be carried, even though a bus stop or facility may be physically capable of serving more buses than are actually scheduled.

Number of people that *can* be carried vs. number of people that *could* be carried.

This last point is important when reporting person capacity: is the capacity being referred to the maximum number of people that *can* be carried under the current schedule, or the maximum number of people that *could* be carried if all of the buses a facility could accommodate were scheduled? Equation 4-8 illustrates the differences in calculating the two and is applicable to either bus routes or facilities.

Equation 4-8

$$P = \min\begin{cases} P_{\max} f(PHF) \\ P_{\max} B(PHF) \end{cases}$$

where:

P = person capacity (p/h);
P_{max} = maximum schedule load per bus (p/bus);
f = scheduled bus frequency (bus/h);
B = bus facility capacity, from the appropriate Chapter 4, 5, or 6 procedure; and
PHF = peak hour factor.

See the discussions under calculating dwell times, earlier in this chapter, for recommended peak hour factor values. When different sizes of buses are scheduled to use a facility, a weighted average maximum schedule load per bus should be developed to use in Equation 4-8, based on the number of buses of each type and the loading applied to each bus type. Typical bus vehicle types, dimensions, and passenger capacities are given in Exhibit 4-17.

Exhibit 4-17
Characteristics of Common Bus Transit Vehicles—United States and Canada

			Typical Passenger Capacity		
Bus Type	**Length (ft)**	**Width (ft)**	**Seated**	**Standing**	**Total**
Small Bus/Minibus	18-30	6.5-8.5	8-30	0-10	8-40
Transit Bus (high floor)	35	8.0-8.5	35-40	20-30	50-60
	40	8.5	40-45	20-35	65-75
Transit Bus (low floor)	35	8.0-8.5	30-35	20-35	55-70
	40	8.5	35-40	25-40	55-70
Articulated (high floor)	60	8.5	65	35-55	100-120

SOURCES: 1985 Highway Capacity Manual,(R40) manufacturer specifications.
NOTE: In any transit vehicle, the total passenger capacity can be increased by removing seats and by making more standing room available; however, this lowers the passengers' quality of service. The upper ends of the total capacity ranges represent crush capacity and should not be used for transit capacity calculations.

Low-floor buses typically provide 5 or 6 fewer seats than the comparable high-floor bus.

Low-floor buses typically provide five or six fewer seats than a manufacturer's equivalent 35 to 40 foot (10.7-12.2 meter) high-floor bus, due to the space taken up by the wheel wells that is not used for seating. Low-floor articulated buses have been introduced by some transit agencies.

CHAPTER 2. BUS PREFERENTIAL TREATMENTS

INTRODUCTION

This chapter presents operating issues related to the implementation of bus preferential treatments. A wide variety of treatments have been developed in urban areas throughout the world to make bus transit more competitive with the private automobile and to provide a higher quality of service for passengers. This chapter provides an overview of measures developed to date that have shown promising operations. Chapter 3 provides a set of planning guidelines to assist users in deciding whether a particular measure may be appropriate for a particular need.

Bus Preferential Treatment Uses

A significant amount of delay to transit vehicles in urban areas is caused by traffic congestion. This congestion results in longer travel times for passengers, and over time, requires transit agencies to add more buses to routes in order to maintain headways, which results in higher agency operating costs.

Bus preferential treatments seek to offset the delays caused by traffic.

Bus preferential treatments offer the potential to reduce the delays experienced by buses operating in mixed traffic. These measures are aimed at improving schedule adherence and reducing travel times and delays for transit users. The measures may attract new riders, increase transit capacity, and/or improve the transit quality of service.

Successful priority measures are usually characterized by(R17)

- An intensively developed downtown area with limited street capacity and high all-day parking costs,
- A long-term reliance on public transportation,
- Highway capacity limitations on the approaches to downtown,
- Major water barriers that limit road access to the downtown and channel bus flows,
- Fast non-stop bus runs for considerable distances,
- Bus priorities on approaches to or across water barriers,
- Special bus distribution within downtown (often off-street terminals), and
- Active traffic management, maintenance, operations, and enforcement programs.

Transportation policies that give priority to transit vehicles because of their efficiency benefits may allow transit agencies to implement transit priority measures.

Bus preferential treatments defined.

Bus preferential treatments can be generally defined as a range of techniques designed to speed up transit vehicles and improve overall system efficiency. They include physical improvements, operating changes, and regulatory changes. Bus preferential treatments may reduce travel time variability and improve schedule adherence, depending on the application. When considering implementing these treatments, the total change in person-delay (including both passengers in buses and in private vehicles) should be taken into account. Broader transportation policies may limit or expand the potential for application outlined within this manual.

Where there has been a strong policy directive to improve the role of public transit in accommodating a community's travel needs, these measures should be implemented with transit agency and traffic engineering agency staff working in a coordinated manner. Measures should be cost-effective and should consider both long-term changes to mode split and the potential for attracting new riders. Both of these factors may be difficult to quantify. In most cases, bus preferential treatments will be more acceptable to roadway users and decision-makers when improvements to transit operations do not create undue traffic disruptions. However, in a policy environment favoring transit usage over private automobiles, investments in bus preferential treatments rather than expanded roadway capacity may be seen as a means of further improving transit attractiveness and maximizing the person-carrying ability of roadways.

In situations where the policy direction is not as clear, or the inter-agency working relationships are not as strong, an incremental approach to developing preferential treatments may be more successful. This approach could involve demonstration projects that have a good potential for success and could be used to develop support for broader transportation improvement projects in the future.

Bus preferential treatments can provide a cost-effective way of improving transit service based on focused, one-time capital investments as opposed to increased service that requires annual operating funding. They offer the potential for reducing or postponing the need for added service to respond to congestion and can attract new riders to transit, if the treatments provide a noticeable improvement in travel time and/or service reliability.

Person Delay Concepts

The net change in person delay is an important factor to consider before implementing transit priority measures.

In many cases, providing bus preferential treatments involves trade-offs among the various users of a roadway facility. Providing a bus queue jump at a traffic signal, for example, provides a time-savings benefit for bus passengers, while possibly causing additional delay for motorists, their passengers, bicyclists, and some pedestrians. When considering implementing a preferential measure, one factor to consider should be the net change in person delay to all roadway users as a result of the measure. Of course, other factors such as cost, change in transit quality of service, and local policies encouraging greater transit use should also be considered. An example problem in Chapter 9 illustrates how to evaluate the net change in person delay resulting from implementing a transit signal priority measure.

BUSWAYS AND FREEWAY HOV LANES

Facilities that provide segregated rights-of-way for buses offer a number of advantages that can improve service quality. Bus travel times, schedule adherence, and vehicle productivity are improved when buses are able to use higher-speed, uncongested facilities. These improvements, in turn, promote efficiency, improve reliability, and increase the potential to gain new riders.

Industry usage of the terms *transitway* and *busway* is not consistent, and the terms are often used interchangeably.

Busways and freeway HOV lanes are the facility types offering segregated rights-of-way. Transit industry use of the terms *busway* and *transitway* is inconsistent, with the two terms often used interchangeably. The term *busway* has been used to describe facilities ranging from bus lanes in the medians of urban streets, to exclusive bus roads with at-grade intersections, to freeway HOV lanes used exclusively by buses, to Ottawa-style exclusive, grade-separated bus facilities with rail-like infrastructure. The TCQSM uses the terms *median busway, at-grade busway, freeway HOV lanes,* and *grade-separated busway,* respectively, to describe these facility types.

In North America, busways and freeway HOV lanes are found mainly in larger cities, usually with a large downtown employment and heavy peak-hour bus ridership.[2] However, these facilities have found application internationally as a substitute for, or supplement to, rail systems. When facilities are located on exclusive rights-of-way, they may not be easy to walk to. In these cases, most ridership stems

---

[2] A rural HOV lane used by Roaring Fork Transit Authority buses exists along sections of Colorado Highway 82 between Glenwood Springs and Vail.

from park-and-ride lots located along the facilities, from transfers from other routes, or from buses using the facilities after circulating through a neighborhood.

Operational Overview

Exhibit 4-18 presents operational characteristics of significant grade-separated busway and freeway HOV lanes. A more complete listing of these treatments can be found in the TRB *HOV Systems Manual*.(R44)

Exhibit 4-18
Operating Characteristics of Selected North American Busways and Freeway HOV Facilities(R29,R44)

		Length			
Region	**# of Lanes**	**(mi)**	**(km)**	**HOV hours[1]**	**Eligibility**
GRADE-SEPARATED BUSWAYS					
Ottawa					
Southeast Transitway	1 each dir.	5.1	8.2	24 hours	Buses only
West Transitway	1 each dir.	3.0	4.9	24 hours	Buses only
Southwest Transitway	1 each dir.	2.2	3.5	24 hours	Buses only
East Transitway	1 each dir.	4.0	6.5	24 hours	Buses only
Central Transitway	1 each dir.	1.7	2.7	24 hours	Buses only
Pittsburgh					
East Busway	1 each dir.	9.1	14.6	24 hours	Buses only
South Busway	1 each dir.	4.1	6.6	24 hours	Buses only
West Busway	1 each dir.	5.0	8.0	24 hours	Buses only
Seattle (Bus Tunnel)	1 each dir.	1.3	2.1	24 hours[2]	Buses only
Minneapolis (Univ. of Minnesota)	1 each dir.	1.1	1.8	24 hours	Buses only
Boston (South Boston Tunnel)	1 each dir.	1.0	1.6	Scheduled 2004 opening	
Boston (Harvard Square)	1 each dir.	0.2	0.3	24 hours	Buses only
Dallas (SW Texas Medical Center)	1 each dir.	0.6	1.0	24 hours	Buses only
Providence (Bus Tunnel)	1 each dir.	0.4	0.6	24 hours	Buses only
AT-GRADE BUSWAYS					
Miami (South Dade Busway)	1 each dir.	8.2	13.2	24 hours	Buses only
Seattle (south tunnel access)	1 each dir.	1.6	2.6	24 hours	Buses only
Vancouver (No. 3 Road)	1 each dir.	1.2	2.0	24 hours	Buses only
BARRIER-SEPARATED TWO-WAY HOV LANES					
Los Angeles (I-10 El Monte)	1 each dir.	4.0	6.4	24 hours	3+ HOVs
Seattle (I-90)	1 each dir.	1.6	2.5	24 hours	2+ HOVs
BARRIER-SEPARATED REVERSIBLE FLOW HOV LANES					
Northern Virginia (I-95/I-395)	2	15	24	24 hours	3+ HOVs
Houston					
I-10 (Katy Freeway)	1	13	21	5-12, 2-9[3]	3+ HOVs
I-45 (Gulf Freeway)	1	12.1	19.4	5-12, 2-9	2+ HOVs
US 290 (Northwest Freeway)	1	13.5	21.6	5-12, 2-9	2+ HOVs
I-45 (North Freeway)	1	13.5	21.6	5-12, 2-9	2+ HOVs
US 59 (Southwest Freeway)	1	11.5	18.4	5-12, 2-9	2+ HOVs
CONCURRENT-FLOW HOV LANES					
Miami (I-95)	1 each dir.	32	52	7-9 am SB, 4-6 pm NB	2+ HOVs
Atlanta (I-75)	1 each dir.	12.0	19.3	24 hours	2+ HOVs
Honolulu (H-2)	1 each dir.	8.1	13.1	6-8, 3:30-6	2+ HOVs
Montgomery County, MD					
I-270	1 each dir.	16.0	25.8	peak periods	2+ HOVs
US 29 (shoulders)	1 each dir.	3.0	4.8	peak periods	Buses only
Ottawa					
Hwy. 417 Kenta	1 EB only	3.0	4.8	7-9 am	Buses only
Hwy. 17 Orleans	1 WB only	3.0	4.8	7-9 am	Buses only
CONTRAFLOW HOV LANES					
New Jersey (Lincoln Tunnel appr.)	1 EB only	2.5	4.0	6-10 am	Buses only
Dallas	1 each pk. dir.	5.2	8.3	6-9, 4-7	2+ HOVs
Boston	1 each pk. dir.	6.0	9.6	6-10, 3-7	3+ HOVs
Montréal	1	4.3	6.9	6:30-9:30 NB, 3:30-7 SB	Buses only
HOV QUEUE BYPASSES					
Oakland (Bay Bridge Toll Plaza)	3	0.9	1.4	5-10, 3-7	3+ HOVs
San Diego ("A" Street ramp to I-5)	1	0.4	0.6	24 hours	Buses only
Los Angeles (250 freeway ramps)	1	0.1	0.2	as demand warrants	2+ HOVs
Chicago (I-90 toll plaza)	1 EB only	0.5	0.8	peak periods	Buses only

NB: northbound, SB: southbound, EB: eastbound, WB: westbound
[1] Part-time periods are weekdays only unless otherwise noted.
[2] Buses operate through tunnel 5 am-11 pm weekdays, 10 am-6 pm Saturdays; closed other times.
[3] Also 5 am-5 pm westbound Saturdays, 5 am-9 pm Sundays.
NOTE: Emergency and maintenance vehicles may also be allowed on bus-only facilities.

At-grade busways, including median busways.

At-grade busways in North America include the 8-mile (13-km) South Dade Busway in Miami; the 1.6-mile (2.6 km) at-grade busway south of Seattle's bus tunnel; and a 1.2-mile (2.0 km) median busway in the Vancouver suburb of Richmond. Median busways are used in a number of South American cities, including Belo Horizonte, Curitiba, Porto Alegre, and São Paulo, Brazil; Bogotá, Colombia; and Quito, Ecuador. Median busways are also planned as part of BRT routes in Cleveland, Los Angeles, and Eugene.

Exhibit 4-19(a) shows an example of the type of median busway, with high-level, pre-paid stations, pioneered by Curitiba. Dwell times are similar to rail transit, resulting in higher average speeds and higher vehicle utilization, due to high-level boarding from fare-paid stations. Bi-articulated buses capable of carrying up to 270 passengers are operated on Curitiba's five express bus lanes. Larger terminals located at the ends of the bus lanes, along with smaller terminals located about every 1.25 miles (2 km) along the lanes, provide transfer opportunities to inter-district and local feeder buses. These terminals are fare-paid areas, so passengers do not have to pay a separate fare or show a fare receipt when transferring between buses, similar to transfers at a heavy rail transfer station. Curitiba's distinctive high-level "tube stations" are equipped with wheelchair lifts, allowing passengers in wheelchairs to roll directly onto the bus when it arrives. Passengers pay an attendant at the tube station when they enter so that no fares need be collected aboard the bus.(R31,R35)

Exhibit 4-19
Median Bus Lane Examples

(a) Curitiba, Brazil

(b) Montréal

Separating buses from other traffic reduces the potential for conflicts that result in delays. In some cases, operating speeds may increase significantly with the use of freeway facilities; in others, the savings are less dramatic. After freeway HOV lanes were opened along several routes in Houston, peak hour operating speeds increased from 26 to 51 mph (42 to 83 km/h).(R19)

Effective distribution of buses within downtown areas remains a challenge. Freeway-related treatments generally provide good access to the downtown perimeter, but do not substantially improve service within the downtown core. Furthermore, transit terminals are not always located near major employment locations, and may require secondary distribution. However, other means exist to continue to favor bus movements once buses enter the downtown street network.(R27)

Bus tunnels.

A capital-intensive solution to downtown bus distribution, a 1.3-mile (2.1-km), five-station bus tunnel (Exhibit 4-20a), opened in Seattle in 1991. Bus routes using the tunnel are operated with a special fleet of dual-mode buses that run on overhead electric power in the tunnel and diesel power on the surface portions of their routes. Both ends of the tunnel connect to freeway ramps; the south end via an at-grade busway. Boston's Silver Line BRT route will open a 1.0-mile (1.6-km), three-station tunnel in 2004, to be used by dual-powered buses, and plans an additional 1.0-mile (1.6-km), two-station extension in the future. Some bus routes in Providence use a former streetcar tunnel that has been converted to bus use, and the South East Busway in Brisbane, Australia includes tunnel sections.

Exhibit 4-20
Bus Tunnel Examples

(a) Seattle (b) Providence

Many freeway-related bus preferential treatments have produced important passenger benefits. Some have achieved time savings of 5 to 30 minutes—savings that compare favorably with those resulting from rail transit extensions or new systems. The contraflow bus lane leading to the Lincoln Tunnel in New Jersey, for example, provides a 20-minute time saving for bus passengers.

HOV Lanes

An HOV lane is a freeway lane that is restricted to buses and, often, other vehicles occupied by a given number of people (usually two or three). The lanes can be immediately adjacent to regular traffic lanes, separated from other traffic by a painted median or removable pylons, or completely separate and protected from other traffic by physical barriers.(R41)

Houston's HOV system, illustrated in Exhibit 4-21, is the most extensive deployment of restricted lanes in North America. Built primarily for buses, but also used by carpools and vanpools, the HOV lanes are located in the center of most major freeways and are separated from general traffic by physical barriers. These HOV lanes serve nearly 110,000 person trips each weekday, the equivalent of about 35,000 vehicle trips that would otherwise continue traveling on the freeway main lanes. The average rush-hour speed on Houston freeways is roughly 24 mph (39 km/h). HOV lanes maintain an operating speed of 50 to 55 mph (80 to 90 km/h), and save the average commuter 12 to 22 minutes per trip.(R19)

Exhibit 4-21
Houston HOV Lane Examples

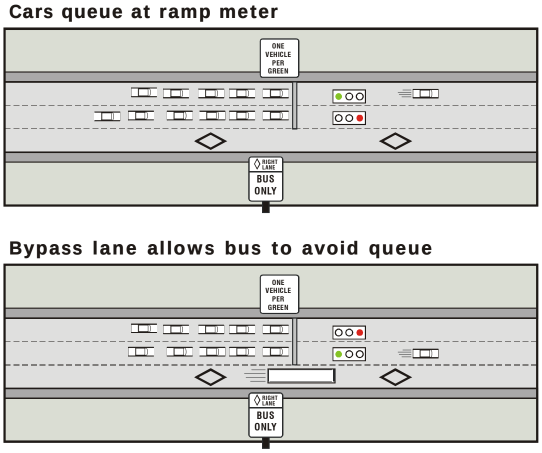
(a) I-10 Katy Freeway (b) I-45 North Freeway

Freeway Ramp Queue Bypasses

Queue bypasses.

Queue bypasses are a form of priority treatment that allow buses to avoid queues of vehicles (such as those that develop at freeway ramp meters) by providing a short HOV lane that avoids the queue. This form of transit priority often involves considerable innovation to find methods of enabling buses to avoid recurring congestion. Exhibit 4-22 depicts a typical queue bypass design on a freeway on-ramp, along with actual applications.

Exhibit 4-22
Freeway Ramp Queue Bypasses



(b) Application (Los Angeles)

(a) Concept

(c) Application (Amsterdam)

ARTERIAL STREET BUS LANES

Arterial street bus lanes provide segregated rights-of-way for buses. Because these facilities have *interrupted flow* (e.g., traffic signals), due to intersections with other streets, they provide a lower level of priority to transit than facilities on exclusive rights-of-way. Nevertheless, arterial street bus lanes offer buses significant advantages over mixed traffic operations. Exhibit 4-23 lists common sources of delays to buses operating in mixed traffic that bus lanes and site-specific preferential treatments help overcome. These delays reduce bus capacity, speed, and reliability, resulting in reduced service quality for passengers and potentially increased operating costs for transit agencies.

Exhibit 4-23
Sources of Delay for Buses Operating in Mixed Traffic at Intersections

Intersection Type	Delay Sources
Signalized	Insufficient traffic signal green time for bus approach Poor signal progression for buses Inadequate vehicle detection at signals
All	Queued vehicles on intersection approach On-street parking maneuvers Inadequate lane width Off-line bus stop re-entry delay Right-turning traffic blocking access to stop Left-turning traffic blocking shared lane

Bus lanes can be created by several means:

- Re-designating an existing travel lane as a bus lane,
- Narrowing existing lanes to provide an additional lane,
- Widening the street to add a new lane, and
- Restricting on-street parking (part-time or full-time) to provide a bus lane.

Where there is a relatively high volume of buses operating on a roadway, coupled with significant bus and automobile congestion, exclusive bus lanes can provide more attractive and reliable bus service. Most bus lanes take the form of reserved lanes on city streets, usually in the same direction as the general traffic flow. However, some cities provide bus-only streets, such as 16th Street in Denver, the Fifth and Sixth Avenue Transit Mall in Portland, Oregon, and the Granville Mall in Vancouver. Contraflow center lanes with center median waiting, such as the part-time Boulevard Pie-IX lane in Montréal, are unusual but have been successful.

Exhibit 4-24 shows applications where (a) on-street parking was removed and existing lanes narrowed to create a bus lane, and (b) parking is restricted during peak periods to provide a bus lane.

(a) Full-time lane (Portland, Oregon)

(b) Part-time lane (San Francisco)

Exhibit 4-24
Bus Lane Development via Parking Restrictions

TRAFFIC SIGNAL PRIORITY

Overview

Signal priority is different than pre-emption, which is normally associated with emergency vehicles.

Traffic signal priority for buses has been used for a number of decades in Europe, but is a newer concept in North America. Early attempts to provide signal priority were based on signal *pre-emption*, where buses were given a nearly immediate green signal, regardless of other conditions, in the same manner that emergency vehicles are able to pre-empt traffic signals. Signal pre-emption is not desirable from a traffic signal control system standpoint, and it raises potential pedestrian crossing safety issues, and thus has been dismissed by most roadway agencies. Current practice is to provide signal *priority*, where providing preferential treatment for buses is balanced against other system needs.

Reducing the traffic signal cycle length on an arterial or downtown grid system is a passive priority measure.

Signal priority measures include passive, active, and real-time priority, in addition to pre-emption. *Passive* strategies attempt to accommodate transit operations through the use of pre-timed modifications to the signal system that occur whether or not a bus is present to take advantage of the modifications. These adjustments are completed manually to determine the best transit benefit while minimizing the impact to other vehicles. Passive priority can range from simple changes in intersection signal timing to systemwide retiming to address bus operations. Passive strategies can utilize transit operations information, such as bus travel times along street segments, to determine signal timing coordination plans.

Conditional strategies can incorporate information on bus schedule status, loading, and recent requests for priority to determine whether or not to grant priority to a given bus.

Active strategies adjust the signal timing after a bus is detected approaching the intersection. Depending on the application and capabilities of the signal control equipment, active priority may be either conditional or unconditional. *Unconditional* strategies provide priority whenever a bus arrives. *Conditional* strategies incorporate information from on-board automatic vehicle location (AVL) equipment (e.g., whether or not the bus is behind schedule, and by how much), and/or automatic passenger counting (APC) equipment (e.g., how many people are on-board), along with signal controller data on how recently priority was given to another bus at the intersection, to decide whether or not to provide priority for a given bus.(R4)

Real-time strategies consider both automobile and bus arrivals at a single intersection or a network of intersections. Applications of real-time control have been limited to date and require specialized equipment that is capable of optimizing signal timings in the field to respond to current traffic conditions and bus locations.

Pre-emption can be classified separately because it results in changes to the normal signal phasing and sequencing of the traffic signal to provide a clear path for the pre-empting vehicle through the intersection. Pre-emption is most commonly associated with emergency vehicles (e.g., ambulances, fire trucks, and police cars), and with trains, when grade crossings are located adjacent to a signalized intersection (to clear vehicles off the grade crossing, and then prevent access to the crossing until the train has cleared the crossing). Because pedestrian crossing phases are also pre-empted, pedestrians can find themselves unexpectedly facing a solid DON'T WALK indication while crossing the street. Because buses do not announce their arrival by sirens and lights, as do emergency vehicles, pre-emption can lead to potentially serious pedestrian safety issues. From a vehicle operations standpoint, pre-emption can disrupt the coordination existing between traffic signals, which may result in significant congestion that also affects subsequent buses.

Exhibit 4-25 summarizes common bus signal priority treatments.

Exhibit 4-25
Bus Signal Priority Systems(R1)

Treatment	Description
	Passive Priority
Adjust cycle length	Reduce cycle lengths at isolated intersections to benefit buses
Split phases	Introduce special phases at the intersection for the bus movement while maintaining the original cycle length
Areawide timing plans	Preferential progression for buses through signal offsets
Bypass metered signals	Buses use special reserved lanes, special signal phases, or are rerouted to non-metered signals
Adjust phase length	Increased green time for approaches with buses
	Active Priority*
Green extension	Increase phase time for current bus phase
Early start (red truncation)	Reduce other phase times to return to green for buses earlier
Special phase	Addition of a bus phase
Phase suppression	Skipped non-priority phases
	Real-Time Priority*
Delay-optimizing control	Signal timing changes to reduce overall person delay
Network control	Signal timing changes considering the overall system performance
	Pre-emption*
Pre-emption	Current phase terminated and signal returns to bus phase

*Any of the listed treatments can be *unconditional* (occur whenever a request is received) or *conditional* (priority is granted if other conditions—schedule status, loading, etc.—are met).

Notes on Application

The importance of the relationship between transit staff and traffic engineering staff cannot be overemphasized. Coordination between these groups is necessary for effective implementation of transit priority measures.

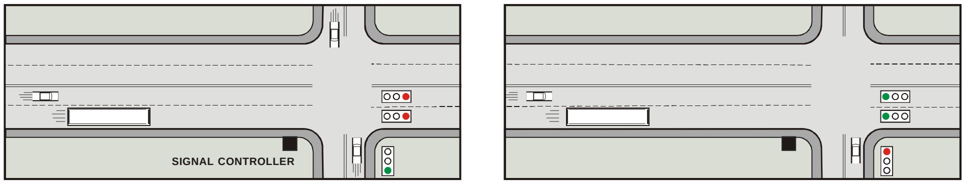
There are number of reasons to justify transit signal priority. However, signal priority should only be implemented at intersections whose traffic operations are well understood. Field data collection on both traffic and transit operating conditions allows for informed decisions by both transit and transportation engineering staff on the benefits and impacts of any proposed signal timing changes. In many cases, analyzing changes in person delay is recommended to adequately quantify these benefits and impacts.

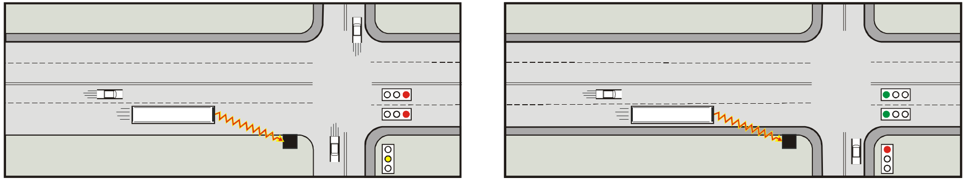
Signal priority systems vary in complexity. Simple systems that rely on bus operator intervention reduce the amount of on-vehicle technology that is needed. However, automated systems that do not require bus operator intervention are preferable, as operators may not always remember to activate the system at the intersections equipped with signal priority equipment. Furthermore, an automated system, when coupled with two-way data communication and AVL equipment, can be set to activate signal priority only when a bus meets certain conditions of priority (e.g., a bus is behind schedule, on route, within a preset area, doors are closed, etc.). The technology employed for transmitting and detecting priority requests varies considerably. Feasibility studies have identified various workable technologies, but there is not any strong evidence that one method will work best for every situation.

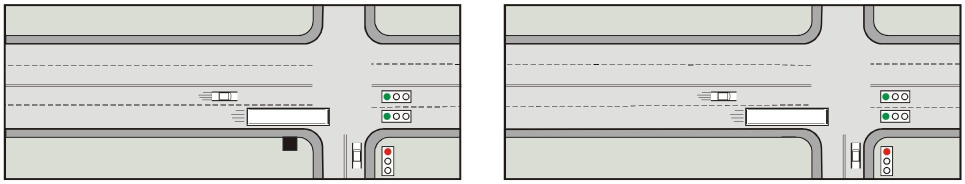
Exhibit 4-26 illustrates both red truncation and green extension associated with an active signal priority implementation. Street-side equipment can detect the bus (for example, using a transponder), or bus-mounted equipment can transmit a request for priority to the signal controller.

Exhibit 4-26
Bus Signal Priority Concept—Red Truncation and Green Extension(R4)

RED TRUNCATION | **GREEN EXTENSION**


Bus approaches red signal
Bus approaches green signal


Signal controller detects bus; terminates side street green phase early
Signal controller detects bus; extends current green phase


Bus proceeds on green signal
Bus proceeds on extended green signal

The City of Portland, Oregon, conducted operational studies on four different corridors. The performance measures studied included bus travel time, delay to non-transit vehicles, and person delay. Using an active signal priority system, bus travel time was reduced by 5 to 12 percent, with an insignificant amount of increased delay to other vehicles.(R2) Exhibit 4-27 identifies five recent transit signal priority implementations where improvements have been documented.

Exhibit 4-27
Reported Benefits Associated with Transit Signal Priority(R14)

Location	Type of Priority	Reported Benefits
Los Angeles	Extension, Truncation	7% bus travel time reduction
Chicago	Priority, Pre-emption	12 to 23% bus travel time reduction
Bremerton, WA	Pre-emption	Average 10% bus travel time reduction
Portland, OR	Extension, Truncation	5 to 12% bus travel time reduction
Anne Arundel County, MD	Pre-emption	13 to 18% bus travel time reduction, 4 to 9% impact on other traffic

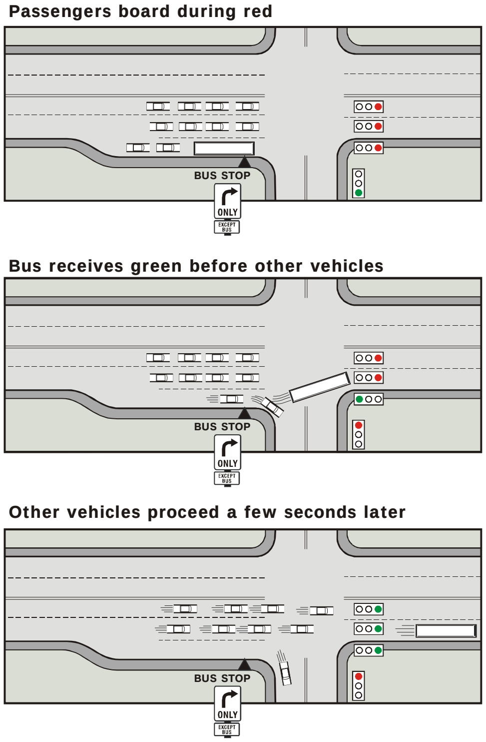
SITE-SPECIFIC PRIORITY TREATMENTS

Queue Jumps

Queue bypass lanes or queue jump treatments allow buses to avoid long queues of vehicles at signalized intersections. A short bus lane and other traffic control measures enable buses to travel through congested areas with reduced delay. Right-turn lanes with bus turn exemptions, or long off-line bus stops allow buses to move past much of the queue.

In some cases, a special right-lane signal may provide an advance green indication for the bus before traffic in the adjacent through lanes proceeds. During this time, the bus exits the right lane and merges into the lane to the left ahead of the other traffic that had stopped for the signal. Alternatively, the bus pulls into the right lane on a red signal and proceeds to a far-side off-line bus stop on green, resulting in reduced delay waiting for the queue in the regular lanes to clear the intersection. Exhibit 4-28 illustrates a typical queue jump design and an example application. In the Copenhagen example, a bus lane ends at a near-side bus stop at the intersection, and a special transit signal (the vertical bar indication adjacent to the regular traffic signal) is used to give buses priority into the regular traffic lanes. Edmonton uses a similar system at eight intersections. In many applications, such as the Portland example shown, regular traffic signals (with appropriate signing and shielding) are used for the bus signal, rather than a special transit signal.

Exhibit 4-28
Bus Queue Jumps(R4)



(a) Near-Side Concept

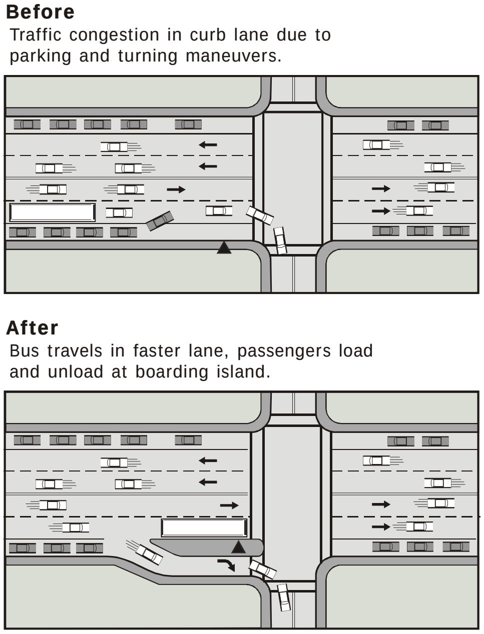
(b) Near-Side Application (Copenhagen)

(c) Far-Side Application (Portland, Oregon)

Boarding Islands

Where significant parking activity, stopped delivery vehicles, heavy right-turning traffic volumes, and other factors slow traffic in the right lane of a multiple-lane street, buses may be able to travel faster in the lane to the left. Boarding islands allow bus stops to be located between travel lanes so that buses can use a faster lane without having to merge into the right lane before every stop. Pedestrian safety issues must be addressed when considering the use of boarding islands. Exhibit 4-29 illustrates the concept and an application of this treatment.

Exhibit 4-29
Boarding Islands(R4)



(a) Concept

(b) Application (Washington, DC)

(c) Application (San Francisco)

Curb Extensions

Curb extensions at transit stops (also known as *bus bulbs*) are similar to boarding islands in that they allow transit vehicles to pick-up passengers without moving into the curb lane. Curb extensions may be used where streets have curbside parking and high traffic volumes. In these cases, it may not be desirable for a bus to pull to the curb to stop because of the delays involved in waiting for a sufficiently large gap in traffic that will allow the bus to pull back into the travel lane. In addition, if the bus stop is located at an intersection, curb extensions also serve to reduce the distance pedestrians must travel to cross the street.

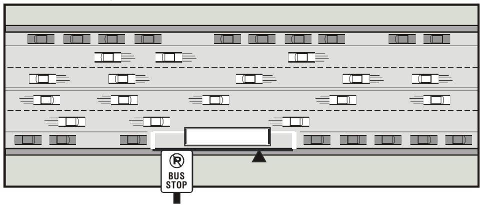
Other advantages of curb extensions include providing (1) a passenger waiting area clear of the main sidewalk, (2) an ADA-compliant landing area for wheeled mobility aid users, and (3) room for a shelter.

Curb extensions are typically developed by extending the curb into the parking lane to allow buses to stop in the travel lane to pick up and discharge passengers. Curb extensions can actually create more on-street parking than would exist with a stop flush with the regular curb line, as the area before or after the bus stop used by buses to pull in or out of the stop can now be used for additional parking. If bicycle lanes exist, they may need to be routed around the curb extension, creating potential pedestrian/bicycle or auto/bicycle conflicts. Curb extensions can change street drainage patterns, and drainage may need to be reworked to prevent water from ponding in the stop vicinity. They may also restrict some right turns, due to the tighter curb radius associated with this treatment.

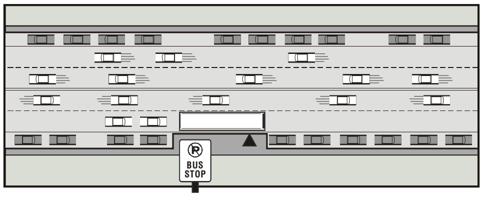
Exhibit 4-30 illustrates the use and application of curb extensions.

Exhibit 4-30
Curb Extensions(R4)

Before
Bus pulls to curb at bus stop: must wait for gap in traffic to proceed.



After
Curb extended into parking lane, bus stops in travel lane; more curbside parking available.



(a) Concept

(b) Application (Vienna, Austria)

(c) Application (Portland, Oregon)

Yield-to-Bus Laws

Some jurisdictions, including the states of Florida, Oregon, and Washington, and the provinces of British Columbia and Québec, have passed laws requiring motorists to yield to buses signaling to re-enter the street from a bus stop. Depending on motorist compliance with the law, the re-entry delay associated with merging back into traffic from an off-line stop can be almost eliminated. Some agencies also view these laws as a way to improve safety for buses and other vehicles. *TCRP Synthesis of Transit Practice 49* (R21) addresses the effectiveness of these laws.

Some jurisdictions (e.g., Québec and Washington) remind motorists of the law through the use of stickers mounted to the back of the bus. Some agencies in areas without yield-to-bus laws also use similar stickers appealing to motorist courtesy to let the bus back in. Oregon has developed a flashing electronic YIELD sign that has traffic control device status (i.e., motorists must obey it like they would a traffic signal or regulatory sign). Examples of these approaches are shown in Exhibit 4-31.

Exhibit 4-31
Yield-to-Bus Law Notifications

(a) Montréal

(b) Portland, Oregon

Parking Restrictions

Parking restrictions can be used to implement several of the transit preferential treatments previously described. Parking restrictions are typically required in the vicinity of a curbside stop to allow buses to pull out of the street and up to the curb to load and unload passengers. In areas where high parking turnover interferes with the flow of traffic on a street, parking restrictions may allow restriping to provide a right-turn-only lane that can also be used by buses as a queue jump lane. Part-time parking restrictions can be used to provide part-time exclusive bus lanes. Whenever parking restrictions are being considered, the impacts to general traffic and adjacent land uses from the loss of on-street parking must also be considered. In some instances, parking restrictions are mitigated through stop consolidation, which can increase the overall number of parking spaces in an area.

Turn Restriction Exemptions

The most direct route for a bus may not be possible because of left-turn restrictions at intersections. These restrictions are often implemented when there is insufficient room to develop left-turn lanes or when traffic volumes preclude good intersection operation when traffic signal cycle time is taken away for left-turning traffic. When left-turn restrictions are a result of traffic congestion, rather than safety, it may be feasible to exempt buses from the restriction without unduly impacting intersection operations, particularly when bus arrivals are relatively infrequent.

TRANSIT OPERATING MEASURES

Roadway and traffic signal improvements are not the only means of improving transit flow. There are a number of options available to transit agencies in the way that transit service is designed and operated that can also provide significant capacity, speed, and quality of service improvements.

Bus Stop Relocation

The traffic signal systems used on arterial streets are often designed to progress the flow of automobile traffic: the signals at a series of intersections are timed to turn green as a platoon of vehicles approaches each intersection from the preceding intersection. When bus stops are consistently placed on one side of an intersection (the near side, for example), buses will often arrive at the intersection while the signal is green. By the time passengers have finished loading and unloading, the signal will have turned red and buses must wait for the other traffic movements to be served.

When signals are spaced relatively close together, buses can take advantage of the existing signal progression when bus stop locations alternate from near side to far side from one intersection to the next. For example, a bus leaves a near-side stop with a platoon of other vehicles when the traffic signal at that stop turns green. The bus proceeds through the next signal with the other vehicles, and arrives at a far-side stop. By the time passenger movements are completed, the signal behind the bus may have turned red and the bus will have an easier time merging back into the street. It can then proceed to a near-side stop at the next signal, arriving and starting its dwell during the red interval, and can continue during the next green interval.

Alternating near-side and far-side stops can allow buses to take advantage of existing signal progression designed to facilitate vehicle flow.

Other factors listed in Exhibit 4-10, such as pedestrian access issues and transfer opportunities, should also be considered before relocating stops. Nevertheless, this is a useful technique for improving bus speeds that does not require any adjustments to the existing traffic signal system.

Bus Stop Consolidation

In general, minimizing the number of stops that buses must make will improve overall bus speeds. However, care must be taken that dwell times at critical stops (those stops with the highest dwell time) are not lengthened when a stop is removed and passengers are required to use a nearby stop that is already well-used.

Consolidating bus stops involves trade-offs between the convenience of the passengers using a particular stop, and those passengers already aboard a bus who are delayed each time the bus stops. Requiring passengers to walk a long distance to another stop may discourage people living or working in the vicinity of a removed stop from using transit. In addition, the pedestrian environment along the street with bus service may not support pedestrian activity (for example, due to a lack of sidewalks). Eliminating a stop can be politically difficult at times when local residents object to having "their" stop removed. However, when stops are located close together (e.g., every block), and a consistent, objective process is used to determine which stops are eliminated, consolidating bus stops can provide benefits to all transit users.

Limited-stop and express services as alternatives to consolidating stops.

In high-passenger-volume corridors, an alternative to eliminating stops is providing peak-period or all-day *limited-stop* (minor stops are skipped) or *express* (only a few very important stops are served) service in conjunction with local service that serves all stops. Passengers traveling long distances can do so more quickly, and it is easier to convey information to passengers about which stops are made when there are fewer stops. Passengers can transfer between services at shared stops or can choose to walk a little farther to get to their destination rather than wait for a local bus. Implementing limited-stop service can be a first step in the development of a bus rapid transit line and is the course of action that AC Transit has chosen for staging the implementation of BRT in the San Pablo Avenue corridor between Oakland, El Cerrito, and San Pablo, California.(R8)

In Los Angeles, two pilot BRT lines were developed along the Wilshire-Whittier and Ventura Boulevard corridors. Limited-stop service, with an average stop spacing of 0.85 mile (1.4 km), was implemented on top of the existing local bus service. Traffic signal priority was provided at intersections within the City of Los Angeles, and other service modifications were also made. The initial service provided a 23 to 29% reduction in average running time, two-thirds of which was attributable to the bus stop consolidation.(R39)

Skip-Stop Operation

When all buses stop at every bus stop, the available capacity is used up more quickly than if buses are spread out among several groups of stops. This technique of spreading out stops among two to four alternating patterns, known as *skip-stops,* offers the ability to substantially improve bus speeds and overall facility bus capacity.

Exhibit 4-32 depicts a portion of the Portland, Oregon, Fifth Avenue bus mall. Buses using the mall are divided into four groups with similar regional destinations. Each group is identified by a particular directional symbol, such as the "W" for "west" shown in the exhibit.[3] All buses belonging to that group make all stops designated for that group, and bypass the other groups' stops. As can be seen, two sets of stops are located in each block, and each group of buses stops every other block. Other signing systems are possible; for instance, Denver uses an "X-Y-Z" lettering system to designate skip-stops located along the downtown portions of 15th and 17th Streets.

---

[3] An older, color-coded symbol used prior to September 2002 is also incorporated into the design, such as the orange deer superimposed on the "W" in the exhibit.

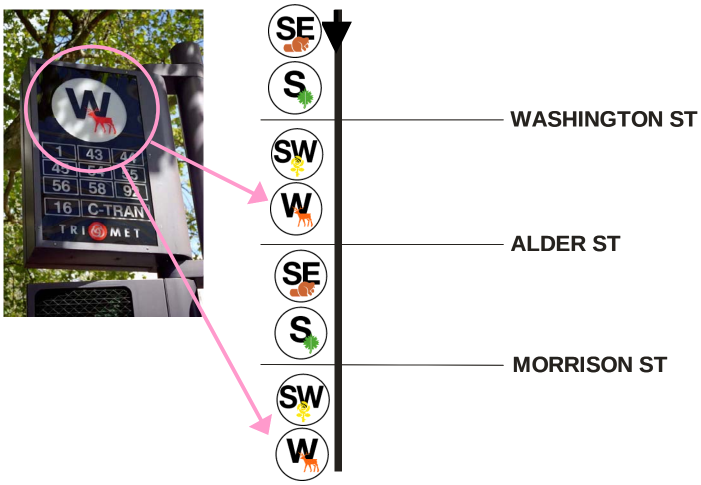


Exhibit 4-32
Example Skip-Stop Pattern and Signing

Skip-stops can greatly increase facility capacity.

These block-skipping patterns allow the bus facility capacity to nearly equal the sums of the capacities of the individual stops, thereby providing a nearly three- or four-fold increase in facility capacity, as well as a substantial improvement in average travel speeds. Due to traffic control delays, the irregularity of bus arrivals, and other factors, the actual capacity increase will be somewhat less than the ideal amount. Also, to maximize the capacity and speed benefits, buses must be able to use the adjacent lane to pass other buses. When that lane operates at or close to capacity, buses may not be able to pass other buses easily.

Platooning

Platooning occurs when a set of buses moves along a street as a group, much like individual cars in a train. Passing activity is minimized, resulting in higher overall travel speeds. Platoons can be deliberately formed, through careful scheduling and field supervision, or can be developed by traffic signals, much as platoons of vehicles form and move down the street together after having been stopped at a traffic signal.

In downtown Ottawa, the city's busway systems feed into arterial street bus lanes. These lanes are able to accommodate the scheduled volumes of buses, in part because the traffic signal progression on those streets is designed to favor buses (i.e., both bus travel time between stops and dwell times at stops are taken into consideration). The combination of the exclusive lanes and the signal progression naturally forms bus platoons, even though buses may not arrive downtown exactly at their scheduled time.(R37)

Design Standards

Developing objective design standards that specify minimum and maximum bus stop spacing, criteria for diverting a route to serve a particular trip generator, and so on can make it easier for transit agencies to improve or at least maintain transit service quality. Having, and consistently applying, these standards can help overcome objections to individual changes and can make larger-scale changes more politically acceptable. For example, having bus stop spacing standards can make it easier to improve service at a later date by justifying the benefits provided by longer stop spacings. Service diversion standards based on person-delay can make a case for or against changes in routing, depending on the net impact on passengers that would result.

SUMMARY

Exhibit 4-33 summarizes the advantages and disadvantages of the transit preferential treatments presented in this chapter.

Exhibit 4-33
Bus Preferential Treatments Comparison(R4,R42)

Treatment	Advantages	Disadvantages
ROADWAY AND TRAFFIC SIGNAL TREATMENTS		
Exclusive Bus Lanes	• Increases bus speed by reducing sources of delay • Improves reliability • Increases transit visibility	• Traffic/parking effects of eliminating an existing travel or parking lane must be carefully considered • Requires on-going enforcement
Signal Priority	• Reduces traffic signal delay • Improves reliability	• Risks interrupting coordinated traffic signal operation • Risks lowering intersection LOS, if intersection is close to capacity • Requires inter-jurisdiction coordination • Cross-street buses may experience more delay than time saved by the favored routes
Queue Bypass	• Reduces delay from queues at ramp meters or other locations	• Bus lane must be available and longer than the back of queue
Queue Jump	• Reduces delay from queues at signals • Buses can leap-frog stopped traffic	• Right lane must be available and longer than the back of queue • Special transit signal required • Reduces green time available to other traffic • Bus drivers must be alert for the short period of priority green time
Curb Extensions	• Eliminates re-entry delay • Riding comfort increased when buses don't pull in and out of stops • Increases on-street parking by eliminating need for taper associated with bus pullouts • More room for bus stop amenities • Reduces ped crossing distance	• Requires at least two travel lanes in bus's direction of travel to avoid blocking traffic while passengers board and alight • Bicycle lanes require special consideration
Boarding Islands	• Increases bus speed by allowing buses to use faster-moving left lane	• Requires at least two travel lanes in bus's direction of travel and a significant speed difference between the two lanes • Uses more right-of-way than other measures • Pedestrian/ADA accessibility, comfort, and safety issues must be carefully considered
Parking Restrictions	• Increases bus speed by removing delays caused by automobile parking maneuvers • Increases street capacity and reduces traffic delays	• May significantly impact adjacent land uses (both business and residential) • Requires on-going enforcement
Turn Restriction Exemption	• Reduces travel time by eliminating detours to avoid turn restrictions	• Potentially lowers intersection level of service • Safety issues must be carefully considered
BUS OPERATIONS TREATMENTS		
Bus Stop Relocation	• Uses existing signal progression to bus's advantage	• May increase walking distance for passengers transferring to a cross-street bus
Bus Stop Consolidation	• Reduces number of stops, thereby improving average bus speeds	• Increases walking distances for some riders • Pedestrian environment may not support walking to the next closest stop
Skip-stops	• Substantially improves bus speed and capacity	• Unfamiliar riders may be unsure about where to board their bus • Requires available adjacent lane
Platooning	• Reduces bus passing activity	• May be difficult to implement
Design Standards	• Service changes to improve operations more easily justified • Supports consistent transit planning and design	• Too rigid an application of standards can be just as bad as not having standards

CHAPTER 3. PLANNING APPLICATIONS

INTRODUCTION

This chapter consists of two major sections. The first section presents guidelines for implementing many of the transit preferential treatments discussed in Chapter 2. The second section, which also includes the material in Appendix D, provides planning-level capacities for various kinds of bus stops and facilities.

The planning guidelines presented in this chapter are based on experiences with specific applications and previous studies on the effectiveness of particular kinds of transit preferential treatments. The guidelines suggest typical ranges of passenger, bus, and/or motor vehicle volumes which may suggest the need for certain kinds of improvements. This level of detail may be used to develop a range of alternatives suitable for planning-level analyses and should only be represented as such. More detailed analysis using the procedures presented in subsequent chapters, as well as *Highway Capacity Manual* procedures where appropriate, should be conducted prior to selecting or implementing particular treatments.

Consider a series of complementary efforts when implementing a transit priority program.

One of the most critical factors in the success of a transit priority measure is the careful planning and design of particular improvements. The guidelines in this chapter focus on individual types of treatments. However, it is emphasized that one of the ways to maximize the effectiveness of a transit priority program is by implementing a whole series of complementary efforts.

TRANSIT PREFERENTIAL TREATMENTS

Uninterrupted Flow Facilities

Policy and cost considerations usually dictate the lower limit for bus volumes that warrant busway or freeway HOV lane treatments. Lower minimum vehicle thresholds can be expected, and are usually accepted, with busways than with HOV lanes; however, the minimum vehicle threshold may be higher in a heavily congested corridor than in one with lower levels of congestion. Non-users in heavily congested areas may be much more vocal about a facility they feel is under-utilized than commuters in a corridor where congestion is not at serious levels. Whenever considering providing busway or HOV facilities, the perceptions of commuters and the public, as well as any unique local conditions, should be considered when developing minimum operating thresholds.(R44)

Exhibit 4-34 presents typical minimum freeway HOV lane operating thresholds in vehicles per hour per lane, based on U.S. experience. These thresholds balance the number of people using the lane with the cost of constructing the lane.

Exhibit 4-34
Typical Busway and HOV Lane Minimum Operating Thresholds(R44)

Facility Type	Minimum Operating Threshold (veh/h/lane)
Separate right-of-way, HOV	800-1,000
Freeway, exclusive two-directional	400-800
Freeway, exclusive reversible	400-800
Freeway, concurrent flow	400-800
Freeway, contraflow HOV	400-800
HOV queue bypass lanes	100-200

NOTE: Volumes include both buses and private vehicles that are HOVs.

Exhibit 4-35 presents general planning guidelines for busways and bus priority treatments associated with freeways. Exhibit 4-36 provides guidance on the effects of these treatments. For more information on busway and freeway HOV facility planning guidelines, design, and operation, consult the TRB *HOV Design Manual*.(R44)

Exhibit 4-35
General Planning Guidelines for Bus Preferential Treatments: Uninterrupted Flow Facilities(R27)

Treatment	Minimum One-Way Peak Hour Bus Volumes	Minimum One-Way Peak Hour Passenger Volumes	Related Land Use and Transportation Factors
Exclusive busways on special right-of-way	40-60	1,600-2,400	Urban population: 750,000; CBD employment: 50,000; 1.85 million m^2 CBD floor space; congestion in corridor; save buses 1 min/mi (0.6 min/km) or more.
Exclusive busways within freeway right-of-way	40-60	1,600-2,400	Freeways in corridor experience peak-hour congestion; save buses 1 min/mi (0.6 min/km) or more.
Busways on railroad right-of-way	40-60	1,600-2,400	Potentially not well located in relation to service area. Stations required.
Freeway bus lanes, normal flow	60-90	2,400-3,600	Applicable upstream from lane drop. Bus passenger time savings should exceed other road user delays. Normally achieved by adding a lane. Save buses 1 min/mi (0.6 min/km) or more.
Freeway bus lanes, contraflow	40-60	1,600-2,400	Freeways with six or more lanes. Imbalance in traffic volumes permits freeway LOS D in off-peak travel direction. Save buses 1 min/mi (0.6 min/km) or more.
Bus lane bypasses at toll plazas	20-30	800-1,200	Adequate queuing area on toll plaza approach, so bus lane access is not blocked.
Exclusive bus access to non-reserved freeway or arterial lane	10-15	400-600	
Bus bypass lane at metered freeway ramp	10-15	400-600	Alternate surface street route available for metered traffic. Express buses leave freeways to make intermediate stops.
Bus stops along freeways	5-10	50-100*	Generally provided at surface street level in conjunction with metered ramp.

*Boarding or alighting passengers in the peak hour.

Exhibit 4-36
General Planning Guidelines on the Effects of Bus Preferential Treatments: Uninterrupted Flow Facilities(R12,R34,R36)

Treatment	Travel Time Improvements	Person Delay Impacts	Additional Considerations
Busways	up to 10 percent; varies depending on routing and other design details	Minimal to significant, depending on the project	Applications may include special bus detection technologies that distinguishes buses from general traffic
HOV lanes	Up to 20 percent; varies on out of direction travel	Significant, dependent on application	
Freeway bus lanes	3-15% of overall travel time, up to 75% of delay	Minimal to significant, highly dependent on the strategy and location	Travel time improvements are a function of the existing delay.
Bus lane bypasses	Up to 20%; up to 90% of ramp meter delay	Potentially significant	Potential disruptions to queue storage needs on ramps.

Interrupted Flow Facilities

Urban Streets

Bus lanes have been provided on urban streets by adding lanes, developing contraflow lanes, and converting roadway shoulders for bus use. Several studies offer guidance in identifying factors that influence whether bus lanes may be appropriate. These factors include(R36)

- Congestion,
- Travel time savings,
- Person throughput,
- Vehicle throughput,
- Local agency support,
- Enforceability, and
- Physical roadway characteristics.

Policy and cost considerations generally set the lower limit for bus volumes that warrant priority treatments on arterials, while bus vehicle capacity sets the upper limit. A study of bus operations in Manhattan recommended the following desirable maximum a.m. peak hour bus volumes for arterial street bus lanes:(R28)

- Two lanes exclusively for buses: 180 bus/h;
- One lane exclusively for buses, partial use of adjacent lane: 100 bus/h;
- One lane exclusively for buses, no use of adjacent lane: 70 bus/h; and
- Buses in curb lane in mixed traffic: 60 bus/h.

Exhibit 4-37 presents general planning guidelines for bus priority treatments on arterial streets. A comparison of person volumes on buses operating in mixed traffic with person volumes in other vehicles operating on the street can also be used to help decide when to dedicate one or more lanes to exclusive bus use.

Exhibit 4-37
General Planning Guidelines for Bus Preferential Treatments: Urban Streets(R27,R44)

Treatment	Minimum One-Way Peak Hour Bus Volumes	Minimum One-Way Peak Hour Passenger Volumes	Related Land Use and Transportation Factors
Bus streets or malls	80-100	3,200-4,000	Commercially oriented frontage.
CBD curb bus lanes, main street	50-80	2,000-3,200	Commercially oriented frontage.
Curb bus lanes, normal flow	30-40	1,200-1,600	At least 2 lanes available for other traffic in same direction.
Median bus lanes	60-90	2,400-3,600	At least 2 lanes available for other traffic in same direction; ability to separate vehicular turn conflicts from buses.
Contraflow bus lanes, short segments	20-30	800-1,200	Allow buses to proceed on normal route, turnaround, or bypass congestion on bridge approach.
Contraflow bus lanes, extended	40-60	1,600-2,400	At least 2 lanes available for other traffic in opposite direction. Signal spacing greater than 500-ft (150-m) intervals.

Intersections

The use of bus preferential treatments at intersections should be based on person-delay studies at the intersection and local jurisdiction policies. In certain jurisdictions, priority of transit vehicles is maximized where possible to improve transit operations and the quality of service. In these instances, one need only evaluate the application and its feasibility from a cost and implementation perspective. Exhibit 4-38 presents general planning guidelines for bus preferential treatments at intersections. A comparison of typical effects on bus travel time and overall person delay is reported in Exhibit 4-39.

Exhibit 4-38
General Planning Guidelines for Bus Preferential Treatments: Intersections

	Application Considerations		
Treatment	**Primary**	**Secondary**	**Related Land Use and Transportation Factors**
Bus-activated signal phases	Low-volume movement	High bus delay on approach	At access points to bus lanes, busways, or terminals; or where bus turning movements experience significant delays.
Bus signal priority	Intersections with high bus delay, coordinated signal system	Preferable at intersections with far-side stops	Traffic signal controller software may need to be upgraded.
Bus signal pre-emption	Intersections with high bus delay, uncoordinated signal system	Preferable at intersections without pedestrians	Pedestrian clearance or signal network constraints.
Special bus turn provisions	Route deviations to avoid turn prohibitions		Wherever vehicular turn prohibitions are located along routes.
Queue Jump	Intersections with large amounts of control delay (HCM LOS D or worse)	Right turn lane existence, bus routes with sub-15 minute headways	Merge on opposite side of intersection should consider bus operations.
Curb Extensions	Areas with high pedestrian traffic	Insufficient sidewalk space for shelter	Impacts to other road users and drainage issues.
Boarding Islands	Streets with four or more lanes	Locations where geometric conditions allow	Impacts to other road users, ped access to island may be a concern.
Parking Restrictions	Need for additional bus capacity	On-street parking exists	Local business and residence parking impacts.
Stop Consolidation (permanent or temporary)	Long routes with high ratio of dwell time to travel time	Pedestrian environment	May reduce access to transit routes if stops are too far apart.

BUS STOP AND FACILITY CAPACITY

The capacity analysis for transit facilities presented in the following chapters provides a highly detailed treatment of transit operations. The level of precision inherent in that analysis may exceed the accuracy of the available data. In contrast, for planning purposes, the only requirement is a concept for a potential improvement and a general understanding of how existing service operates.

Bus Volume and Capacity Relationships

The observed peak hour bus movements along freeways and city streets, and to or from bus terminals, provide guidelines for estimating the capacity of similar facilities. They also provide a means of checking or verifying more detailed capacity calculations. General planning guidelines are presented in Exhibit 4-40 that match scheduled bus volumes on downtown streets and arterial streets leading to the city center to qualitative descriptions of bus flow along those streets. Where stops are not heavily patronized, as along outlying arterial streets, bus volumes could be increased by about 25%.

Exhibit 4-39
General Planning Guidelines on the Effects of Bus Preferential Treatments: Intersections

Treatment	Bus Travel Time Improvements	Vehicle Delay Impacts	Additional Considerations
Bus-activated signal phases	up to 10%	Minimal	Applications may include special bus detection technologies that distinguish buses from general traffic.
Bus signal priority	3-15% of overall travel time, up to 75% of signal delay	Minimal to significant, highly dependent on the strategy and location	Travel time improvements are a function of the existing signal delay.
Bus signal pre-emption	Up to 20%, up to 90% of signal delay	Potentially significant	Potential disruptions to signal coordination and transportation capacity.
Special bus turn provisions	Depends on route	Minimal	Safety concerns may require changes to signalization for bus-only movement.
Queue Jump	5-25%	None, if using existing turn lane	Advance green at the intersection may facilitate exit from queue jump lane.
Curb Extensions	Not enough data	Potentially significant	Potential impacts to general traffic.
Boarding Islands	Not enough data		Potential impacts to general traffic.
Parking Restrictions	Not enough data	None	Auto access to local land uses is reduced.
Stop Consolidation (permanent or temporary)	3-20% of overall run time, up to 75% of dwell time	None	Accessibility to transit service is reduced.

Exhibit 4-40
Planning-Level Bus Lane Service Volumes[R17,R46]

These service volumes may be used for planning purposes. More precise values for operations and design purposes should be computed from the capacity relationships and procedures presented later in Part 4.

The values for forced flow conditions should not be used for planning or design. They are merely given for comparative purposes.

Description	Service Volume bus/lane/h	Average bus/lane/h
ARTERIAL STREETS		
Free Flow	25 or less	15
Stable Flow, Unconstrained	26 to 45	35
Stable Flow, Interference	46 to 75	60
Stable Flow, Some Platooning	76 to 105	90
Unstable Flow, Queuing	106 to 135	120
Forced Flow, Poor Operation	over 135*	150*
DOWNTOWN STREETS		
Free Flow	20 or less	15
Stable Flow, Unconstrained	21 to 40	30
Stable Flow, Interference	41 to 60	50
Stable Flow, Some Platooning	61 to 80	70
Unstable Flow, Queuing	81 to 100	90
Forced Flow, Poor Operation	over 100*	110*

*Results in more than one-lane operation.

The number of people per hour that can be served by various bus flow rates and passenger load factors on exclusive bus lanes are given in Exhibit 4-41. This exhibit provides a broad person-capacity planning guide that assumes that key boarding points are sufficiently dispersed to achieve these bus loads. It suggests *maximum* person-flow rates of about 6,450 people per hour per lane on downtown streets and 8,700 people per hour per lane on arterial streets. Corresponding maximum values for *seated* passenger flows are 4,300 and 5,800 people, respectively. Exclusive use of articulated buses would increase these values by 15 to 20%.

Exhibit 4-41
Maximum Bus Passenger Service Volumes for Planning Purposes

	Load Factor (p/seat)				
Buses per Hour	**0.00-0.50**	**0.51-0.75**	**0.76-1.00**	**1.01-1.25**	**1.26-1.50**
ARTERIAL STREETS					
25 or less	535	805	1,075	1,340	1,610
26 to 45	965	1,450	1,935	2,415	2,900
46 to 75	1,610	2,415	3,225	4,030	4,835
76 to 105	2,255	3,385	4,515	5,640	6,770
106 to 135	2,900	4,350	5,805	7,255	8,705
DOWNTOWN STREETS					
20 or less	430	645	860	1,075	1,290
21 to 40	860	1,290	1,720	2,150	2,580
41 to 60	1,290	1,935	2,580	3,225	3,870
61 to 80	1,720	2,580	3,440	4,300	5,160
81 to 100	2,150	3,225	4,300	5,375	6,450

NOTE: Assumes 43 seats per bus and a peak hour factor of 1.00.

The passenger volumes presented in Exhibit 4-41 indicate the number of people that can be carried, assuming uniform flow during the peak hour (i.e., a peak hour factor of 1.00). As uniform flow rarely occurs and indicates underservicing of demand when it does occur, appropriate peak hour factors should be used to reduce these values to design levels to reflect passenger flow variations within the 15-minute peak period.

Busways

Illustrative downtown busway bus and person capacities are given in Exhibit 4-42 for a variety of bus types and service conditions. The key assumptions are:

- Fares are pre-paid at downtown busway stations. This eliminates the time required to pay fares on-board the bus and allows all doors to be used for loading. These measures greatly decrease the service time required per passenger, since several passengers can board at the same time and each individual passenger’s boarding time is minimized.
- Fifty percent of the maximum load point passengers board at the heaviest stop (i.e., boarding volumes at the critical downtown stop, rather than the busway facility itself, constrain capacity). A peak hour factor of 0.67 is used.
- No delays due to signals (grade-separated facility).
- The bus clearance time at stops is 10 seconds. The design failure rate is 7.5%, and a 60% coefficient of variation is assumed.
- Three linear loading areas are provided at each station.
- The maximum load section passenger volume is limited to 40 passengers per bus for standard buses and 60 passengers for articulated buses; this equates to a load factor of approximately 1.00 and provides a seat for all passengers.

Arterial Street Bus Lanes

Exhibit 4-68 through Exhibit 4-72 in Appendix D provide graphs of arterial street bus lane capacities for various situations. These graphs replicate the detailed capacity calculation procedures provided in Chapter 5 for the conditions identified with each graph. Note that these graphs provide capacities based on a single loading area at the critical stop. Multiply these capacities by the appropriate loading area equivalency factor from Exhibit 4-12 to obtain bus capacities for stops with multiple loading areas.

Exhibit 4-42
Illustrative Downtown Busway Capacities

	Loading Condition							
	A		**B**		**C**		**D**	
Stations: On-Line/Off-Line	**On**	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**
PASSENGERS BOARDING AT HEAVIEST STATION								
Boarding passengers per bus	20	20	20	20	20	20	30	30
Boarding time per passenger (s)	2.0	2.0	1.2	1.2	0.7	0.7	0.5	0.5
Dwell time (s)	40.0	40.0	24.0	24.0	14.0	14.0	15.0	15.0
VEHICLE CAPACITY								
Loading area capacity (bus/h)	42	42	65	65	100	100	95	95
Effective loading areas	2.45	2.65	2.45	2.65	2.45	2.65	2.45	2.65
Station capacity (bus/h)	103	111	159	172	245	265	233	251
PASSENGERS PER HOUR AT MAXIMUM LOAD POINT								
Peak—flow rate (15 min x 4)	4,120	4,440	6,360	6,880	9,800	10,600	13,980	15,060
Average—peak hour (with PHF)	2,760	2,970	4,260	4,600	6,570	7,100	9,370	10,090

Loading condition A: Single-door conventional bus, simultaneous loading and unloading.
Loading condition B: Two-door conventional bus, both doors loading or double-stream doors simultaneously loading and unloading.
Loading condition C: Four-door conventional bus, all double-stream doors loading.
Loading condition D: Six-door articulated bus, all doors loading.

NOTE: Assumes 10-second clearance time, 7.5% failure rate, 60% coefficient of variation, 3 linear loading areas, *g/C* = 1.0, random bus arrivals, PHF = 0.67, 50% of passengers board at heaviest downtown station, 40 seats per conventional bus, 60 seats per articulated bus, no standees allowed.

Mixed Traffic Bus Operations

Exhibit 4-73 in Appendix D provides graphs of mixed traffic capacities for various situations. These graphs replicate the detailed capacity calculation procedures provided in Chapter 6 for the conditions identified with each graph. As before, these graphs provide capacities based on a single loading area at the critical stop. Multiply these capacities by the appropriate loading area equivalency factor from Exhibit 4-12 to obtain bus capacities for stops with multiple loading areas.

Bus Stops and Loading Areas

Exhibits 4-64 through 4-66 in Appendix D provide graphs of bus capacities for individual loading areas and bus stops consisting of a single loading area, based on various situations. These graphs replicate the detailed capacity calculation procedures provided in Chapter 1 for the conditions identified with each graph. Once again, multiply the capacities given by these graphs by the appropriate loading area equivalency factor from Exhibit 4-12 to obtain bus capacities for stops with multiple loading areas.

Factors Influencing Bus and Person Capacity

Exhibit 4-43 summarizes the factors influencing bus capacity, bus speed, and person capacity and suggests ways that each can be improved to provide additional capacity. Note that in some cases, increasing capacity or speed requires a trade-off with decreased quality of service.

Exhibit 4-43
Factors Influencing Bus Capacity and Speed

Item	Ways To Improve Each Item
CAPACITY INPUTS	
Dwell Time	Greater use of pre-paid fares Use low-floor vehicles (may reduce seating area) Encourage one-way door flows on two-door buses Provide multiple-stream doors for boarding and alighting Increase bus frequency to reduce the number of standees Implement proof-of-payment fare collection
Clearance Time	Use on-line stops when only 1-2 loading areas at stop Enact and enforce yield-to-bus laws Implement queue jumps at traffic signals
Coefficient of Variation	Generally constant for a given area
Failure Rate	Increase the number of loading areas at a stop Schedule fewer buses per hour using the stop (reduces availability)
CAPACITY OUTPUTS	
Loading Area Capacity	Reduce dwell time Implement transit priority treatments Increase the accepted failure rate (reduces reliability)
Bus Stop Capacity	Increase loading area capacity Use off-line loading areas when 3 or more loading areas at stop Consider non-linear loading area designs Increase the number of loading areas
Bus Lane Capacity	Increase the capacity of the critical stop Reserve lanes for buses Implement skip-stop operation Prohibit right turns by automobiles
Bus Speeds	Reduce dwell time Implement transit preferential treatments Enforce restrictions on use of bus lane by other vehicles Balance the number of stops with passenger convenience and demand Consider supplementing local service with limited-stop service Implement skip-stop operation

CHAPTER 4. GRADE-SEPARATED FACILITIES

INTRODUCTION

This chapter presents methodologies for analyzing bus operations on grade-separated busways and freeway HOV lanes. *Grade-separated busways* are characterized by uninterrupted flow (i.e., no traffic signals), exclusive use by buses, and lanes physically separated from other traffic. At-grade busways, such as Miami's South Dade Busway, have interrupted traffic flow due to traffic signals. These facilities should be analyzed using the arterial street bus lane procedures given in Chapter 5. *Freeway HOV lanes* also have uninterrupted flow, but may be shared with other passenger vehicles with a designated number of occupants (typically 2 or 3), and are not necessarily physically separated from other traffic.

Grade-separated busways are characterized by at least one separated lane reserved exclusively for buses and uninterrupted flow.

At-grade busways (having interrupted flow) are analyzed as arterial street bus lanes and are addressed in Chapter 5.

BUS CAPACITY

Grade-Separated Busways

Exhibit 4-44 shows typical design features that influence capacity and quality of service, using the South East Busway in Brisbane, Australia, as an example.

Exhibit 4-44
Typical Grade-Separated Busway Design Features

(a) Exclusive, Grade-Separated Facility

(b) Passing Lanes at Stations

(c) Multiple Loading Areas

(d) Grade-Separated Pedestrian Crossings

(e) Integration with Adjacent Land Uses

(f) Park-and-Ride Lots, Feeder Bus Access

- *Exclusive, grade-separated, uninterrupted flow facilities* eliminate delays due to signals and other non-transit vehicles. This results in higher capacity, higher operating speeds (typically 45 to 50 mph or 70 to 80 km/h), and higher average speeds, when station stops or slowdowns are accounted for. Reliability is improved, as most factors that tend to delay buses are removed.

Express buses typically slow to 15 to 30 mph (25 to 50 km/h) within stations, with the lower end applying when pedestrians can cross the busway at grade.

- *Passing lanes at stations* allow both express and local service. Express buses can bypass stations, although for safety reasons they often slow to 15 to 30 mph (25 to 50 km/h) within stations. When passing lanes are provided at all stations, express services are not delayed by local buses making stops, and the total number of buses that can use the busway therefore is significantly greater than the capacity of an individual busway station.
- *Multiple loading areas* allow more buses to stop simultaneously, increasing local bus service capacity and minimizing the possibility of a bus stop failure occurring (a bus arriving to find all loading areas already occupied).
- *Pre-payment of fares*, or *pay-on-exit* fare systems allow all doors to be used for boarding at the stops with the highest boarding volumes. This minimizes dwell time and improves both speed and capacity.
- *Grade-separated pedestrian crossings* improve safety by separating bus and pedestrian traffic. Express buses may be able to operate faster through stations when pedestrian crossings are not allowed, although typical operating practice calls for a reduced speed through stations due to potential conflicts with other buses and pedestrians illegally crossing the busway.
- *Busway connections to the local street system* allow local neighborhood buses to access the busway after picking up passengers and then continuing as a local or express service to the downtown. This operation provides a one-seat ride to the downtown for passengers, eliminating delays to passengers associated with transferring between buses.
- *Park-and-ride lots* focus passenger demand to a limited number of stops, allowing each stop to serve a relatively high passenger demand.
- *Integrating the busway with major land uses* minimizes passenger walking distances to major destinations and may avoid the need for passengers to cross wide or busy streets to get to their destination.

Typically, the maximum number of buses that can use a busway will not be constrained by the busway itself but by conditions before or after the busway—often the surface street system that buses use to get to downtown stops. For example, in Brisbane, the South East Busway exits onto an arterial street bus lane that leads to a bridge into downtown; this street also serves a number of local routes that do not use the busway proper. Presently, a station along this street that has no passing lane (due to limited space) constrains capacity. When this constraint is addressed, then traffic signals along the street will become the capacity constraint.

Exhibit 4-45
Illustrative Capacity Constraints After Exclusive Busway Section

(a) No Passing Lane Available

(b) Traffic Signals

The capacity of local services using the busway will be constrained by the stop with the highest dwell time along the busway, assuming all stations are designed with a similar number of loading areas. Peak hour factors of 0.67 to 0.75 are reasonable for busways, depending on the location and type of operation.

Grade-separated busways with a limited number of downtown stops have passenger distribution characteristics similar to rail lines.

If the busway extends into the downtown (for example, Seattle's bus tunnel) and has a limited number of stations in the downtown area, the busway's passenger distribution characteristics will be similar to those of a rail line. A reasonable design assumption is that 50% of the maximum load point volume will be served at the heaviest downtown busway station—assuming a minimum of three stops in the downtown area. (For comparison, the Washington-State Street subway station in Chicago accounts for about one-half of all boarding passengers at the three downtown stops on the State Street subway line.)(R40)

Equation 4-9 provides the bus capacity of local service (making all stops) using the busway; Equation 4-8 in Chapter 1 provides the corresponding person capacity. Planning-level estimates of busway person capacity can be found in Exhibit 4-42. To determine the total number of local and express buses that can use the busway, and the corresponding person capacity, use the procedures in Chapters 5 and 6 (for arterial street bus lanes and mixed traffic, respectively) and Part 7 (bus stop, station, and terminal capacity) to determine the capacity constraint prior to or following the busway section.

$$B = B_{s,min}$$

Equation 4-9

where:

B = bus capacity for local busway service (bus/h); and

$B_{s,min}$ = minimum bus stop capacity along the busway (bus/h).

Freeway HOV Lanes

Freeway HOV lanes are designed to increase the potential person capacity of a freeway by reserving one or more lanes, either part-time or full-time, for the use of vehicles with multiple occupants. When the regular freeway lanes experience congestion, vehicles in the HOV lane should still travel freely, so that the HOV lane provides the time-savings benefit that attracts users to the lane and thus results in a more efficient use of the freeway lanes.

In order to maintain this time-savings incentive (and to continue to move more people through the freeway segment than would be possible without the HOV lane), HOV lanes should not operate at or near capacity. The level of service provided to persons traveling in an HOV lane should be better during peak periods than the level of service provided to vehicles traveling in the regular freeway lanes. This level of service can be calculated using the procedures given in the *Highway Capacity Manual.*

Calculating the theoretical bus capacity, or *service volume*, for freeway HOV lanes used exclusively by buses is not practical for two reasons. First, with the exception of the New Jersey approach to the Lincoln Tunnel, no North American transit agency schedules so many buses as to come close to the capacity of a basic freeway segment. The Lincoln Tunnel approach, an a.m. peak hour contraflow lane, is used by 735 buses per hour that make no stops along the lane. The buses feed the Port Authority Bus Terminal, which provides 210 berths to accommodate these and other buses.(R30)

Second, the number of buses that can be scheduled along the freeway HOV lane will be constrained by the vehicle capacity of off-line ("freeway flyer") stops along the HOV lane (see Exhibit 4-46), or by the capacity of on-street sections or a bus terminal following the bus lane. When all buses stop at off-line stops along the HOV lane, the lane's bus capacity can be calculated using Equation 4-9 above, and its person capacity can be calculated using Equation 4-8 in Chapter 1.

Exhibit 4-46
Freeway HOV Lane with Off-Line Stop (Seattle)

(a) Right-Side HOV Lane (b) Off-Line HOV Bus Stop

BUS SPEEDS

The average speed of a bus operating on a grade-separated busway or freeway HOV lane depends on three factors:

- The running speed of the bus in the lane,
- Bus stop or station spacing, and
- Dwell time at bus stops or stations.

The running speed of buses operating in a grade-separated busway or an exclusive freeway HOV lane (not shared with other vehicles) can be assumed to be equivalent to the posted speed limit. For freeway HOV lanes shared with other vehicles, the *Highway Capacity Manual* may be used to estimate the running speed of vehicles in the lane, given the lane's free-flow speed, the traffic volume, and the mix of passenger vehicles and buses using the lane. Note that the HCM procedures only apply to lanes operating below capacity. The time required to travel the length of the HOV lane, without stopping, can be calculated from this running speed.

Bus stop spacing affects how often buses must stop or slow. The dwell time and acceleration/deceleration delays associated with each stop reduce overall bus speeds. A rate of 4.0 ft/s² (1.2 m/s²) may be assumed for acceleration and deceleration, in the absence of local data.(R36) Exhibit 4-47 presents average travel speeds for a selection of running speeds, dwell times, and bus stop spacings. As would be expected, average bus speeds decrease as the stop spacing increases and as the average dwell time per stop increases.

Exhibit 4-47
Estimated Average Speeds of Buses Operating on Busways and Exclusive Freeway HOV Lanes (mph)

An alternative exhibit using metric units appears in Appendix A.

Average Stop Spacing (mi)	Average Dwell Time (s) 0	15	30	45	60
50 mph Running Speed					
0.5	36	26	21	18	16
1.0	42	34	30	27	24
1.5	44	38	35	32	29
2.0	46	41	37	35	32
2.5	46	42	39	37	35
55 mph Running Speed					
0.5	37	27	22	18	16
1.0	44	36	31	28	25
1.5	47	40	36	33	30
2.0	49	43	40	37	34
2.5	50	45	42	39	37
60 mph Running Speed					
0.5	37	27	22	19	16
1.0	46	37	32	28	25
1.5	50	43	38	34	31
2.0	52	46	42	39	36
2.5	54	48	45	41	39

NOTE: Assumes constant 4.0 ft/s² acceleration/deceleration rate. Use the zero dwell time column for express buses slowing, but not stopping at stations (25 mph station speed limit and 325-ft-long speed zone through station assumed).

CHAPTER 5. ARTERIAL STREET BUS LANES

INTRODUCTION

This chapter presents methodologies for analyzing the operation of buses using arterial street bus lanes and at-grade busways. The key characteristics of these facilities are at least one lane reserved exclusively for use by buses (except possibly at intersections), and interrupted flow (e.g., traffic signals, stop signs, etc.). Busways that have traffic signals located along them should be analyzed using the procedures in this chapter.

Arterial street bus lanes are characterized by at least one lane exclusively for buses (except possibly at intersections) and interrupted flow.

BUS LANE TYPES

Several types of exclusive bus lanes exist. The capacity procedures used in this chapter define three types of bus lanes, based on the availability of the adjacent lane for buses to pass each other. Exhibit 4-48 illustrates and describes each kind of lane.

Exhibit 4-48
Exclusive Bus Lane Types

Type 1

- Buses have no use of adjacent lane
- Contraflow lanes
- Physically channelized lanes

(a) Denver, (b) Orlando

Type 2

- Buses have partial use of adjacent lane, depending on other traffic
- Right turns by other vehicles may or may not be prohibited

(c) Montréal, (d) Madison

Type 3

- Buses have full use of adjacent lane
- Right turns prohibited (except buses)
- Includes at-grade busways with single lanes, but passing lanes at stops

(e) New York, (f) Miami

BUS CAPACITY

The bus capacity of an arterial street bus lane depends on several factors:

- The bus capacity of the critical bus stop(s) along the lane,
- The bus lane type,
- Whether or not skip-stops are used,
- Whether or not buses move along the lane in platoons,
- The volume-to-capacity ratio of the adjacent lane (for Type 2 bus lanes), and
- Bus stop locations and right-turning volumes made from the bus lane.

The critical stop capacity depends on average dwell time at the stop, traffic signal timing, the number of loading areas provided, and other factors discussed in Chapter 1.

If no special operational procedures, such as skip-stops, are used and if right turns by non-transit vehicles are prohibited, then the bus lane capacity is simply the bus capacity of the critical bus stop along the bus lane. However, when skip-stops are used or when right turns are allowed, then adjustments must be made to this base capacity, as described in the following sections.

Right-Turning Traffic Delays

Capacity adjustment for the effects of right-turning traffic

Right-turning traffic competes with buses for space at an intersection. This traffic generally turns from the bus lane, although in some cases (as in Houston) some right turns are made from the adjacent lane. The right turns may queue behind buses at a near-side bus stop to make a right turn. Conversely, right-turning traffic may block buses or pre-empt signal green time from them. The interference of right-turning traffic on bus operations can be further magnified by significant pedestrian crossing volumes that block right-turn movements. The placement of the bus stop at the intersection—near-side, far-side, or mid-block—can also influence the amount of delay induced by, and imposed on, the right-turning traffic.

Exhibit 4-49
Examples of Auto Turning Conflicts with Buses

(a) Los Angeles (right turn)

(b) Portland, Oregon (left turn)

The conflicts between buses and right turns are greatest where there is a near-side stop and buses are unable to freely use the bus lane. Automobiles turning right may block access to the bus stop; conversely, buses boarding or discharging passengers on the green signal indication may block right turns. The amount of interference diminishes as the distance between the stop line and bus stop increases. Far-side or mid-block stops therefore minimize the effects of right turns on bus speeds, when buses can use the adjacent lane. Placing stops at locations where there are no right turns can further minimize impacts. Right turns by general traffic are usually prohibited when dual or contraflow bus lanes are used.

Just as right turns across bus lanes delay buses along the arterial, pedestrians using crosswalks parallel to the bus lane delay right-turning vehicles. This, in turn, results in increased delays to buses in the bus lane. The delays introduced by pedestrians are concentrated at the beginning of the signal green interval for bus movement on the arterial, when queued groups of pedestrians step off the curb.

By crossing or utilizing space in the bus lane to execute their turn, right-turning vehicles reduce the bus lane vehicle capacity by using a portion of the green time available to buses. Thus, bus lane vehicle capacity will be approached more quickly when right turns occur. For bus volumes less than one-half of the bus lane capacity, there is generally little impact on bus lane capacity or speed from a moderate volume of right turns, unless pedestrian volumes are very heavy. Detailed procedures for estimating right-turn vehicle capacity are given in the *Highway Capacity Manual*. A planning-level estimate of right-turn vehicle capacity is provided in Exhibit 4-50.

Exhibit 4-50
Right-Turn Vehicle Capacities for Planning Applications (veh/h)

Conflicting ped	*g/C* Ratio for Bus Lane					
volume (ped/h)	0.35	0.40	0.45	0.50	0.55	0.60
0	510	580	650	730	800	870
100	440	510	580	650	730	800
200	360	440	510	580	650	730
400	220	290	360	440	510	580
600	70	150	220	290	360	440
800	0	0	70	150	220	290
1,000	0	0	0	0	70	150

SOURCE: Chapter 16 of the HCM 2000 (R15), based on 1450*(*g/C*)*(1-((ped. volume)/(*g/C*))/2000).
NOTE: Values shown are for CBD locations, multiply by 1.1 for other locations. Calculations assume that the bus lane acts as an exclusive right-turn lane for all vehicles other than buses.

The effects of right turns on bus lane vehicle capacity can be estimated by multiplying the bus lane vehicle capacity *without* right turns by an adjustment factor. The values of this adjustment factor, f_r, may be estimated from Equation 4-10:(R36)

Equation 4-10

$$f_r = 1 - f_l \left(\frac{v_r}{c_r} \right)$$

where:

f_r = right-turn adjustment factor;
f_l = bus stop location factor, from Exhibit 4-51;
v_r = volume of right turns at specific intersection (veh/h); and
c_r = capacity of right turns at specific intersection (veh/h).

Values of the bus stop location factor, f_l, are shown in Exhibit 4-51. Where right turns are allowed, the factor ranges from 0.5 (for a far-side stop with the adjacent lane available for buses) to 1.0 (for a near-side stop with all buses restricted to a single lane). A factor of 0.0 is used for Type 3 lanes, as right turns are not allowed by non-transit vehicles from this type of bus lane. These factors reflect the likely ability of buses to move around right turns. At critical intersections on some bus lanes, all turns could be prohibited and pedestrian walk signals delayed in order to improve bus capacity.

Exhibit 4-51
Bus Stop Location Factors, f_l(R36)

	Bus Lane Type		
Bus Stop Location	**Type 1**	**Type 2**	**Type 3**
Near-side	1.0	0.9	0.0
Mid-block	0.9	0.7	0.0
Far-side	0.8	0.5	0.0

NOTE: f_l = 0.0 for contraflow bus lanes and median bus lanes, regardless of bus stop location or bus lane type, as right turns are either prohibited or do not interfere with bus operations.

Skip-Stop Operations

The total buses per hour that can be served by a series of skip-stops represents the sum of the capacities of bus routes using each stop, multiplied by an impedance factor, f_k, reflecting inefficient arrival patterns and the effects of high volumes of vehicular traffic in the adjacent lane. Equation 4-11 represents the factors that impede buses from fully utilizing the added capacity provided by skip-stop operations.(R36)

Equation 4-11

$$f_k = \frac{1 + f_a f_i (N_{ss} - 1)}{N_{ss}}$$

where:

f_a = arrival type factor, reflecting the ability to fully utilize the bus stops in a skip-stop operation:
= 0.50 for random arrivals (poor scheduling/poor schedule adherence),
= 0.75 for typical arrivals (imperfect schedule adherence), and
= 1.00 for platooned arrivals (buses travel in groups, like cars of a train);
f_i = adjacent lane impedance factor, from Equation 4-12; and
N_{ss} = number of alternating skip-stops in sequence.

The arrival type factor reflects how efficiently buses arrive at stops: do a clump of buses arrive at once, with a lot of passing activity and delay from other buses, or are buses managed to spread out arrivals over time and minimize bus passing activity? The factor depends on how well buses are scheduled and how well they are able to adhere to the schedule.

Equation 4-12

$$f_i = 1 - 0.8 \left(\frac{v}{c} \right)^3$$

where:

v = traffic volumes in the adjacent lane (veh/h); and
c = capacity of the adjacent lane (veh/h).

A planning-level estimate of the adjacent lane vehicle capacity can be made by multiplying the typical downtown lane vehicle saturation flow rate of 1,700 vehicles per lane per hour of green by the g/C ratio of the bus lane. Outside the downtown area, a saturation flow rate of 1,800 veh/lane/hour of green may be used. Consult the *Highway Capacity Manual* if a more detailed estimate of adjacent lane vehicle capacity is required.

The values provided by Equation 4-11 and Equation 4-12 result in added capacity with skip-stops, even when the adjacent lane is fully utilized by passenger vehicles, since non-stopping buses have zero dwell time at the stop. When there is no spreading of stops, there is no increase in capacity rendered by the adjacent lane, as all buses must stop at every stop.

Exhibit 4-52 gives representative values of the capacity adjustment factor, f_k, for various bus lane types and stopping patterns. As indicated previously, these values are applied to the *sum* of the capacities in the sequence of bus stops. Thus, they reflect the actual dwell times at each stop. Exhibit 4-53 gives factors for a Type 2 bus lane with two-block alternating stops. In general, the traffic impacts of the adjacent lane only become significant when that lane operates above 75% of its capacity.

Exhibit 4-52
Typical Values of Adjustment Factor, f_k, for Availability of Adjacent Lanes(R36)

Condition	Adjacent Lane v/c	f_l	N_{ss} - 1	f_a	f_k
Type 1 Bus Lane					
Stops every block	0 to 1	0 to 1	0	0.00	1.00
Type 2 Bus Lane					
Stops every block	0 to 1	0 to 1	0	0.00	1.00
Alternating 2-block stops, random	0	1	1	0.50	0.75
	1	0.2*	1	0.50	0.55
Alternating 2-block stops, typical	0	1	1	0.75	0.88
	1	0.2*	1	0.75	0.58
Alternating 2-block stops, platooned	0	1	1	1.00	1.00
	1	0.2*	1	1.00	0.60
Type 3 Bus Lane					
Alternating 2-block stops, random	0	1	1	0.50	0.75
Alternating 2-block stops, typical	0	1	1	0.75	0.88
Alternating 2-block stops, platooned	0	1	1	1.00	1.00
Alternating 3-block stops, random	0	1	2	0.50	0.67
Alternating 3-block stops, typical	0	1	2	0.75	0.83
Alternating 3-block stops, platooned	0	1	2	1.00	1.00

*approximate

Exhibit 4-53
Values of Adjustment Factor, f_k, for Type 2 Bus Lanes with Alternate Two-Block Skip-Stops(R36)

	Arrival Pattern		
Adjacent Lane v/c	Random	Typical	Platooned
0.0	0.75	0.88	1.00
0.5	0.72	0.84	0.95
0.6	0.71	0.81	0.92
0.7	0.68	0.77	0.87
0.8	0.65	0.71	0.80
0.9	0.60	0.65	0.71
1.0	0.55	0.58	0.60

Capacity Calculation Procedure

The adjustment factors for skip-stop operations and right-turn impacts are used in the following equations for estimating the bus capacity of an arterial street bus lane. Once the bus capacity is known, Equation 4-8 in Chapter 1 can be used to determine person capacity.

Equation 4-13

non-skip-stop operation: $$B = B_l N_{el} f_r$$

Equation 4-14

skip-stop operation: $$B = f_k (B_1 + B_2 + \ldots + B_n)$$

where:

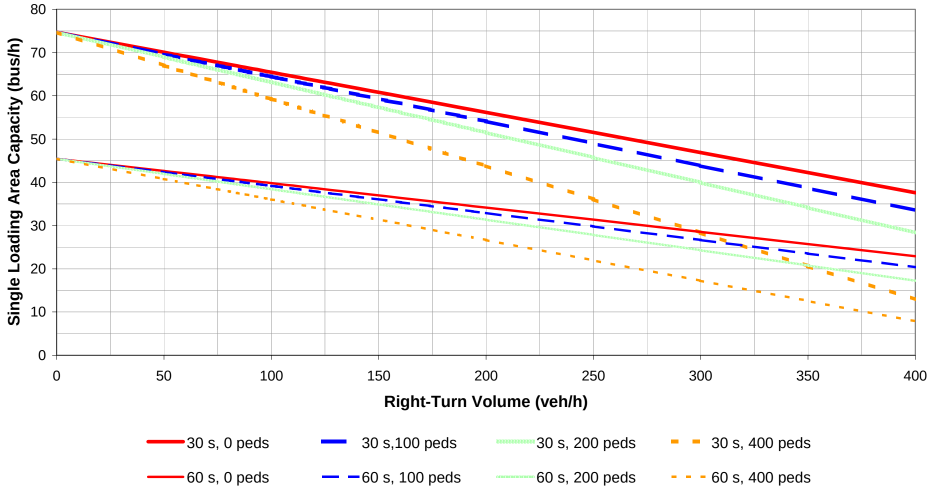
B = bus lane capacity (bus/h);
B_l = loading area bus capacity at the critical bus stop (bus/h);
N_{el} = number of effective loading areas at the critical bus stop;
f_r = capacity adjustment factor for right turns at the critical bus stop;
f_k = capacity adjustment factor for skip-stop operations; and
$B_1 ... B_n$ = bus capacities of each set of routes, at their respective critical bus stops, that use the same alternating skip-stop pattern (bus/h).

The capacities B_1, B_2, and so forth used in Equation 4-14 are calculated separately for each set of routes using a particular skip-stop pattern. When determining the critical stop(s), several bus stops may have to be tested to determine which one controls the bus lane's capacity, as one stop may have high dwell times, while another may have severe right-turning traffic interferences. Chapter 3 provides graphs depicting arterial street bus lane capacities based on these equations.

Several bus stops may need to be tested to determine the critical bus stop, as either dwell times or right-turning volume may control.

Exhibit 4-54 illustrates the effects of dwell time, right-turning volume from the bus lane, and conflicting pedestrian volumes on bus lane capacity, based on various dwell times, right-turning volumes, and pedestrian volumes, as well as other assumptions listed in the exhibit.

Exhibit 4-54
Illustrative Bus Lane Vehicle Capacity: Non-Skip-Stop Operation

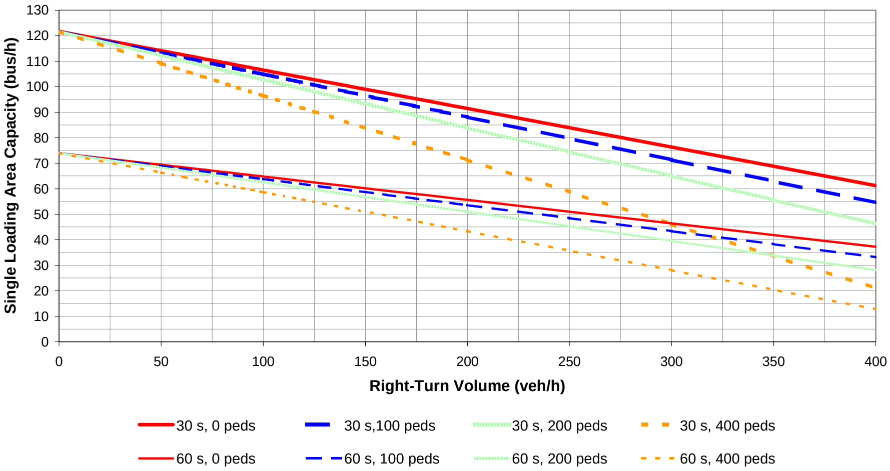


NOTE: Exhibit uses the following assumptions: g/C = 0.5, near-side stops, Type 2 bus lane, 2 linear loading areas per stop, 60% coefficient of variation of dwell times, 25% failure rate, 15-s clearance time, typical bus arrivals, permitted right-turn signal phasing, shared right-turn lane, and bus volumes minimal in relation to right-turn volumes (P_{RT} = 1.0).

It can be seen that at low right-turn and pedestrian volumes, dwell time controls capacity. Conflicting pedestrian volumes under 200 per hour have little effect on bus vehicle capacity, but have substantial effects at higher conflicting volumes, especially as right-turning volumes increase. However, when right-turn conflicts do not exist, conflicting pedestrian volumes have no impact on vehicle capacity, and the lines for a given dwell time converge to a single point. It can also be seen that the lines for a given pedestrian volume converge toward a point where the right-turn capacity is exceeded and the bus lane capacity drops to zero. Between these two extremes, bus vehicle capacity steadily declines as right-turning volumes increase, until a point is reached where the bus demand volumes exceed the lane's bus capacity.

Exhibit 4-55 illustrates the same situations, except that the buses employ a two-stop skip-stop operation, and the adjacent lane is assumed to have 500 vehicles per hour (resulting in an approximate v/c ratio of 0.6 at a g/C ratio of 0.5). For a given right-turning volume, the corresponding bus lane vehicle capacity is about 63% higher than if skip-stops were not used.

Exhibit 4-55
Illustrative Bus Lane Vehicle Capacity: Skip-Stop Operation



NOTE: Exhibit uses the following assumptions: *g/C* = 0.5, near-side stops, two-stop pattern, Type 2 bus lane, 2 linear loading areas per stop, 60% coefficient of variation of dwell times, 25% failure rate, 15-s clearance time, typical bus arrivals, permitted right-turn signal phasing, shared right-turn lane, and bus volumes minimal in relation to right-turn volumes (P_{RT} = 1.0).

Comparing the slopes of the lines in Exhibit 4-54 and Exhibit 4-55, the bus lane capacity drops to zero at the same right-turn volume, whether or not skip-stops are used. This suggests that controlling right turns (either through turn restrictions or bus stop location that takes advantage of one-way street grids) should be the first consideration for improving capacity, particularly in areas with relatively high pedestrian volumes. As will be seen shortly, actions that improve bus capacity also have a beneficial effect on bus speeds. When right turns are not a significant capacity factor, skip-stops can be used to further increase capacity and speed.

BUS SPEEDS

Bus speeds are best measured directly or estimated based on local conditions and operating experience.

The best way to determine bus travel speeds is to measure them directly. When this is not possible (for example, when planning future service), speeds can be estimated by driving the route, making an average number of stops with simulated dwells and making two or three runs during peak and off-peak times; scheduling buses based on similar routes and adjusting running times as needed based on the operating experience; or using the analytical methods described below.

Arterial Streets

Bus speeds on arterial street bus lanes are influenced by bus stop spacing, dwell times, delays due to traffic signals and right-turning traffic, skip-stop operations, and interferences caused by other buses. These factors are reflected in Equation 4-15, which can be used to estimate bus travel speeds on arterial streets. A bus running time is determined from Exhibit 4-56 and Exhibit 4-57, accounting for the effects of stop spacing, dwell times, and traffic and signal delays. This running time is then converted into a speed and adjusted to account for the effects of skip-stop operations and the interference of other buses operating in the lane.

Equation 4-15

$$S_t = \left(\frac{60}{t_r + t_l}\right) f_s f_b$$

where:

S_t = travel speed (mph, km/h);
t_r = base bus running time (min/mi, min/km);
t_l = bus running time losses (min/mi, min/km);
f_s = stop pattern adjustment factor, from Equation 4-16; and
f_b = bus-bus interference adjustment factor, from Exhibit 4-59.

Bus Travel Time Rates

Exhibit 4-56 and Exhibit 4-57 together provide an estimate of bus running times as a function of stop spacing, average dwell time per stop (not just the critical stop), and operating environment. These values were derived from field observations. First, a base bus running time is determined from Exhibit 4-56. This running time reflects the speed at which buses would travel without any signal or traffic delays. Next, additional running time losses are determined from Exhibit 4-57, accounting for the effects of signals and other traffic sharing the bus lane. If actual observed delays are available, they could be used in lieu of the estimates given in Exhibit 4-57. The two running times are added to each other and divided into 60 to determine a base bus speed for use in Equation 4-15.

Dwell times used for speed analysis are the average of all stops in the study section, not the critical stop average dwell time used for capacity analysis.

Average speeds can be calculated for any distance and series of stop patterns. When examining a corridor, the length of the study area, the number of bus stops, and the dwell times at each stop will affect the speed results. The capacity calculation should be made at the critical stop along the arterial, where the combination of dwell time and dwell variation result in the lowest calculated capacity. Maximum capacity (i.e., a 25% failure rate) should be used for speed calculation purposes. Sections chosen for analysis should have generally homogeneous characteristics in terms of street geometry, bus lane features, stop frequency, and dwell times. The average dwell time and highest *v/c* ratio in each section should be used in estimating speeds. Sections should be at least 0.25 mile (400 m) and preferably 0.5 mile (800 m) long.

The bus capacity used for speed analysis is based on a 25% failure rate (i.e., maximum capacity) at the critical stop.

When applying Exhibit 4-57, the additional running time loss selected from a possible range of losses should consider both signal timing and enforcement efforts (or the lack thereof) to keep non-authorized vehicles out of a bus lane.

Exhibit 4-56
Estimated Base Bus Running Time, t_r (min/mi)(R37)

An alternative exhibit using metric units appears in Appendix A.

	Stops per mile							
Dwell Time (s)	**2**	**4**	**5**	**6**	**7**	**8**	**10**	**12**
10	2.40	3.27	3.77	4.30	4.88	5.53	7.00	8.75
20	2.73	3.93	4.60	5.30	6.04	6.87	8.67	10.75
30	3.07	4.60	5.43	6.30	7.20	8.20	10.33	12.75
40	3.40	5.27	6.26	7.30	8.35	9.53	12.00	14.75
50	3.74	5.92	7.08	8.30	9.52	10.88	13.67	16.75
60	4.07	6.58	7.90	9.30	10.67	12.21	15.33	18.75

NOTE: Data based on field measurements. Interpolate between dwell time values on a straight-line basis.

Exhibit 4-57
Estimated Base Bus Running Time Losses, t_l (min/mi)(R37)

An alternative exhibit using metric units appears in Appendix A.

Condition	Bus Lane	Bus Lane, No Right Turns	Bus Lane With Right Turn Delays	Bus Lanes Blocked by Traffic	Mixed Traffic Flow
CENTRAL BUSINESS DISTRICT					
Typical		1.2	2.0	2.5-3.0	3.0
Signals Set for Buses		0.6	1.4		
Signals More Frequent Than Bus Stops		1.5-2.0	2.5-3.0	3.0-3.5	3.5-4.0
ARTERIAL ROADWAYS OUTSIDE THE CBD					
Typical	0.7				1.0
Range	0.5-1.0				0.7-1.5

NOTE: Data based on field measurements. Traffic delays shown reflect peak conditions.

Adjustment for Skip-Stop Operation

Skip-stop operations spread buses out among a series of bus stops, allowing for an increase in speeds. The analytical procedure accounts for the skip-stop operations by considering only the bus stops in the skip-stop pattern. For example, if bus stops are located 400 feet (125 m) apart (say a stop at each intersection), a two-block skip-stop pattern provides 800 feet (250 m) between stops for a bus using that pattern. A bus with a two-block stop pattern would be able to proceed faster than a bus with a one-block stop pattern. However, some of this increase will be offset by increases in dwell times, as each stop will have to accommodate more passengers.

The ability of buses to leave the curb lane to pass stopped vehicles is another factor in the ability to attain an increase in speed. This ability depends on the availability of an adjacent lane or the provision of an off-line bus stop. Where dual bus lanes or off-line bus stops are provided, the anticipated bus speed can be calculated using the distance between the bus stops served. Where congestion in the adjacent lane results in essentially no passing-lane availability, the buses will progress as if they were stopping at each stop with a zero dwell time at the intermediate stops. When partial use of the adjacent lane is available, the bus speed will be somewhere in between.

Equation 2-17 expresses the speed adjustment factor for skip-stop operation, f_s, as a function of both the traffic in the adjacent lane and the buses in the curb lane.(R36) This factor reduces the faster base running time that results from the longer distances between stops used in the skip-stop pattern. If skip-stops are not used, f_s = 1.0 and the base running speed is based on the actual stop spacing.

Equation 4-16

$$f_s = 1 - \left(\frac{d_1}{d_2}\right)\left(\frac{v}{c}\right)^2\left(\frac{v_p}{B_p}\right)$$

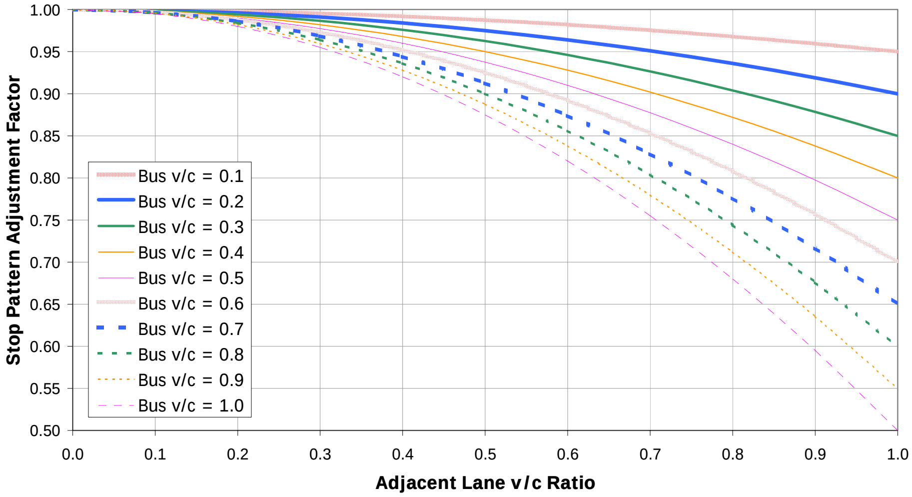
where:

f_s = stop pattern adjustment factor;
d_1 = distance for one-block stop pattern (ft, m);
d_2 = distance for multiple-block stop pattern (ft, m);
v = volume in adjacent lane (veh/h);
c = vehicular capacity of adjacent lane (veh/h);
v_p = bus volume in pattern (bus/h); and
B_p = maximum bus capacity of critical bus stop in pattern (bus/h).

Speed should be estimated separately for each pattern. Bus capacity should be based on a 25% failure rate.

Exhibit 4-58 illustrates the effects of increases in the bus v/c ratio and general traffic v/c ratio in the adjacent lane on the stop pattern adjustment factor. The exhibit assumes a two-block stop pattern. It can be seen that until the volume of the adjacent lane becomes more than about 50% of the bus lane capacity, the ability to achieve the two-fold increase in speed is not significantly reduced, regardless of the bus lane v/c ratio. At higher v/c ratios, both the bus lane volumes and the adjacent lane volumes play an important role in determining bus speeds.

Exhibit 4-58
Illustrative Skip-Stop Speed Adjustment Effects



NOTE: Assumes two-block skip-stop pattern.

Bus-Bus Interference

Bus speeds within a bus lane along an arterial street decline as the lane becomes saturated with buses. This is because as the number of buses using the lane increases, there is a greater probability that one bus will delay another bus, either by using available loading areas or by requiring passing and weaving maneuvers. Simulation runs reported in *TCRP Report 26*,(R36) as well as observations of actual bus lane operations(R33) show a sharp drop in bus speeds as bus volumes approach capacity. Exhibit 4-59 presents the speed adjustment factor for bus volumes. These factors were developed through simulation of Type 1 and Type 2 bus lanes, using an 80-second cycle, a g/C ratio of 0.5, 400-foot (125-meter) block spacing, 20- to 50-second dwell times, and a 33% coefficient of dwell time variation.

Speed adjustment factor for bus volumes, f_b.

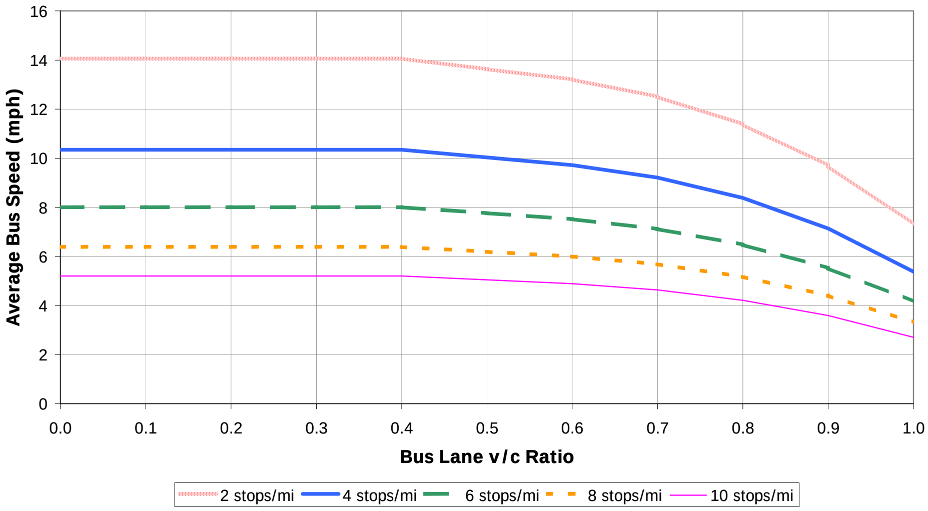
Exhibit 4-59
Bus-Bus Interference Factor, f_b(R36)

Bus Lane *v/c* Ratio	Bus-Bus Interference Factor
<0.5	1.00
0.5	0.97
0.6	0.94
0.7	0.89
0.8	0.81
0.9	0.69
1.0	0.52
1.1	0.35

NOTE: Capacity should be based on a 25% failure rate (i.e., maximum capacity).

Exhibit 4-60 illustrates the effects of increasing bus lane volumes on bus speeds. There is little effect on bus speeds until approximately 70% of the bus lane's capacity is being used.

Exhibit 4-60
Illustrative Bus-Bus Interference Factor Effects



NOTE: Assumes 30-second dwell times, CBD bus lane with right-turn delays, and typical signal timing.

An alternative exhibit using metric units appears in Appendix A.

This page is intentionally blank.

CHAPTER 6. MIXED TRAFFIC

INTRODUCTION

Buses operating in mixed traffic situations is the most common operating scenario in North American cities and rural areas. It applies to small and large buses, both standard and articulated, and to both fixed-route and demand-responsive services. The unusual exceptions occur in larger cities with very high capacity routes that may lend themselves to busways or downtown bus lanes.

Mixed traffic is the most common bus operating environment in North America.

Because buses operate much like other vehicles in a traffic lane, their impact on the lane's overall vehicle capacity may be calculated as if they were another vehicle, using the procedures given in the *Highway Capacity Manual* and a passenger vehicle equivalence of 2.0.(R14) The lane's bus vehicle capacity is calculated in the same way as for arterial street bus lanes, except that the interference of other traffic on bus operations must be accounted for. This traffic interference is greatest when off-line stops are used and buses must wait for a gap in traffic to merge back into the street.

Mixed traffic bus capacity is calculated similarly to arterial street bus lanes, except that the interference of other traffic sharing a lane with buses must be accounted for.

TYPES OF BUS OPERATION

Paralleling the arterial street bus lane procedures, the mixed traffic procedure also defines bus lane types. Unlike exclusive bus lanes, there are only two types of mixed traffic bus operations, as shown in Exhibit 4-61. The opportunity to move from the curb lane is the determining factor between the two types.

Bus lane types described.

Exhibit 4-61
Types of Mixed Traffic Bus Operations

Type 1

- One travel lane in bus' direction of travel
- Lane is shared by buses and other vehicles
- Parking activities and turning maneuvers may delay buses

(a) Portland, (b) New Orleans

Type 2

- Two travel lanes in bus' direction of travel
- Lanes are shared by buses and other vehicles
- Buses can leave curb lane to avoid stopped vehicles

(c) Portland, (d) Milwaukee

BUS CAPACITY

The volume of mixed traffic sharing the curb lane with buses affects bus capacity in two ways. First, the interference caused by other traffic in the lane, particularly at intersections, may block buses from reaching a stop or may delay a bus blocked behind a queue of cars. Second, at off-line stops, the additional re-entry delay encountered when leaving a stop and re-entering traffic reduces capacity, as was discussed in Chapter 1. Re-entry delay is incorporated into the clearance time used to calculate bus stop capacity. Traffic interference is accounted for by the following capacity adjustment factor:

Equation 4-17

$$f_m = 1 - f_l \left(\frac{v}{c} \right)$$

This mixed traffic bus capacity procedure is an extension of the exclusive bus lane capacity procedures developed by TCRP Project A-7. The theoretical basis exists for the mixed traffic procedures, but they have not yet been validated in the field.

where:

f_m = mixed traffic adjustment factor;
f_l = bus stop location factor, from Exhibit 4-51;
v = curb lane volume at a specific intersection; and
c = curb lane capacity at a specific intersection.

The mixed traffic adjustment factor is essentially the same as the right-turn adjustment factor presented in Equation 4-10 for arterial street bus lanes. The difference is that in a mixed traffic situation, the non-transit traffic will be greater and it may not just be turning right—it could also be going straight or even left—and thus bus vehicle capacity will be lower in a mixed traffic situation than in an arterial street bus lane. The most recent version of the *Highway Capacity Manual* should be used to determine the curb lane's vehicle capacity.

Equation 4-18 may be used to calculate the bus capacity of a mixed traffic lane in which buses operate. Once the bus capacity is known, Equation 4-8 in Chapter 1 may be used to determine person capacity. The planning graphs in Chapter 3 may be used to estimate capacity, based on Equation 4-18, for a variety of situations.

Equation 4-18

$$B = B_l N_{el} f_m$$

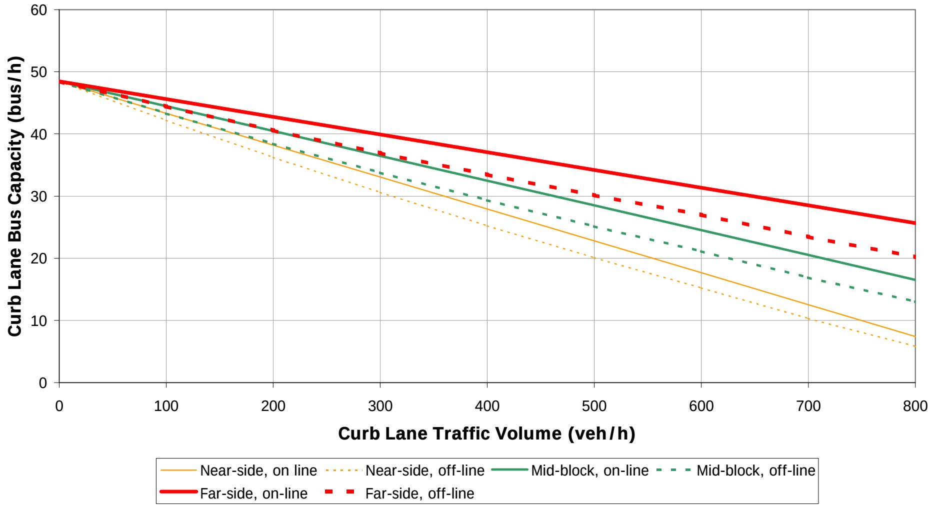
where:

B = mixed traffic bus capacity (bus/h);
B_l = bus loading area capacity at the critical bus stop (bus/h);
N_{el} = number of effective loading areas at the critical bus stop; and
f_m = capacity adjustment factor for mixed traffic interference at the critical bus stop.

In mixed traffic situations, on-line stops may provide greater capacity than off-line stops, depending on traffic volumes and the number of loading areas provided.

Exhibit 4-62 illustrates how bus vehicle capacity declines as curb lane traffic volumes increase and how bus vehicle capacity varies by bus stop location. It should be noted that in mixed traffic situations, off-line linear stops may provide less bus vehicle capacity than on-line stops for identical dwell times, as the additional fractional effective loading areas provided by off-line stops are outweighed by the additional delay buses encounter when re-entering traffic.

Exhibit 4-62
Illustrative Mixed Traffic Maximum Bus Vehicle Capacity



NOTE: Assumes a Type 2 lane, one linear loading area per stop, g/C = 0.5, 30-second dwell time, 25% failure rate, and 60% coefficient of variation.

BUS SPEEDS

As with arterial street bus lanes, the best way to determine bus travel speeds is to measure them directly. If this is not possible (for example, when planning future service), speeds can be estimated by (1) driving the route, making an average number of stops with simulated dwells and making two or three runs during peak and off-peak times; (2) scheduling buses based on similar routes and adjusting running times as needed based on the operating experience; or (3) using the analytical method described below to estimate speeds.

The speeds of buses operating in mixed traffic are influenced by bus stop spacing, dwell times, delays due to traffic signals, and interferences from other traffic operating in the lane. The method used to estimate bus speeds in mixed traffic is the same as that used for arterial street bus lanes, with the exception that the "mixed traffic flow" column in Exhibit 4-57 should be used to estimate additional running time losses.

This page is intentionally blank.

CHAPTER 7. DEMAND-RESPONSIVE TRANSPORTATION

INTRODUCTION

Demand-responsive transportation (DRT) is variable route service, activated in response to users' requests, provided as shared ride (typically door-to-door or curb-to-curb), and operated on a point-to-point basis. DRT point-to-point service can be operated as many origins to many destinations, many origins to few destinations, few origins to many destinations, few origins to few destinations, and many origins to one destination.

Illustrations of these service types can be found in Part 2.

Beyond the type of point-to-point operation, other service parameters impact DRT operations, such as response time (whether the service is immediate response with real time dispatching similar to taxi service, or advance reservation) and the nature of the ridership (whether the service is designed for the general public or a special subset such as the elderly and disabled or only individuals with disabilities certified as ADA eligible). Many of these parameters are policy decisions on the part of the DRT provider. There are also a variety of environmental factors that impact DRT operations, including service area size, street pattern, and, importantly, demand density, defined as riders per hour per square mile or square kilometer of the service area.

SERVICE CHARACTERISTICS

DRT is provided in communities throughout the United States and Canada. In larger urban areas in the United States, such service is often provided as ADA complementary paratransit service. In smaller communities, demand-responsive service may be provided in lieu of fixed-route service or to supplement other transit service, and may be available to the general public rather than a subset such as the elderly and persons with disabilities. In rural areas, demand-responsive service may be the only service available, and it may only be offered on certain days of the week or even month.

Since demand-responsive service can be designed in many different ways (for the general public or a subset; as many-to-many, many-to-few, etc.), many of the service characteristics tend to reflect the operating design and policies of the DRT system. For example, an ADA complementary paratransit system in a large urban area will typically have long travel times, particularly during peak hours, and very low productivity (e.g., typically less than two one-way passenger trips per revenue hour). These same characteristics may be found in a general public demand-responsive program in a rural area, with low productivity due to the lower demand density (as opposed to long wait and dwell times for riders with disabilities), and with long travel times due to the larger service area and longer distances between activity centers (rather than the congestion and traffic of large urban areas). Thus, it is important to understand that many characteristics and differences among DRT operations stem from operating design and policies.

Such differences are particularly true for specialized transportation services, where the DRT system is designed for a subset of the population and policies are structured to provide a higher level of assistance to the riders. ADA complementary paratransit, in particular, is different from other types of specialized transportation service as its operating parameters are so highly prescribed by federal regulations (49 CFR Part 37, Subpart F), which address not only capacity, but service quality as well.

VEHICLE TYPES

There are a wide variety of vehicles available for use in demand-responsive services. DRT vehicles are typically smaller than vehicles used for fixed-route services because of the smaller passenger loads carried and the greater variety of roadways traveled upon. The kinds of vehicles used for DRT services include sedans, taxicabs, vans, and small- and mid-sized buses.

Accessibility for passengers using mobility aids—particularly wheelchairs—is an important issue in the selection of vehicles for DRT service, as DRT systems are often designed to serve persons with mobility limitations. Riders using wheelchairs and certain other mobility devices require a lift or ramp on the vehicle, which is typically a van or a bus. Sedans are not accessible to those using wheelchairs unless the passengers transfer to the sedan seat. Taxicab companies in some areas have added accessible taxi vehicles to their fleets to accommodate riders with wheelchairs. For other mobility-limited riders, such as those who are ambulatory but frail, sedans may be the most accessible type of vehicle due to an easier entry and a smoother ride, compared with a small- or mid-sized bus.

DRT CAPACITY

Capacity Factors

Determining capacity for DRT is a different proposition than for fixed-route transit. The issue for DRT is not how many vehicles a facility can accommodate, but rather how many vehicles and vehicle service hours are required to accommodate a given passenger demand and service area.

Every passenger is provided a seat in DRT service.

For many-to-one and few-to-one types of DRT service, vehicles may be assigned to geographic areas, with the number of vehicles assigned to each area dependent on the number of passengers from that area who need to be accommodated at a given time. Every passenger should be provided a seat in DRT service.

For most types of DRT service with a greater dispersion of origins and destinations, the number of vehicles and vehicle service hours required is dependent on a number of factors, including ridership demand, ridership characteristics, peak-period demand, service area size and characteristics, type of DRT service (i.e., many-to-many, many-to-few, etc.), and service policies that affect DRT operations.

Ridership demand is one of the most important capacity factors, as DRT vehicles carry only a small number of passenger trips each hour.

Ridership demand is clearly one of the most important factors. The demand for DRT service in terms of one-way passenger trips should be determined or estimated as one key factor for the calculation of capacity. These data should also be determined on an average weekday basis as well as a peak-period basis. Should the peak-period demand be significantly greater than off-peak demand, the number of vehicles required will be greater. Given that DRT vehicles carry only a limited number of passenger trips each hour, fluctuations in ridership numbers can have a significant effect on the number of vehicles required and the resulting capital and operations costs.

Wait and dwell times differ depending on the type of DRT service.

Passenger characteristics are also important in calculating capacity. Is the DRT service designed for general public users; a specialized group, such as the elderly and persons with disabilities; or just ADA-certified users? A key difference between ridership types in terms of calculating DRT capacity are the amounts of wait time and dwell time required. A general public DRT service will typically have quite short wait times for users at pick-up locations (1 to 2 minutes, for example). Dwell times are also relatively short. Specialized DRT services designed for users with disabilities will have longer wait times (5 to 10 minutes and in some cases longer), and dwell times are also longer. Increased wait and dwell times mean that fewer passenger trips can be carried per day, translating to lowered productivities and additional vehicle capacity needed.

More DRT vehicles may be needed if demand is strongly peaked.

Peak-period demand is another important factor. Where DRT systems have peaked ridership demand, additional capacity is required at those peak times. Unlike a fixed-route bus during peak times that is able to accommodate additional passengers at each bus stop until no more standees can fit, a given DRT vehicle generally does not carry more passengers during peak times than off-peak. (An exception is when the operating characteristics change during peak times to become more productive, e.g., from many-to-many during off-peak, to many-to-few or many-to-one during peaks.) DRT system policy for scheduling trips is particularly important in relation to peak-period capacity needs. The extent to which a DRT provider can manage its peak-period demand will affect the amount of capacity that is needed. Some DRT providers are able to "spread" some of the peak-period trips to the shoulders of the peak or to the off peak by encouraging alternative travel times for riders, by using a longer pick-up window for scheduling trip pick-ups, or by only offering trip pick-ups that can be handled.

Larger service areas and longer trips result in fewer trips being provided by each vehicle.

Service area size and characteristics have a critical influence on DRT capacity. With a larger service area and long distances between residential areas and destination areas, DRT riders will have longer trips, both in miles and time. Where DRT vehicles are serving longer trips, fewer trips are provided by each vehicle, resulting in lowered productivities and additional DRT capacity needed to serve the demand. The service area characteristics also impact capacity. For example, those characteristics that delay travel will have a similar effect as a large service area, resulting in longer travel times, lowered productivity, and the need for additional DRT capacity to serve the demand. Locations of major bridges and railroad crossings and the geographic shape of the service area are some of the travel constraints that may characterize a DRT service area and increase travel times.

The ability to group passenger trips results in more trips being provided by each vehicle.

The type of point-to-point service (i.e., many-to-many, many-to-few, etc.) provided by the DRT system will affect capacity. A DRT service that is able to group more riders through a many-to-one, many-to-few, or few-to-few type of service will have higher productivity, with each DRT vehicle carrying more passenger trips. Conversely, a many-to-many type of DRT service is not able to group as many trips, given the greater dispersion of origins and destinations, and therefore each vehicle carries fewer passenger trips with a resulting need for additional capacity.

Service policies may also impact capacity. Those policies that increase the time to serve each passenger trip, such as a ten-minute wait time for riders at a pick-up location, will increase riders' travel times, with a similar effect as long trip travel times—that is, lowering productivity with a need for additional capacity.

Capacity Calculation Procedure

The number of vehicles and vehicle service hours for a DRT system can be estimated using data from a similar DRT system or several similar DRT systems operating in a similar community or area. This is the *analogy* method, which, straightforward and simple, can provide useful information to help assess the number of passenger trips per day and per service hour that can be served with a given number of vehicles. These data can then be used to estimate capacity for the community or area where DRT service is being planned.

A second approach is use of the DRT *resource estimation model* that is being developed through TCRP Project B-23. This model, anticipated to be available in late 2003, will estimate vehicles and vehicle service hours needed to provide DRT service for a given level of ridership demand and service quality in a defined service area. Users of the model will define specific inputs, such as the DRT service area, using place and county subdivision geographic units from the 2000 Census, average number of weekday trips, type of ridership (e.g., general public, elderly, transportation disadvantaged), and service characteristics. The model will then simulate trip-making with two modeling phases: trip generation and trip distribution. Results of the modeling will then be used by the vehicle resource estimation portion of the software to estimate resource requirements for the DRT system being planned.(R45)

A third approach to estimating the required number of DRT vehicles is Fu's *analytical model.* This model is intended to help planners and designers quickly determine the minimum number of vehicles required to achieve a given quality of service, the maximum number of trips that a given fleet can serve, and the quality of service that can be provided by a given fleet.(R11) Unlike the TCRP Project B-23 resource estimation model, Fu's model assumes that demand is known in advance. The quality of service indicators in Fu's model do not exactly match those in the TCQSM's DRT quality of service framework, and the model was calibrated for idealized scenarios, but with refinement it potentially could be incorporated into a future edition of the TCQSM.

CHAPTER 8. REFERENCES

1. Bullard, Diane L. and Lisa G. Nungesser, "Texas Public Transit Reference Manual," *Technical Report 1082-1F,* Texas State Department of Highway and Public Transportation, Austin, TX (1985).
2. Callas, Steve, Tri-Met's Transit Signal Priority System and Evaluation, presented at the 81st Annual Meeting of the Transportation Research Board, Washington, DC (2002). http://signalsystems.tamu.edu/documents/SignalControlWorkshop2002/TRB_SignalPriority_Callas.pdf
3. Cervero, Robert, *Paratransit in America. Redefining Mass Transportation,* Praeger Publishers, Westport, CT (1997).
4. City of Portland, *Transit Preferential Streets Program Sourcebook: Guidelines for Implementing Transit Preferential Streets Measures,* Office of Transportation, Portland, OR (1997). http://www.trans.ci.portland.or.us/Plans/TransitPreference/default.htm
5. Cuntill, M.A., and P.F. Watts, "Bus Boarding and Alighting Times." *Report LR 521,* Great Britain Transport and Road Research Laboratory, Crowthorne, England (1973).
6. Dowling, Richard, Wayne Kittelson, John Zegeer, Alexander Skabardonis, and Barton Aschman Associates, *NCHRP Report 387: Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications,* TRB, National Academy Press, Washington, DC (1997).
7. Edwards, Jr., John D. (editor), *Transportation Planning Handbook,* Prentice-Hall Inc., Englewood Cliffs, NJ (1992).
8. Federal Transit Administration, *Bus Rapid Transit Demonstration Projects,* http://www.fta.dot.gov/brt/projects/index.html, accessed April 3, 2002.
9. Florida Department of Transportation, Systems Planning Office, *2002 Quality/Level of Service Handbook,* Tallahassee, FL (2002). http://www.dot.state.fl.us/planning/systems/sm/los/pdfs/QLOS2002Novcd.pdf
10. Fritz, Marshall S. Effect of Crowding on Light Rail Passenger Boarding Times. In *Transportation Research Record 908,* TRB, National Academy Press, Washington, DC (1983).
11. Fu, Liping, An Analytical Model for Paratransit Capacity and Quality of Service Analysis, *Paper 03-2179*, presented at the 82nd Annual Meeting of the Transportation Research Board, Washington, DC (2003).
12. Fuhs, Charles A., *NCHRP Synthesis of Highway Practice 185: Preferential Lane Treatments for High-Occupancy Vehicles,* TRB, National Academy Press, Washington, DC (1993).
13. Guenthner, R.P. and K.C. Sinha. Modeling Bus Delays Due to Passenger Boardings and Alightings. In *Transportation Research Record 915,* TRB, National Academy Press, Washington, DC (1983).
14. Head, K. Larry, "Improved Traffic Signal Priority for Transit," *TCRP A-16 Interim Report,* TRB, Washington, DC (1998).
15. *Highway Capacity Manual.* TRB, National Research Council, Washington, DC (2000).

16. Hoel, Lester A. and Larry G. Richards (editors), *Planning and Development of Public Transportation Terminals,* Report DOT/RSPA/DPB-50/81/19, U.S. Department of Transportation, Washington, DC (1981).
17. Hoey, W.F. and H.S. Levinson. Bus Capacity Analysis. In *Transportation Research Record 546,* TRB, National Academy Press, Washington, DC (1975).
18. Homburger, W.S. (editor), *Transportation and Traffic Engineering Handbook,* Second Edition, Prentice-Hall Inc., Englewood Cliffs, NJ (1982).
19. Houston Metro, http://www.ridemetro.org/HOV_Lanes/HOV01.htm, accessed April 2, 2002.
20. King, Rolland D, *TCRP Report 41: New Designs and Operating Experiences with Low-Floor Buses,* TRB, National Academy Press, Washington, DC (1998). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_41-a.pdf
21. King, Rolland D., *TCRP Synthesis of Transit Practice 49: Yield to Bus – State of the Art,* TRB, Washington, DC (2003). http://gulliver.trb.org/publications/tcrp/tcrp_syn_49.pdf
22. Kohler, U., "Capacity of Transit Lanes," *Proceedings of the International Symposium on Highway Capacity,* Karlsruhe, Germany (1991).
23. Kraft, W.H., *An Analysis of the Passenger Vehicle Interface of Street Transit Systems with Applications to Design Optimization,* Doctoral Dissertation, New Jersey Institute of Technology, Newark, NJ (1975).
24. Kraft, W.H., and P. Eng-Wong, *Passenger Service Time Characteristics of Street Transit Systems,* Compendium of Technical Papers, Institute of Transportation Engineers, 47th Annual Meeting, Mexico City, Mexico (1977).
25. Levinson, H.S. Analyzing Transit Travel Time Performance. In *Transportation Research Record 915,* TRB, National Academy Press, Washington, DC (1983).
26. Levinson, H.S., *INET Transit Travel Times Analysis,* prepared for the Urban Mass Transit Administration, Washington, DC (April 1982).
27. Levinson, H.S., C.L. Adams, and W.F. Hoey, *NCHRP Report 155: Bus Use of Highways – Planning and Design Guidelines,* TRB, National Academy Press, Washington, DC (1975).
28. Levinson, H.S., L. Lennon and J. Cherry. Downtown Space for Buses—The Manhattan Experience. In *Transportation Research Record 1308,* TRB, National Academy Press, Washington, DC (1991).
29. Levinson, Herbert, Samuel Zimmerman, Jennifer Clinger, Scott Rutherford, Rodney L. Smith, John Cracknell, and Richard Soberman, *TCRP Report 90: Bus Rapid Transit, Volume 1: Case Studies in Bus Rapid Transit,* TRB, Washington, DC (2003). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_90v1.pdf
30. Levinson, Herbert S. and Kevin R. St. Jacques. Bus Lane Capacity Revisited. In *Transportation Research Record 1618,* TRB, National Academy Press, Washington, DC (1998).
31. Major, Michael J., "Brazil's Busways: A 'Subway' That Runs Above the Ground," *Mass Transit,* Vol. XXIII, No. 3 (May/June 1997).
32. Marshall, Leo. F., Herbert S. Levinson, Lawrence C. Lennon and Jerry Cheng. Bus Service Times and Capacities in Manhattan. In *Transportation Research Record 1266,* TRB, National Academy Press, Washington, DC (1990).
33. Papacostas, C.S., "Capacity Characteristics of Downtown Bus Streets," *Transportation Quarterly,* Vol. 36, No. 4 (October 1982).

34. Pratt, Richard H., Texas Transportation Institute, Cambridge Systematics, Inc., Parsons Brinckerhoff Quade & Douglas, Inc., SG Associates, Inc., and McCollum Management Consulting, Inc., *TCRP Web Document 12: Traveler Response to Transportation System Changes: Interim Handbook,* TRB, Washington, DC (2000). http://gulliver.trb.org/publications/tcrp/tcrp_webdoc_12.pdf
35. Rabinovitch, Jonas and Josef Leitman, "Urban Planning in Curitiba," *Scientific American,* Vol. 274, No. 3 (March 1996).
36. St. Jacques, Kevin and Herbert S. Levinson, *TCRP Report 26: Operational Analysis of Bus Lanes on Arterials,* TRB, National Academy Press, Washington, DC (1997). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_26-a.pdf
37. St. Jacques, Kevin and Herbert S. Levinson, *TCRP Research Results Digest 38: Operational Analysis of Bus Lanes on Arterials: Application and Refinement,* TRB, National Research Council, Washington, DC (2000). http://gulliver.trb.org/publications/tcrp/tcrp_rrd_38.pdf
38. Scheel, W. and J.E. Foote, "Bus Operation in Single Lane Platoons and Their Ventilation Needs for Operation in Tunnels," *Research Publication GMR-808,* General Motors Research Laboratories, Warren, MI (1962).
39. Skehan, Sean, "Traffic Signal Priority for Metro Rapid Buses: The Los Angeles Experience," *Compendium of Technical Papers,* 2001 Institute of Transportation Engineers Annual Meeting, Chicago, IL (2001).
40. *Special Report 209: Highway Capacity Manual,* TRB, National Research Council, Washington, DC (1985).
41. Stockton, William R., Ginger Daniels, Douglas A. Skowronek, and David W. Fenno, "The ABC's of HOV: The Texas Experience," *Report 1353-I,* Texas Transportation Institute, College Station, TX (September 1999). http://tti.tamu.edu/product/catalog/reports/1353-I.pdf
42. *TCRP Web Document 6: Transit Capacity and Quality of Service Manual,* First Edition, TRB, Washington, DC (1999). http://gulliver.trb.org/publications/tcrp/tcrp_webdoc_6-a.pdf
43. Texas Transportation Institute, *TCRP Report 19: Guidelines for the Location and Design of Bus Stops,* TRB, National Academy Press, Washington, DC (1996). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_19-a.pdf
44. Texas Transportation Institute, Parsons Brinckerhoff Quade and Douglas, Inc., and Pacific Rim Resources, Inc., *NCHRP Report 414: HOV Systems Manual,* TRB, National Academy Press, Washington, DC (1998).
45. The Transportation Center, Northwestern University, *Draft Users' Manual: Resource Requirements for Demand-Responsive Transportation Services,* available on loan from the Transit Cooperative Research Program, TRB, Washington, DC (October 2002).
46. *Transportation Research Circular 212: Interim Materials in Highway Capacity,* TRB, National Academy Press, Washington, DC (1980).

This page is intentionally blank.

CHAPTER 9. EXAMPLE PROBLEMS

Example Problem 1

The Situation

An express route is planned along an arterial from a suburb to the CBD with 10 stops, including one at a transit center midway (stop #5). The route will operate in mixed traffic in the CBD (stops #7 to 10).

The Question

What will be the average dwell time at each of the 10 stops, and how might these dwell times affect how the route is developed?

The Facts

- The route will use 40-seat standard buses.
- Exact fare is required upon boarding.
- The door opening and closing time is 4 seconds.
- All passengers board through the front door and alight through the back door.
- The transit agency has estimated potential ridership for the route and predicts the following average number of boarding and alighting passengers per stop:

Stop #	1	2	3	4	5	6	7	8	9	10
Alighting Passengers	0	0	3	2	14	6	16	19	15	11
Boarding Passengers	20	16	11	12	16	8	2	1	0	0

Assumptions

- Assume 3.5 seconds boarding time per passenger (4.0 seconds with standees).
- Assume 2.0 seconds alighting time per passenger.

Outline of Solution

All input parameters are known. Method 3 (calculation) will be used to determine dwell times. As there are two doors, one used by boarding passengers and the other by alighting passengers, boarding and alighting times will need to be calculated separately for each stop to determine which governs dwell time. The total number of passengers on board the bus will need to be tracked to determine the stops where standees will be present on the bus.

Steps

1.	Determine the stops where the bus arrives with standees.	There will be more than 40 passengers on the bus when it arrives at stops 4 to 8. The last 3 passengers to board at stop #3 will encounter standees.
2.	Calculate the boarding time.	The boarding time is the number of boarding passengers times 3.5 or 4.0 seconds, depending on whether or not standees are present.
3.	Calculate the alighting time.	The alighting time is the number of alighting passengers times 2.0 seconds.
4.	Determine the dwell time.	The dwell time is the larger of the boarding and alighting times at each stop, plus the 4-second door opening and closing time.

The Results

Estimated dwell times are shown below for each stop:

Stop #	1	2	3	4	5	6	7	8	9	10
Dwell Time (s)	74	60	44	52	68	36	36	42	34	26

Boarding times govern at stops #1 to 6, while alighting times govern at stops #7 to 10. Stop #8 has the longest dwell time within the CBD area. If stop #8 also has the longest dwell time among the other routes using it, the stop will likely be the critical stop for the CBD bus facility.

Comments

Because of the long dwell times at stops #1 to 4 in the suburban portion of the corridor, off-line stops (pullouts) should be considered at these locations to avoid substantial traffic delays to other vehicles in the curb lane. At the same time, to minimize delays to the express buses when re-entering the arterial, transit priority treatments such as queue jumps should also be considered at these locations.

The dwell time at stop #5 required to serve passenger movements is 68 seconds. However, since this stop is located at a transfer center, buses will likely need to occupy the berth for longer periods of time to allow for connections between routes. This extra berth occupancy time needs to be accounted for when sizing the transfer center.

Having standees on a long-distance express bus is undesirable from a quality of service point-of-view. Increasing service frequency so that all riders may have a seat should also be considered.

Example Problem 2

The Situation

A downtown Type 2 bus lane currently serves 32 buses during the evening peak hour. The transit agency wishes to add another route to the corridor with 10-minute headways during the peak hour.

The Question

What is the existing bus capacity along the corridor? Will additional loading areas be required at the busiest stop, and if so, how many?

The Facts

- The g/C ratio (the ratio of effective green time to cycle length) along the route is 0.45.
- All bus stops are on-line and currently have one linear berth each.
- Average bus dwell time at the critical stop is 30 seconds.
- The desired bus stop failure rate is 10%.
- Right turns are prohibited along the street.

Comments

- Assume c_v (the coefficient of variation in dwell times) is 0.60.
- Assume buses arrive randomly.
- For on-line stops, assume a 10-second clearance time.

Outline of Solution

All input parameters are known. As right turns are prohibited, the vehicle capacity of the critical bus stop will determine the bus lane vehicle capacity (i.e., f_r from Equation 4-10 is 1.0). The vehicle capacity of a linear bus stop is the vehicle capacity of the a loading area times the number of effective loading areas.

Steps

1. Calculate the bus capacity of a bus stop with a single loading area, from Equation 4-6.

$$B_l = \frac{3{,}600(g/C)}{t_c + (g/C)t_d + Zc_v t_d}$$

$$B_l = \frac{3{,}600(0.45)}{10 + (0.45)(30) + (1.28)(0.60)(30)}$$

$$B_l = 35 \text{ bus/h}$$

2. One loading area is sufficient to accommodate the existing demand of 32 buses per hour. Adding another route with 10-minute headways will result in six more buses per hour, which will exceed the critical stop's bus capacity. A second linear loading area has the effectiveness of 1.75 loading areas (from Exhibit 4-12).

From Equation 4-7:

$$B_s = N_{el} B_l$$

$$B_s = (1.75)(35)$$

$$B_s = 61 \text{ bus/h}$$

The Results

Adding a second linear loading area to the critical bus stop will give it sufficient vehicle capacity to accommodate the new route. The new critical bus stop should now be checked to make sure that it, too, can accommodate the proposed additional buses.

As a general rule, most downtown stops in larger cities should have two or three loading areas wherever possible.

Comments

The planning-level graphs also could have been used to solve this problem. From Exhibit 4-68 (Appendix C), the capacity of a single loading area under the stated conditions is 35 buses per hour. (There are no conflicting pedestrians when right turns are prohibited.) Multiplying this result by the number of effective loading areas (1.75) gives the final result of 61 buses per hour.

Example Problem 3

The Situation

As part of a package of service improvements that include the route restructuring described in Example Problem 2, the transit agency also wishes to improve overall transit speeds in the downtown area. Options include lengthening bus stops to reduce bus congestion, reducing the number of stops, and/or implementing a skip-stop pattern.

The Question

Will each option provide sufficient capacity to accommodate the 38 planned buses? What is the bus operating speed under each scenario?

The Facts

- Same assumptions as Example Problem 2.
- Under a skip-stop scenario, there would be two groups of routes: NE Metro (20 buses) and NW Metro (18 buses). Buses would be scheduled to minimize congestion, but schedule adherence is expected to be imperfect due to traffic signal and other delays.
- 500 veh/h use the adjacent lane.
- Trucks make up 2% of the traffic in the adjacent lane.
- Bus stops are located on the near sides of intersections.
- The average dwell time *at their critical stop* is 30 seconds. Bus dwell time, *averaged for all downtown stops,* is 20 seconds. These averages would be the same for both groups under a skip-stop scenario.
- Stops are located every block, 125 meters apart (8 stops/km). If stops are eliminated or a skip-stop pattern is implemented, stops would be located every two blocks.
- The *Highway Capacity Manual* should be used to determine the capacity of the adjacent lane. The base saturation flow rate, v_0, is 1,900 passenger vehicles per hour of green. The heavy vehicle saturation adjustment factor, f_{HV}, is 0.98. The area saturation flow adjustment factor, f_A, is 0.90 for CBDs.

Outline of Solution

The bus lane capacity will be determined for each scenario. For scenarios not involving skip-stops, the procedure is the same as in Example Problem 2. For skip-stop scenarios, the bus lane capacity is the sum of the capacity of the individual group capacities, multiplied by an adjustment factor for the effect of random bus arrivals and the impedance of other traffic in the adjacent lane.

If the capacity is greater than the number of scheduled buses, the average bus speed will be calculated. This procedure involves identifying the base bus speed in mixed traffic, from Exhibit 4-56m and Exhibit 4-57m, and modifying this speed by adjustment factors for skip-stop operation and bus-bus interferences.

Steps

1. Calculate the capacity of the adjacent lane, using the procedures given in Chapter 16 of the *Highway Capacity Manual.* This will be the same for all scenarios.

$$c = v_0 (g/C) f_{HV} f_A$$

$$c = (1{,}900 \text{ veh/h})(0.45)(0.98)(0.90)$$

$$c = 754 \text{ veh/h}$$

Add a Second Loading Area

2. For the purposes of determining speed, the critical bus stop capacity should be recalculated using a 25% failure rate. The other inputs are the same as in Example Problem 2.

$$B_l = \frac{3{,}600(g/C)}{t_c + (g/C)t_d + Zc_v t_d}$$

$$B_l = \frac{3{,}600(0.45)}{10 + (0.45)(30) + (0.675)(0.60)(30)}$$

$$B_l = 45 \text{ bus/h}$$

$$B_s = N_{el} B_l$$

$$B_s = (1.75)(45)$$

$$B_s = 78 \text{ bus/h}$$

3. Bus speeds are calculated from Equation 4-15. In this scenario, f_s = 1.0, as there are no skip-stops. The bus-bus interference factor, f_b, is determined from Exhibit 4-59: v/c = (38/78) = 0.49 and, therefore, f_b is 1.00.

$$S_t = \frac{60}{t_r + t_l} f_s f_b$$

4. The base bus running time, t_r, is determined from Exhibit 4-56m (20 second average dwell time and 8 stops per kilometer gives 7.24 min/km. The bus running time loss, t_l, is determined from Exhibit 4-57m. For a CBD bus lane with no right turns, under typical conditions, this loss is 0.7 min/km.

$$S_t = \left(\frac{60}{7.24 + 0.7} \text{km/h}\right)(1.0)(1.00)$$

$$S_t = 7.6 \text{ km/h}$$

Stop Every Two Blocks

5. In this scenario, average dwell times are assumed to double, as each remaining stop must accommodate twice as many passengers as before. Critical stop capacity is calculated from Equation 4-6. Here, the value of Z corresponding to a 10% failure rate is used, because the question of interest is how many buses can use the stop at that desired level of reliability, and not how fast they will travel.

   The added dwell times reduce the critical stop capacity by too much. Even with a second loading area, capacity would only be 34 bus/h, not enough to accommodate the planned number of buses.

$$B_l = \frac{3{,}600(g/C)}{t_c + (g/C)t_d + Zc_v t_d}$$

$$B_l = \frac{3{,}600(0.45)}{10 + (0.45)(60) + (1.28)(0.60)(60)}$$

$$B_l = 19 \text{ bus/h}$$

Implement Skip-Stops with Two Loading Areas

6. In this scenario, buses would be divided into two groups. Instead of having 38 buses per hour scheduled to use a stop that has a capacity to accommodate no more than 34 per hour, the largest group would only have 20 buses scheduled per hour. Thus, we know that the 38 scheduled buses can be accommodated.

   To begin, calculate the adjacent lane impedance factor from Equation 4-12.

$$f_i = 1 - 0.8\left(\frac{v}{c}\right)^3$$

$$f_i = 1 - 0.8\left(\frac{500}{754}\right)^3$$

$$f_i = 0.77$$

7. Calculate the skip-stop adjustment factor from Equation 4-11. Arrivals are typical; therefore, the f_a factor is 0.75.

$$f_k = \frac{1 + f_a f_i (N_{ss} - 1)}{N_{ss}}$$

$$f_k = \frac{1 + (0.75)(0.77)(2-1)}{2}$$

$$f_k = 0.79$$

8. The capacity used for calculating speed should be based on maximum capacity (25% failure), which is 46 buses/h, rather than the 34 buses/h used previously.

   The bus lane vehicle capacity is given by Equation 4-14 and is equal to the sum of the two patterns' critical bus stop vehicle capacities, multiplied by the factor calculated in Step 7. Because the two patterns have identical characteristics, their capacities are the same.

$$B = f_k (B_1 + B_2)$$

$$B = 0.79(46 + 46)$$

$$B = 72 \text{ bus/h}$$

9. The skip-stop speed adjustment factor is calculated from Equation 4-16. The larger of the two patterns' bus v_p / B_p ratios should be used in the calculation; thus, v_p / B_p = (20/46) = 0.43.

$$f_s = 1 - \left(\frac{d_1}{d_2}\right)\left(\frac{v}{c}\right)^2 \left(\frac{v_p}{B_p}\right)$$

$$f_s = 1 - \left(\frac{125}{250}\right)\left(\frac{500}{754}\right)^2 \left(\frac{20}{46}\right)$$

$$f_s = 0.90$$

10. The bus-bus interference factor, f_b, is determined from Exhibit 4-59: v/c = 0.59, and by interpolation, f_b is 0.94.

    The base bus running time, t_r, is determined from Exhibit 4-56m (40 second average dwell time and 4 stops per kilometer gives 4.82 min/km. The bus running time loss, t_l, is the same as before, 0.7 min/km.

$$S_t = \frac{60}{t_r + t_l} f_s f_b$$

$$S_t = \left(\frac{60}{4.82 + 0.7} \text{ km/h}\right)(0.90)(1.00)$$

$$S_t = 9.8 \text{ km/h}$$

11. For comparison, the existing bus speeds on the street (32 buses and single loading areas) are:

$$S_t = \frac{60}{t_r + t_l} f_s f_b$$

$$S_t = \left(\frac{60}{7.24 + 0.7} \text{km/h}\right)(1.0)(0.88)$$

$$S_t = 6.6 \text{ km/h}$$

The Results

All options, except increasing stop spacing (with or without a second loading area), provide sufficient bus capacity to accommodate the proposed route modification. Adding a second loading area to each stop will accommodate the additional buses and will result in travel speeds similar to, or slightly greater than, existing speeds.

Implementing a skip-stop pattern, in conjunction with increasing stop spacing and adding a second loading area, will improve speeds by nearly 50%, compared with existing levels. The trade-off is that some passengers will have to walk an extra block to board their bus.

Example Problem 4

The Situation

A transit agency wants to consolidate its outbound downtown bus routes, which currently use several streets, onto a single three-lane one-way street.

The Question

How will the street operate with the added buses from the perspective of bus operations?

The Facts

- $g/C = 0.45$.
- 40 buses per hour will use the street.
- An average of 1,200 automobiles per hour also use the street. Because of existing bus activity, automobiles tend to avoid the curb lane except to make right turns.
- To reduce walking distances for passengers from the shelter to the bus door and thus minimize dwell times, the transit operator desires to limit the number of loading areas to two per stop.
- Near-side, on-line stops will be located every two blocks.
- Dwell times, curb lane auto right-turn volumes, and conflicting pedestrian volumes are as follows:

Stop #	Average Dwell Time (s)	Right-Turn Volume (veh/h)	Conflicting Ped Volume (ped/h)
1	30	350	100
2	35	200	300
3	40	100	500
4	20	300	200

Assumptions and Derived Values

- The bus stop location factor, f_l, is 0.90 (Type 2 lane, near-side stop), from Exhibit 4-51.
- For on-line stops, assume a 10-second clearance time.
- $Z = 1.44$ for 7.5% failure rate, from Exhibit 4-6.
- Assume 60% coefficient of variation of dwell times.
- For two linear on-line berths, the number of effective loading areas, N_{el}, is 1.75, from Exhibit 4-12.

Outline of Solution

All input parameters are known. The critical bus stop will determine the bus lane capacity. Because of the variety of dwell times, right-turn volumes, and conflicting pedestrian volumes, the critical stop is not immediately obvious. The bus capacity of each stop must be found first, which will then be modified by the number of effective loading areas at each stop and the mixed traffic adjustment factor from Equation 4-17.

Steps

1. Estimate the right lane's vehicle capacity at each intersection. The HCM could be used. However, since this lane effectively acts as a right-turn lane for all vehicles other than buses, Exhibit 4-50 can also be used. The value for stops #1 and #4 can be read directly from the exhibit. The other values can be determined by interpolation, or from the equation provided in the exhibit.

For stop #1:

$$c = 580 \text{ veh/h}$$

2. Calculate the mixed traffic interference factor from Equation 4-17. Traffic volumes include the right-turning traffic and the 40 buses per hour.

For stop #1:

$$f_m = 1 - f_l \left(\frac{v}{c} \right)$$

$$f_m = 1 - 0.90 \left(\frac{390}{580} \right)$$

$$f_m = 0.39$$

3. Calculate the loading area bus capacity from Equation 4-6.

For stop #1:

$$B_l = \frac{3{,}600(g/C)}{t_c + (g/C)t_d + Zc_v t_d}$$

$$B_l = \frac{3{,}600(0.45)}{10 + (0.45)(30) + (1.44)(0.60)(30)}$$

$$B_l = 33 \text{ bus/h}$$

4. Calculate the curb lane's bus capacity at each bus stop from Equation 4-18.

For stop #1:

$$B = B_l N_{el} f_m$$

$$B = (33 \text{ bus/h})(1.75)(0.39)$$

$$B = 22 \text{ bus/h}$$

Summary table for all stops:

Stop #	*c*	*v*	f_m	B_l	*B*
1	580	390	0.39	33	22
2	435	240	0.50	29	25
3	290	140	0.57	26	25
4	510	340	0.40	45	31

The Results

Although bus stop #3 has the highest dwell time and the lowest individual loading area bus capacity, it is not the critical stop in this case, because right-turn interferences at stop #1 result in a lower overall facility capacity. The curb lane bus capacity is 22 buses per hour, which is insufficient to accommodate the proposed number of buses at the desired level of reliability.

Comments

The simplest way, if space permits, to add capacity to bus stop with one or two loading areas is to add another loading area. However, in this case, the transit operator desires to minimize pedestrian walking distances by limiting the number of loading areas to two. Further, a review of Exhibit 4-12 shows that even five loading areas would not provide enough capacity, because of the decreasing efficiency of each additional loading area.

Another option is to increase the design failure rate. However, doing so decreases schedule and headway reliability and should be avoided when possible. Therefore, other potential solutions will need to be evaluated. These possibilities are the subjects of subsequent example problems.

Example Problem 5

The Situation

The CBD street from Example Problem 4. Having determined that a mixed traffic lane with near-side stops will not work, the transit agency would like to try far-side stops to avoid some of the right-turn interferences.

The Question

How will buses operate on this street under this scenario?

The Facts

Same assumptions as Example Problem 4, except that stops are now on the far side.

Outline of Solution

All input parameters are known and the critical bus stop (known to be stop #1 from Example Problem 4) will determine the bus lane capacity. The only factor that changes is the location factor, f_l, which is 0.5 for a Type 2 mixed traffic lane.

Steps

1. Calculate the mixed traffic interference factor at stop #1 from Equation 4-17. Traffic volumes include the right-turning traffic and the 40 buses per hour.

$$f_m = 1 - f_l\left(\frac{v}{c}\right)$$

$$f_m = 1 - 0.50\left(\frac{390}{580}\right)$$

$$f_m = 0.66$$

2. Calculate the curb lane's bus capacity at stop #1, using Equation 4-18.

$$B = B_l N_{el} f_m$$

$$B = (33 \text{ bus/h})(1.75)(0.66)$$

$$B = 38 \text{ bus/h}$$

The Results

Repeating these steps for the other stops, stop #3 becomes the critical stop once right-turn interferences are minimized by far-side stopping, with a capacity of 34 buses per hour. The street's bus capacity improves substantially as a result of using far-side stops, but is still below the 40 buses per hour that will be scheduled to use it.

Comments

At this point, the transit agency could reconsider having only two loading areas at each stop. Adding a third loading area at stop #3 would provide a capacity of 48 buses per hour. Additional loading areas also would be required at stops #1 and #3. Extending bus stops may require the cooperation of the local road authority, particularly in situations when on-street parking is provided.

Another option would be to prohibit right turns at key intersections, to remove the interference of right-turning traffic on the buses. The mixed traffic interference factor would be 1.0 and the capacity of stop #1, for example, would be 57 buses per hour. This action would result in 350 vehicles per hour having to find another route and would require the cooperation of the local road authority.

The next problem looks at a potential bus operations solution to add capacity.

Example Problem 6

The Situation

The CBD street from Example Problems 4 and 5. The transit agency would next like to try a skip-stop operation to improve capacity.

The Question

Is sufficient bus capacity provided under this scenario?

The Facts

The assumptions used in Example Problems 4 still apply. However, if a skip-stop operation utilizing the existing near-side stops does not provide sufficient capacity, far-side stops will be tried next.

Half of the buses will use "A"-pattern stops, which are the same ones used in Problem 5. The other half will use "B"-pattern stops in the alternate blocks. For this example, the critical "B" stop has the same characteristics as the critical "A" stop.

Assumptions and Derived Values

- Buses will be scheduled to spread out bus arrivals, but some service irregularities are expected as a result of mixed traffic operations.
- Automobile volumes in the left two lanes are assumed to be evenly distributed.
- The adjustment factor, f_a, for typical arrivals, from Equation 4-11, is 0.75.
- From the *Highway Capacity Manual*, the base saturation flow rate (v_0) is 1,900 passenger vehicles per hour of green per lane, the heavy vehicle saturation flow adjustment factor (f_{HV}) is 0.97, and the area saturation flow adjustment factor (f_A) is 0.90 for a CBD.

Outline of Solution

All input parameters are known. The critical "A" and "B" bus stops will determine the bus lane capacity. The v/c ratio of the adjacent lane will need to be calculated to determine how well buses can use that lane to pass other buses. The bus lane capacity will be the sum of the capacities of the "A" and "B" stop patterns, multiplied by an adjustment factor for the effect of random bus arrivals and the impedance of other traffic in the adjacent lane.

Steps

1. Calculate the adjacent lane volume and capacity.

At stop #1:

$$v = (1{,}200 - 350)/2 = 425 \text{ vph}$$

$$c = v_0 (g/C) f_{HV} f_A$$

$$c = (1{,}900 \text{ vph})(0.45)(0.97)(0.90)$$

$$c = 746 \text{ veh/h}$$

2. Calculate the adjacent lane impedance factor, from Equation 4-12.

At stop #1:

$$f_i = 1 - 0.8\left(\frac{v}{c}\right)^3$$

$$f_i = 1 - 0.8\left(\frac{425}{746}\right)^3$$

$$f_i = 0.85$$

3. Calculate the skip-stop adjustment factor from Equation 4-11.

$$f_k = \frac{1 + f_a f_i (N_{ss} - 1)}{N_{ss}}$$

$$f_k = \frac{1 + (0.75)(0.85)(2-1)}{2}$$

$$f_k = 0.82$$

4. The "A" pattern bus lane capacity for near-side stops, from Example Problem 4, is 22 buses per hour, based on the capacity of the critical stop (stop #1). The "B" pattern's critical stop has similar characteristics and, thus, similar capacity. Calculate the total bus capacity of the street, using Equation 4-14.

$$B = f_k (B_1 + B_2 + \ldots + B_n)$$

$$B = (0.82)(22 + 22)$$

$$B = 36 \text{ bus/h}$$

5. As skip-stop operation using near-side stops do not provide enough capacity, far-side stops are tried next. The critical stop capacity was 34 buses per hour, from Example Problem 5.

$$B = f_k (B_1 + B_2 + \ldots + B_n)$$

$$B = (0.82)(34 + 34)$$

$$B = 55 \text{ bus/h}$$

The Results

If skip-stops are implemented and bus stops are placed on the far sides of intersections, there will be sufficient capacity for the proposed 40 buses per hour, with some excess capacity to accommodate more buses in the future.

Comments

The agency now has several options to accommodate the proposed route restructuring. To help narrow down the choices, additional analysis could be done to determine the effect of each option on bus travel speeds, overall person delay, capital costs (e.g., to move shelters to new stop locations), and so on.

Example Problem 7

The Situation

The CBD street from Example Problems 4 through 6.

The Question

How many people can be carried at the street's maximum load point if skip-stop operation is implemented?

The Facts

- Same assumptions as Example Problem 6.
- All buses are 43-passenger buses.
- Ten buses are express buses operating on freeways. The agency's policy is not to allow standees on buses that travel on freeways.
- The remaining local buses allow standees.

Assumptions

- Assume maximum schedule loads for the local buses, equivalent to a load factor of 1.50 for standard buses.
- The peak hour factor is 0.75.

Outline of Solution

The person capacity at the street's maximum load point is equal to the street's bus capacity, multiplied by the allowed passenger load per bus and the peak hour factor. From Example Problem 6, the street's bus capacity is 55 buses per hour.

Steps

1. Calculate the street's bus person capacity at its maximum load point, under the proposed operation.

$$P = [(10 * 43) + (30 * 43 * 1.50)] * 0.75$$

$$P = 1{,}770 \text{ p/h} \ \text{(rounded)}$$

2. Calculate the street's maximum bus person capacity at its maximum load point, assuming no more than 10 express buses.

$$P = [(10 * 43) + (45 * 43 * 1.50)] * 0.75$$

$$P = 2{,}500 \text{ p/h} \ \text{(rounded)}$$

The Results

Under the proposed operation, the street can carry about 1,770 people per hour in buses at its maximum load point. If the street's bus capacity of 55 buses per hour were to be scheduled, the street's person capacity would be about 2,500 people per hour in buses at the maximum load point.

Example Problem 8

The Situation

A transit agency operates its buses in mixed traffic on a three-lane one-way street in downtown. The combination of the volume of buses and the volume of traffic on the street is causing operational and reliability problems for the buses. To address these issues, the agency is proposing that one lane of the street be converted to exclusive bus use over an eight-block section, with right turns prohibited from the bus lane. This conversion would also accommodate future growth in bus volumes and help the operator maintain schedules as city streets become more congested. The city traffic engineer is concerned about the additional delay that will be experienced by motorists if the lane is implemented.

The Question

Will the proposed bus lane increase or decrease overall peak hour person delay?

The Facts

- 1,050 vehicles (including 3% trucks) and 52 buses use the street during the peak hour. Because this analysis addresses average person delay during the peak hour, rather than the peak 15 minutes of the peak hour, no vehicle PHF is required.
- Far-side, on-line stops with three loading areas are located every two blocks.
- No right turns would be allowed across the bus lane.
- Buses will be able to use the adjacent mixed traffic lane to pass other buses in the bus lane (i.e., the lane will be a Type 2 bus lane).
- Blocks are 440 ft (135 m) long, with traffic signals at the end of each block.
- The buses in use have 40 seats. The average peak hour load per bus is 30 passengers. Average vehicle occupancies are 1.2 persons per automobile.
- With a bus lane, the automobiles currently making right turns from this street will have to divert to a parallel street to make their turns, incurring an extra 60 seconds of delay each. Added delay to vehicles on these parallel streets, as well as the reduced delay to other vehicles that take their place on the bus street, is neglected.
- Average bus dwell times at the critical stop are 45 seconds. An average of 150 vehicles per hour make right turns from the bus street at the critical stop and an average of 650 vehicles per hour make right turns along the entire eight-block section. An average of 400 pedestrians per hour conflict with the right-turn movement at the critical bus stop’s intersection.
- The average dwell time for the four stops located along the proposed bus lane is 35 seconds.
- Pre-timed signals, 60-second cycle, g/C = 0.45, HCM arrival type 5, 25 mph (40 km/h) free-flow speed, no on-street parking, no grades, 12-ft (3.6-m) travel lanes, HCM arterial class IV.

Assumptions and Derived Values

- From the *Highway Capacity Manual*, the base saturation flow rate (v_0) is 1,900 passenger vehicles per hour of green per lane and the area saturation flow adjustment factor (f_A) is 0.90 for a CBD. Traffic volumes in the left two lanes are assumed to be evenly distributed. The heavy vehicle factor, f_{HV}, is 0.97.

The g/C ratio is known. The combination of these factors results in a per-lane capacity of 746 vehicles per hour.

- The bus stop location factor, f_l, is 0.50 for a Type 2 bus lane, from Exhibit 4-51.
- For pre-timed signals, the actuated control adjustment factor, k, is 0.50. (This is an input to an HCM procedure in Step 7.)
- For on-line stops, assume a 10-second clearance time.
- When calculating speeds, maximum capacity (i.e., a 25% failure rate) is used; thus, Z = 0.675.
- Assume a 60% coefficient of variation of dwell times.
- Assume buses are scheduled to spread out arrivals. The adjustment factor, f_a, for typical bus arrivals, from Equation 4-11, is 0.75.
- For three linear on-line berths, the number of effective berths, N_{el}, is 2.45, from Exhibit 4-12.

Outline of Solution

All of the input parameters are known. Travel speeds will be calculated for passenger vehicles and buses with and without the bus lane. Passenger vehicle speed will be calculated using methodologies from the *Highway Capacity Manual 2000*. The speeds will be converted to travel times over the length of the 3,520-ft (1,080-m) analysis section. The difference in travel times with and without the bus lane will be calculated for each mode. These time differences will be multiplied by the number of people affected and the results will provide the net change in person delay.

Steps

(a) Determine Transit Travel Times

1. Calculate the street's maximum bus capacity, using Equation 4-13 and Equation 4-10. The capacity of the right-turn movement is estimated from Exhibit 4-50.

$$B = B_l N_{el} f_r$$

$$B_l = \frac{3{,}600(g/C)}{t_c + (g/C)t_d + Zc_v t_d}$$

$$B_l = \frac{3{,}600(0.45)}{10 + (0.45)(45) + (0.675)(0.60)(45)}$$

$$B_l = 33 \text{ bus/h}$$

$$f_r = 1 - f_l\left(\frac{v_r}{c_r}\right)$$

$$f_r = 1 - 0.5\left(\frac{150}{360}\right)$$

$$f_r = 0.79$$

$$B = (33)(2.45)(0.79)$$

$$B = 63 \text{ bus/h}$$

2. With 52 buses per hour scheduled and a capacity of 63 buses per hour (a *v/c* ratio of 0.83), bus speeds will be affected by bus-bus interference. Equation 4-15 is used to calculate bus speed. Interpolating from Exhibit 4-56, base bus running times are 6.80 min/mi for stops every 880 feet (6 per mile). Additional running time losses are 3.75 min/mi for mixed traffic CBD operations, when traffic signals are more frequent than bus stops. There are no skip-stop stop operations, so the skip-stop factor, f_s , is 1.0. Exhibit 4-59 gives the bus-bus interference factor f_b.

$$S_t = \left(\frac{60}{t_r + t_l}\right) f_s f_b$$

$$S_t = \left(\frac{60}{6.80 + 3.75}\right)(1.0)(0.77)$$

$$S_t = 4.4\ \text{mph}$$

3. With a bus lane, right-turning traffic interference is removed (f_r = 1.0) and the bus facility capacity increases.

$$B = B_l N_{el} f_r$$

$$B = (33)(2.45)(1.0)$$

$$B = 80\ \text{bus/h}$$

4. The increased capacity reduces interference between buses, which increases speeds. The new *v/c* ratio is 52/80, or 0.65, resulting in a bus-bus interference factor of 0.92. An exclusive bus lane reduces running time losses from the interference of other traffic, which also results in increased speeds. The step #2 calculations are repeated for the “with bus lane” scenario.

$$S_t = \left(\frac{60}{t_r + t_l}\right) f_s f_b$$

$$S_t = \left(\frac{60}{6.80 + 1.75}\right)(1.0)(0.92)$$

$$S_t = 6.5\ \text{mph}$$

5. Calculate the time to travel the 3,520-foot analysis section with and without the exclusive bus lane.

Without:
t = (0.67 mi)/(4.4 mph) = 0.152 h
t = 9.1 min

With:
t = (0.67 mi)/(6.5 mph) = 0.103 h
t = 6.2 min

6. Calculate the change in person-minutes of travel time for transit passengers.

Δt = (52 bus*30 p/bus) * (9.1 min – 6.2 min)
Δt = 4,524 person-minute decrease

(b) Determine Automobile Travel Times

7. Using the procedures provided in Chapter 16 of the *Highway Capacity Manual 2000,* calculate the average travel speeds for automobiles on the street under the present situation (there are several steps to this process, which are not shown here).

$$S_A = 11.6\ \text{mph}$$

8. With a bus lane, the volume in the remaining two general-purpose lanes increases from 350 veh/lane to 525 veh/lane, resulting in increased traffic delays and lower speeds. Repeat Step 7 for the bus lane scenario.

$$S_A = 10.9\ \text{mph}$$

9.	Calculate the time to travel the 3,520-foot analysis section with and without the exclusive bus lane.	Without: t = (0.67 mi)/(11.6 mph) = 0.058 h t = 3.5 min With: t = (0.67 mi)/(10.9 mph) = 0.061 h t = 3.7 min
10.	Calculate the change in person-minutes of travel time for automobile passengers, including the added delay to the 650 diverted right-turning vehicles.	Δt = (1,200 veh*1.2 p/veh)(3.7 min – 3.5 min) + (650 veh*1.2 p/veh)(1 min) Δt = 1,068 person-minute increase

(c) Determine the Net Change in Person Delay

11.	Subtract the increased travel time for automobile passengers from the decreased travel time for bus passengers.	Δt = (4,524 person-min) – (1,068 person-min) Δt = 3,456 person-minute savings

The Results

The proposed arterial street bus lane will reduce peak-hour person delay by over 3,400 person-minutes. Buses will be able to traverse the section nearly three minutes faster than before, through vehicles will be slowed by about 12 seconds, and diverted right-turning vehicles will be slowed by 1.0 minute. Because the proposed bus lane will result in an overall travel time savings to users of the street, the proposal should be viewed favorably from that perspective. (There may be other perspectives, not stated in the problem, that may also need to be considered.)

Example Problem 9

The Situation

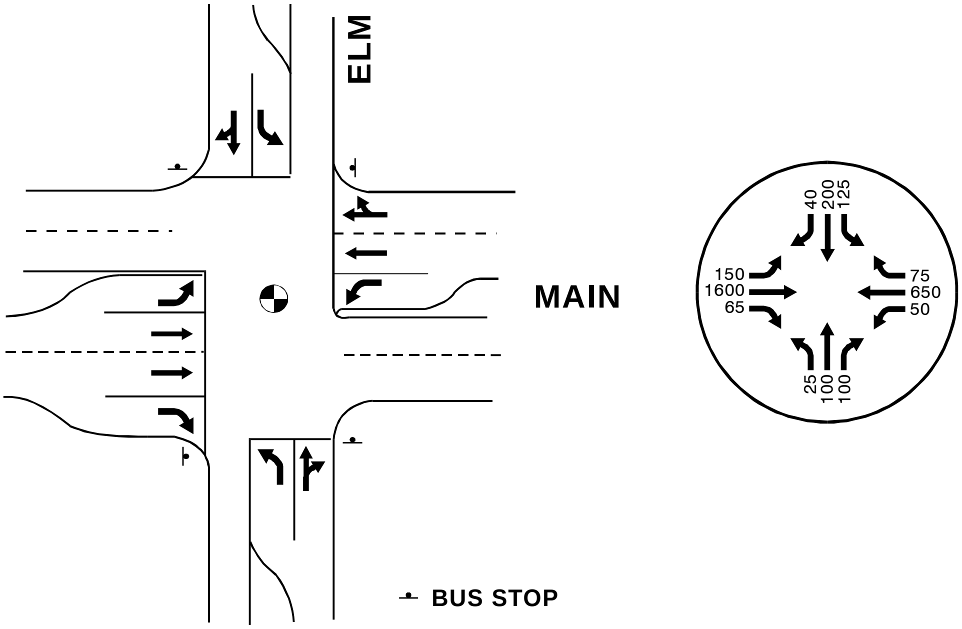
A transit operator would like to implement queue-jump signal priority at a signalized intersection on a city arterial street. The city traffic engineer is concerned about how automobile traffic will be affected.

The Question

Compare the change in person delay as a result of the signal priority measure.

The Facts

- Buses arrive at a near-side stop located in a right-turn lane during the green signal phase for Main Street. Boarding and discharging passengers is completed before the end of the red signal phase for Main Street. The proposed queue jump will give eastbound peak-direction buses a green indication for 3.0 seconds in advance of other traffic moving in the peak direction, allowing these buses to merge back into the travel lane ahead of the other vehicles stopped at the signal. A detector at the bus stop is used to provide a queue jump signal phase only when a bus occupies the stop. The 3.0 seconds is taken from the green time for the peak direction of travel.
- Lane configurations and traffic volumes are given in the figure below. The queue jump operates on the eastbound direction on Main Street.



- The traffic signal cycle length is 90 seconds. Protected left-turn phasing (i.e., a green arrow) is provided on Main Street and permitted left-turn phasing (i.e., a solid green circle indication) is provided on Elm Street.
- The peak hour factor is 0.94.
- Buses operate at 10-minute headways on Main Street and at 30-minute headways on Elm Street.

- During the peak hour, average passenger vehicle occupancy is 1.2, average bus occupancy on Main Street is 40 in the peak direction and 20 in the off-peak direction, and average bus occupancy on Elm Street is 25 in the peak direction and 10 in the off-peak direction.

Assumptions and Derived Values

- Bus re-entry delay cannot be calculated from Exhibit 4-5 in this case because the re-entry delay is caused by waiting for a queue to clear at a signalized intersection, rather than waiting for a gap in a traffic stream of randomly arriving vehicles. Field measurements indicate that it takes 18 seconds on average for the queue to clear before buses are able to re-enter the street. The proposed queue jump would eliminate this delay.
- A capacity analysis using the *Highway Capacity Manual* finds that the intersection's volume-to-capacity ratio is sufficiently low that the added 3.0 seconds of delay to peak-direction traffic during a queue jump should not cause cycle failures (i.e., all queued peak-direction traffic will clear the intersection on the next green signal).

Outline of Solution

All of the input parameters are known. Because the queue jump only takes green time away from through traffic in one direction, it is not necessary to calculate delays for all movements. Rather, the average delay for peak-direction automobile traffic is 3.0 seconds longer for those cycles when the queue jump is used. The added delay to persons in automobiles during the queue jump cycles will be compared with the delay savings experienced by persons in peak-direction buses. All other persons in all other vehicles at the intersection experience no net change in person-delay.

Steps

1. Calculate the delay savings to persons on peak-direction buses.

$$\Delta t = (18\text{ s})(6\text{ bus/h})(40\text{ p/bus})$$
$$\Delta t = 4{,}320\text{ person-seconds}$$
$$\Delta t \approx 72\text{ person - minute decrease}$$

2. The average number of peak-direction automobiles traveling through the intersection during a cycle in which a queue jump occurs is (1600/40), or about 40 veh/cycle. At 10-min headways, a queue jump would occur six times an hour. Calculate the added delay to the occupants of these vehicles.

$$\Delta t = (3\text{ s})(6\text{ cycle/h})(40\text{ veh/cycle})(1.2\text{ p/veh})$$
$$\Delta t = 864\text{ person - seconds}$$
$$\Delta t \approx 15\text{ person - minute increase}$$

3. Subtract the increased travel time for automobile passengers from the decreased travel time for bus passengers.

$$\Delta t = (72\text{ person - min}) - (15\text{ person - min})$$
$$\Delta t = 57\text{ person - minute savings}$$

The Results

The proposed queue jump will decrease person-delay by approximately 57 person-minutes during the peak hour. Because the proposed queue jump will result in an overall travel time savings to users of the street, the proposal should be viewed favorably from that perspective. (There may be other perspectives, not stated in the problem, that may also need to be considered.)

This page is intentionally blank.

APPENDIX A: EXHIBITS IN METRIC UNITS

Exhibit 4-47m
Estimated Average Speeds of Buses Operating on Busways and Exclusive Freeway HOV Lanes (km/h)

Average Stop Spacing (km)	Average Dwell Time (s)				
	0	15	30	45	60
80 km/h Running Speed					
1.0	61	46	38	33	29
1.5	66	53	47	41	37
2.0	69	58	52	47	43
3.0	73	64	59	54	51
4.0	74	67	63	59	56
90 km/h Running Speed					
1.0	64	47	40	34	30
1.5	71	56	49	43	38
2.0	75	62	55	49	45
3.0	79	69	63	58	54
4.0	82	74	68	64	60
100 km/h Running Speed					
1.0	65	49	40	35	30
1.5	74	59	50	44	39
2.0	79	65	58	51	46
3.0	85	74	67	61	57
4.0	88	79	73	68	63

NOTE: Assumes constant 1.2 m/s^2 acceleration/deceleration rate. Use the zero dwell time column for express buses slowing, but not stopping at stations (40 km/h station speed limit and 100-m-long speed zone through station assumed).

Exhibit 4-56m
Estimated Base Bus Running Time, t_r (min/km)(R37)

Dwell Time (s)	Stops per km							
	1	2	3	4	5	6	7	8
10	1.39	1.82	2.29	2.83	3.46	4.18	5.04	5.91
20	1.55	2.15	2.79	3.49	4.29	5.19	6.20	7.24
30	1.72	2.49	3.29	4.16	5.12	6.18	7.37	8.58
40	1.89	2.82	3.78	4.82	5.96	7.18	8.54	9.91
50	2.06	3.15	4.28	5.49	6.80	8.18	9.70	11.24
60	2.22	3.48	4.77	6.15	7.63	9.18	10.87	12.58

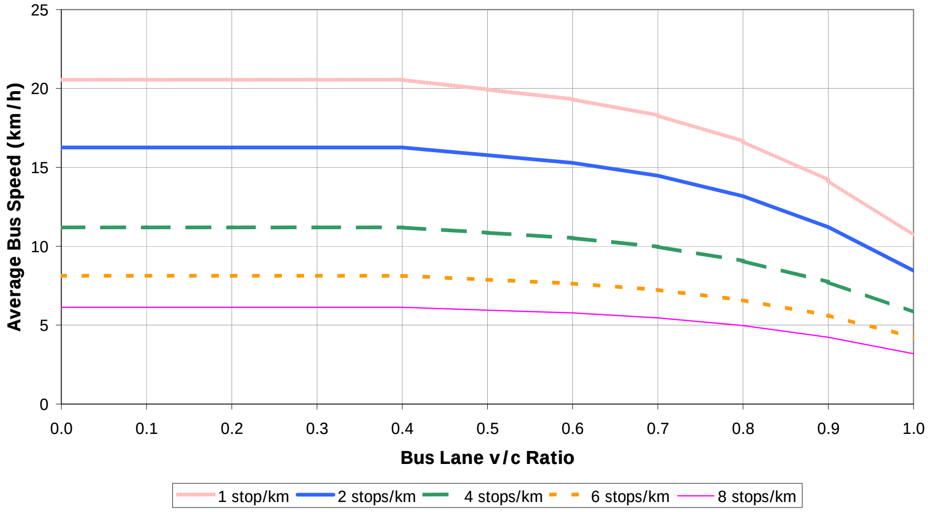
NOTE: Data based on field measurements. Interpolation between dwell time values is done on a straight-line basis.

Exhibit 4-57m
Estimated Base Bus Running Time Losses, t_l (min/km)(R37)

Condition	Bus Lane	Bus Lane, No Right Turns	Bus Lane With Right Turn Delays	Bus Lanes Blocked by Traffic	Mixed Traffic Flow
CENTRAL BUSINESS DISTRICT					
Typical		0.7	1.2	1.5-1.8	1.8
Signals Set for Buses		0.4	0.8		
Signals More Frequent Than Bus Stops		0.9-1.2	1.5-1.8	1.8-2.1	2.1-2.4
ARTERIAL ROADWAYS OUTSIDE THE CBD					
Typical	0.4				0.6
Range	0.3-0.6				0.4-0.9

NOTE: Data based on field measurements. Traffic delays shown reflect peak conditions.

Exhibit 4-60m
Illustrative Bus-Bus Interference Factor Effects



NOTE: Assumes 30-second dwell times, CBD bus lane with right-turn delays, and typical signal timing.

APPENDIX B: DWELL TIME DATA COLLECTION PROCEDURE

INTRODUCTION

As discussed in Chapter 1, passenger service times (and dwell times) can vary greatly depending on many factors. For example, passenger service times reported in the literature range from 1 to 10 seconds per passenger.(R1,R13,R27,R32) For this reason, it is recommended that field data be collected when estimating passenger service times and dwell times for a given system.

Although a transit vehicle's passenger service time may be affected by many factors, most of these factors are constant for a given system. For this reason, the principal determinants of service time typically include aspects of passenger demand. Therefore, for a given transit system with constant operating characteristics (i.e., fare collection system, number and width of doors, number of steps to board/alight, etc.), the major factors affecting service time will be

- The number of passengers boarding,
- The number of passengers alighting, and
- The number of passengers on board.

This appendix presents methodologies for measuring passenger service times and dwell times in the field for buses and light rail transit (LRT).

PASSENGER SERVICE TIMES

Passenger movements at most stops are small, typically one or two passengers boarding or alighting per stop. In these situations, dwells are relatively independent of passenger service times and it is not possible to collect statistically useful data. To determine passenger service times for use in evaluating the differences between systems (such as single- and dual-stream doors, high- and low-floor buses, or alternate fare collection systems), data collection should be done only at high-volume stops. These stops are typically downtown or at major transfer points. The data collection effort will require one or two persons, depending on the number of passengers.

The following are steps that may be used to collect field data on passenger service times. An example of a data collection sheet is shown in Exhibit 4-63.

1. From a position at the transit stop under study, record the identification number and run number for each arriving vehicle.
2. Record the time that the vehicle comes to a complete stop.
3. Record the time that the doors have fully opened.
4. Count and record the number of passengers alighting and the number of passengers boarding.
5. Record the time that the major passenger flows end. (Note: This is somewhat subjective but essential to correlate flows per unit of time. The time for stragglers to board or exit should not be included.)
6. When passenger flows stop, count the number of passengers remaining on board. (Note: If the seating capacity of the transit vehicle is known, the number of passengers on board may be estimated by counting the number of vacant seats or the number of standees).
7. Record the time when the doors have fully closed.

8. Record the time when the vehicle starts to move. (Note: Leave time should exclude waits at timepoints or at signalized intersections where the vehicle must wait for a traffic signal to turn green.)
9. Note any special circumstances. In particular, any wheelchair movement times should be noted.

The passenger service time for each transit vehicle arrival is computed by taking the difference between the time that the door opens and the time that the main flow stops. The service time per passenger is computed by dividing the number of passengers boarding (or alighting) by the total service time.

Exhibit 4-63
Sample Passenger Service Time Data Collection Sheet

Passenger Service Time Data Sheet #____

Date ________ **Time** ________

Route ________ **Location** ______ **Direction** ________

Bus Run #	Arrival Time	Doors Open	Main Flow Stops	Doors Closed	Bus Leaves	Passengers Boarding		Passengers Alighting		Psgrs. Departing On Board	Notes
						Front	Rear	Front	Rear		

DWELL TIMES

The procedure for determining dwell times is similar to that for estimating passenger service times, except that dwell times are best determined with ride checks. With ride checks, the observer rides the transit vehicle over the entire route for several runs at different times of day. A single observer can usually monitor both doorways on a 40-foot (12-meter) bus. While it is more difficult for a single observer to handle articulated buses that have three doorways, it is possible with an experienced checker. For LRT vehicles, at least one observer per car will be required. Automated equipment can also monitor dwell times, possibly in conjunction with automatic passenger counting equipment.

Usually a given route will have similar equipment. Where equipment types such as single or double doors, rigid or articulated bodies, or high- or low-floor cars are intermixed, separate data sets should be obtained for each type of equipment. A sample data collection sheet is shown in Exhibit 4-64. This sheet can be adapted to also record traffic and intersection delays. Where passenger service times are not needed, the door open, end of passenger flow, door close columns can be omitted. The following are steps that may be used to collect field data for estimating dwell times:

1. From a position on the transit vehicle, record the stop number or name at each stop.
2. Record the time that the vehicle comes to a complete stop.
3. Record the time that the doors have fully opened.

4. Count and record the number of passengers alighting and the number of passengers boarding.
5. Record the time that the major passenger flows end.
6. When passenger flows stop, count the number of passengers remaining on board. (Note: If the seating capacity of the transit vehicle is known, the number of passengers on board may be estimated by counting the number of vacant seats or the number of standees).
7. Record the time when doors have fully closed.
8. Record the time when the vehicle starts to move. (Note: Waits at timepoints or at signalized intersections where the dwell is extended due to a red traffic signal should be noted but *not* included in the dwell time. A delay due to a driver responding to a passenger information request is an everyday event and *should* be included in the dwell time calculation. Time lost dealing with fare disputes, lost property, or other events should *not* be included.)
9. Note any special circumstances. In particular, any wheelchair movement times should be noted. Whether this is included in the mean dwell time depends on the system. Dwell times due to infrequent wheelchair movements are often not built into the schedule but rely on the recovery time allowance at the end of each run.

The observer must use judgment in certain cases. At near-side stops before signalized intersections, the driver may wait with doors open as a courtesy to any late-arriving passengers. The doors will be closed prior to a green light. This additional waiting time should *not* be counted as dwell time but as intersection delay time.

Exhibit 4-64
Sample Dwell Time Data Collection Sheet

Dwell Time Data Sheet #____

Date ____ Time ____ Bus No. ______ Bus Type________
Route ___ Run No. ___ Direction _____

Stop # and Name	Arrival Time	Doors Open	Main Flow Stops	Doors Closed	Bus Leaves	Passengers Boarding		Passengers Alighting		Psgrs. Departing On Board	Notes
						Front	Rear	Front	Rear		

This page is intentionally blank.

APPENDIX C: BUS EFFECTS ON ADJACENT LANE VEHICLE CAPACITY

The introduction of single or dual bus lanes reduces a roadway's vehicle capacity for other traffic. The extent of this reduction is determined by (1) the bus lane type, (2) the number of buses using the bus lane, and (3) whether or not the bus lane replaces a curb parking lane.

The following impacts are associated with the provision of a single or dual bus lane:(R36)

- If the lane is already used primarily by buses, the vehicle capacity loss will be relatively small. However, when the lane is introduced for relatively low existing bus flows (i.e., fewer than 40 buses per hour), the reduction in vehicle capacity could be as much as 30 to 50% of one travel lane.
- Introducing a single dedicated curb lane for buses onto a street with no previous bus operations reduces the street vehicle capacity by one lane if buses stay in the lane (Type 1) and right turns are prohibited or made from the second lane. Allowing right turns from a Type 1 bus lane reduces street vehicle capacity by less than one full lane.
- A dual bus lane (Type 3) reduces arterial vehicle capacity by up to two lanes. Because dual lanes usually would be implemented when buses already pre-empt most of the curb lane, the actual capacity reduction in arterial traffic would be less. The Madison Avenue dual bus lane experience in New York indicates that prohibiting right turns, eliminating weaving movements, and strict enforcement of regulations actually increased general traffic flow and speeds over what was experienced with an existing Type 2 bus lane.
- The effects of a Type 2 bus lane where buses may enter the adjacent lane will be between those of the Type 1 and Type 3 lanes. For low bus volumes, buses entering the mixed traffic lane would have little effect on the capacity of the mixed traffic lane. As bus volumes in a Type 2 lane increase, their impact on the adjacent lane increases to a point where some traffic is discouraged from using the adjacent lane. The passenger vehicle equivalency of a bus traveling without stops is estimated in the *Highway Capacity Manual* at 1.5 to 2.0 passenger vehicles. However, for Type 2 bus lanes, merging, weaving, and diverging maneuvers could raise this equivalency to 3 to 4 passenger vehicles or more.

See Chapter 5 for a description of exclusive bus lane types.

The effects of bus lane operations on the adjacent general travel lane can be expressed by multiplying the adjacent lane's vehicle capacity by the adjustment factor given in Equation 4-19, derived from simulation.(R36) The factor is applied to saturation flow similar to the other saturation flow adjustments, including the factor for bus blockage.

Saturation flow adjustment factor for bus use of an adjacent lane.

Equation 4-19

$$f_p = 1 - \left(4 \frac{N_p}{3600}\right)$$

where:

f_p = bus-passing activity factor; and

N_p = number of buses making the maneuver from the curb lane to the adjacent lane, from Equation 4-20.

The delay to through traffic in the adjacent lane is minimal unless buses leave the bus lane. Therefore, an adjustment is needed to determine the actual number of buses, N_p, that would pass other buses using the curb lane. Simulations and field observations(R36) indicate that when buses operate at less than one-half the vehicle capacity of the bus lane, they have little need to pass each other even in a skip-stop operation because of the low arrival headways relative to capacity. Bus use of the adjacent lane increases at an increasing rate as bus activity approaches capacity. Thus, N_p may be approximated by the following relationship:

Equation 4-20

$$N_p = \frac{N_{ss} - 1}{N_{ss}} v_b \left(\frac{v_b}{B} \right)^3$$

where:

N_p = number of buses making the maneuver from the curb lane to the adjacent lane.

N_{ss} = number of alternating skip-stops in pattern;

v_b = volume of buses in the bus lane (bus/h); and

B = bus capacity of the bus lane (bus/h).

As expressed in this equation, the number of buses in the adjacent lane would be one-half the total bus flow when an alternating two-block skip-stop operation approaches capacity. Two-thirds of the buses would use the adjacent lane for a three-block pattern. However, these impacts would not take full effect until the bus volumes approached capacity.

APPENDIX D: PLANNING-LEVEL CAPACITY GRAPHS

This appendix contains graphs providing bus capacities for bus stops and bus lanes for a number of common situations. Because of the number of variables involved, it is not possible to provide a graph for every conceivable situation, and users are cautioned to review the assumptions used to develop each graph to confirm that the graph applies to their situation. The spreadsheets used to develop these graphs are included on the accompanying CD-ROM and allow users to change the assumptions as required for a given situation.

The spreadsheets used to develop Appendix D exhibits are included on the accompanying CD-ROM.

Exhibits 4-65 through 4-67 provide bus stop capacities for both on-line and off-line stops, for various combinations of dwell time, g/C ratios, and curb lane traffic volumes. Graphs are provided for recommended failure rates corresponding to suburban, downtown, and maximum capacity situations. *Note that the capacity values shown are for stops with a single loading area. To obtain the capacity of a stop with multiple loading areas, multiply the value from the graph by the appropriate loading area efficiency factor from Exhibit 4-12, which is reproduced below.*

The graphs are based on the capacity of a single loading area. Multiply graphed values by the appropriate loading area efficiency factor.

Copy of Exhibit 4-12
Efficiency of Multiple Linear Loading Areas at Bus Stops(R25,R27,R28)

	On-Line Loading Areas				Off-Line Loading Areas	
	Random Arrivals		Platooned Arrivals		All Arrivals	
Loading Area #	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas
1	100	1.00	100	1.00	100	1.00
2	75	1.75	85	1.85	85	1.85
3	70	2.45	80	2.65	80	2.65
4	20	2.65	25	2.90	65	3.25
5	10	2.75	10	3.00	50	3.75

NOTE: On-line values assume that buses do not overtake each other.

Exhibits 4-68 through 4-72 provide bus lane capacities based on critical bus stop dwell times of 30 and 60 seconds for combinations of Type 1 and Type 2 lanes, near-side and far-side stops, and various right-turning volumes at the critical stop. These exhibits assume a downtown location, with on-line stops, a 10% failure rate, and a g/C ratio of 0.45 (typical for a one-way downtown grid). Exhibits 4-73 and 4-74 provide similar graphs for mixed traffic situations for various combinations of curb lane volumes. As before, multiply the capacity values shown by the appropriate loading area equivalency factor from Exhibit 4-12.

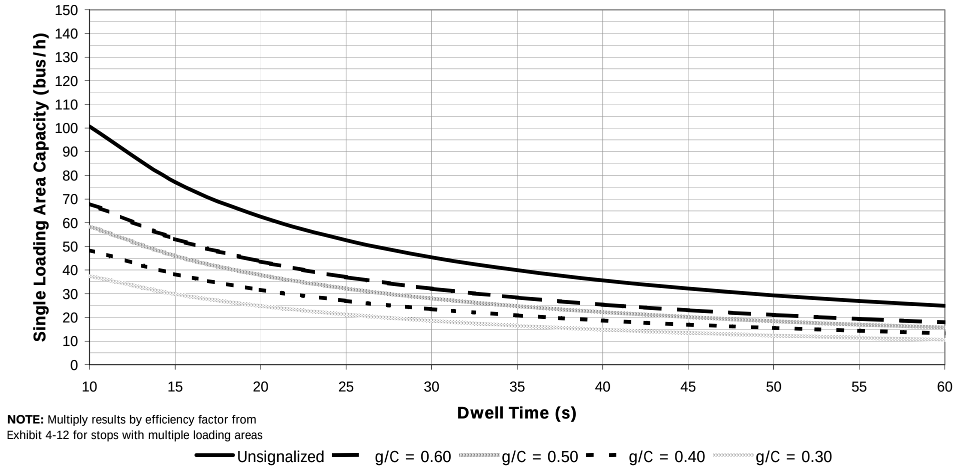
To obtain person capacities, multiply the bus capacity obtained from the graph by an average maximum schedule load per bus (e.g., 60 passengers for a standard 12-meter or 40-foot bus, or 90 to 100 passengers for an articulated bus) and an appropriate peak hour factor (0.60 to 0.95, with 0.75 recommended as a default in the absence of other information).

Default g/C ratios.

If the g/C ratio is not known for a particular roadway, a value of 0.45 may be used as a default for the through movement on the major street where no protected left-turn phase (i.e., left-turn arrow) is present, while 0.40 may be used for the through movement on the major street when protected left-turn phasing is used.(R6) For most other situations, the g/C ratio may range from 0.30 to 0.70 for through movements.(R9) A higher ratio (up to 0.60 or 0.70, if protected left turns are not provided) may be applicable where the major street has much greater traffic volumes per lane than the minor street. A lower ratio (e.g., 0.30) may be appropriate for a minor street through movement, or an even lower one if the two streets' traffic volumes per lane are substantially different. A g/C ratio of 0.10 can be used as a default for a protected left-turn movement.

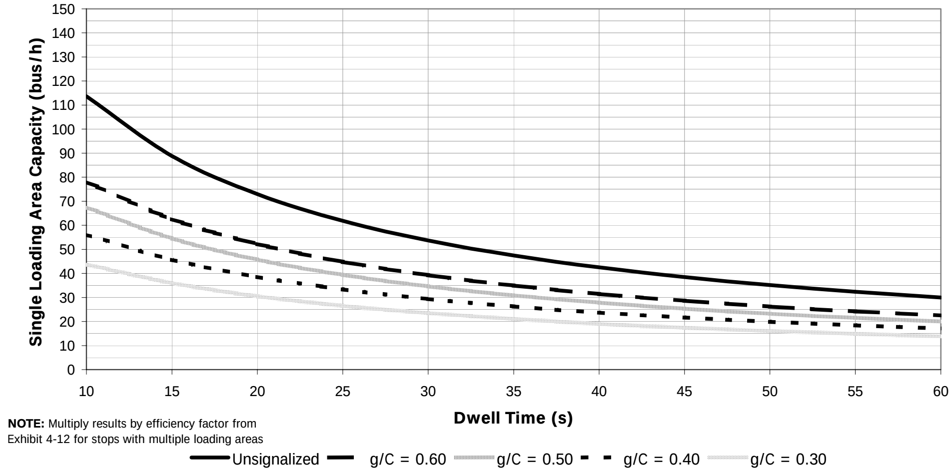
Exhibit 4-65
Bus Stop Capacity with 400 veh/h in Curb Lane and Off-line Stops

Bus Stop Capacity:
Off-line stops, 400 veh/h, Suburban area (2.5% failure rate), 60% c_v



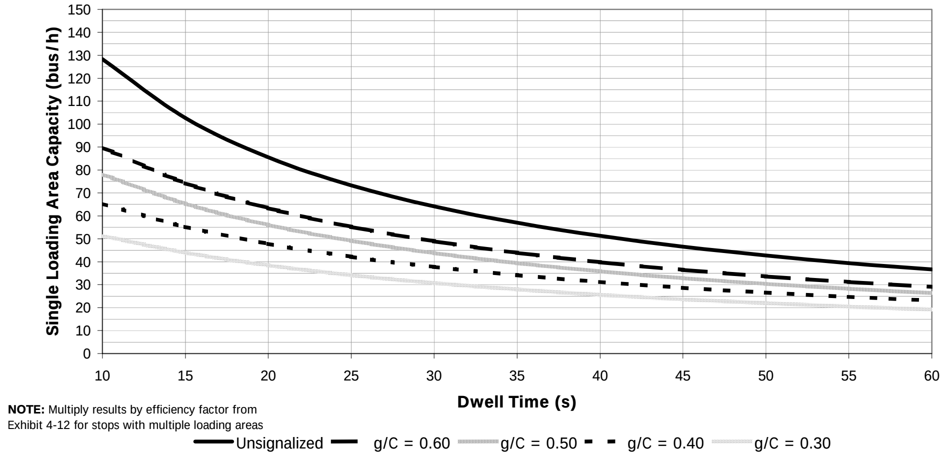
NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Bus Stop Capacity:
Off-line stops, 400 veh/h, Downtown area (10% failure rate), 60% c_v



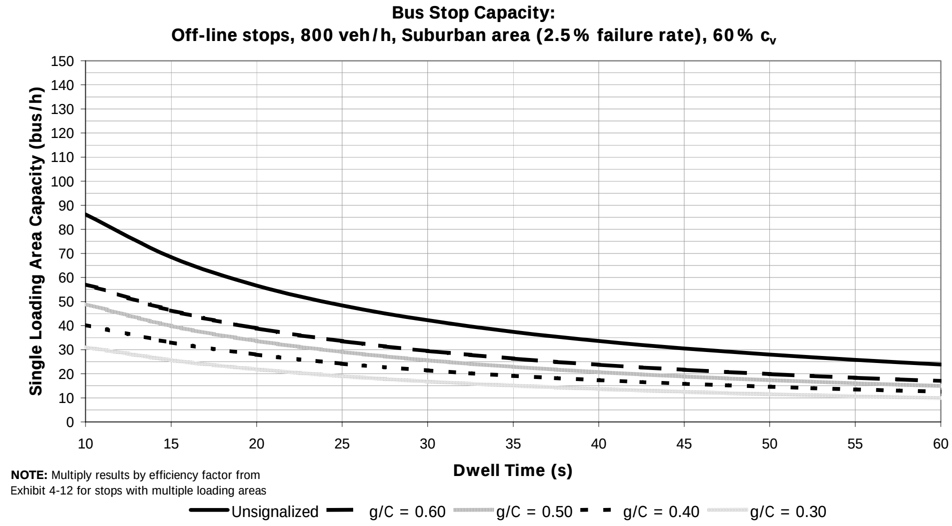
NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Bus Stop Capacity:
Off-line stops, 400 veh/h, Max. Capacity (25% failure rate), 60% c_v

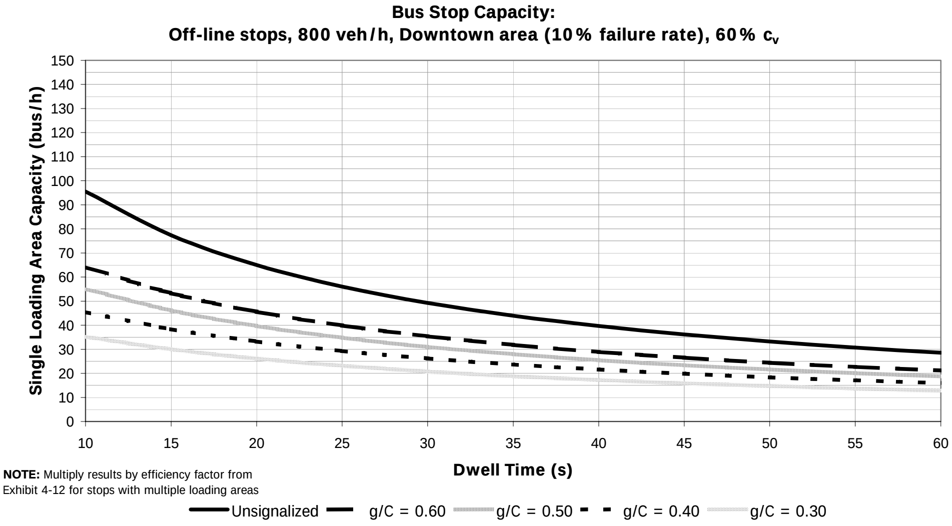


NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

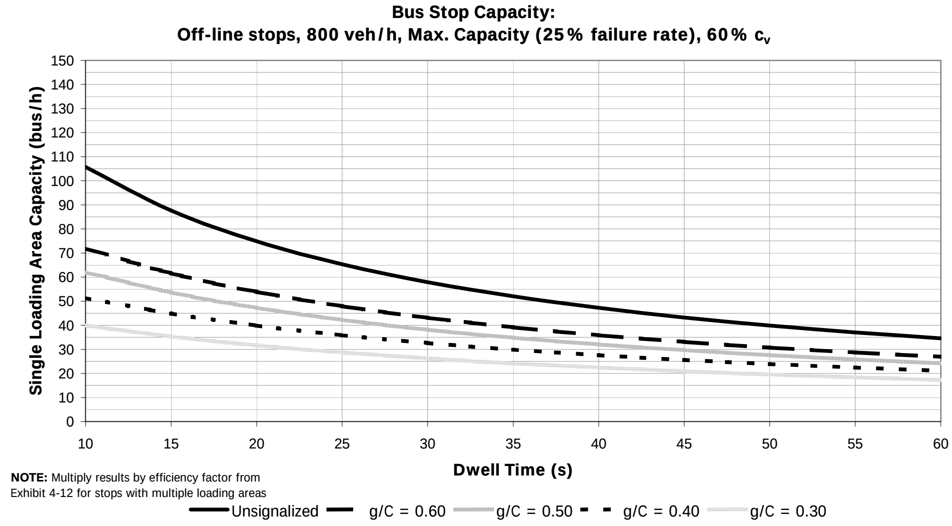
Exhibit 4-66
Bus Stop Capacity with
800 veh/h in Curb Lane and
Off-line Stops


Bus Stop Capacity:
Off-line stops, 800 veh/h, Suburban area (2.5% failure rate), 60% c_v

NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas


Bus Stop Capacity:
Off-line stops, 800 veh/h, Downtown area (10% failure rate), 60% c_v

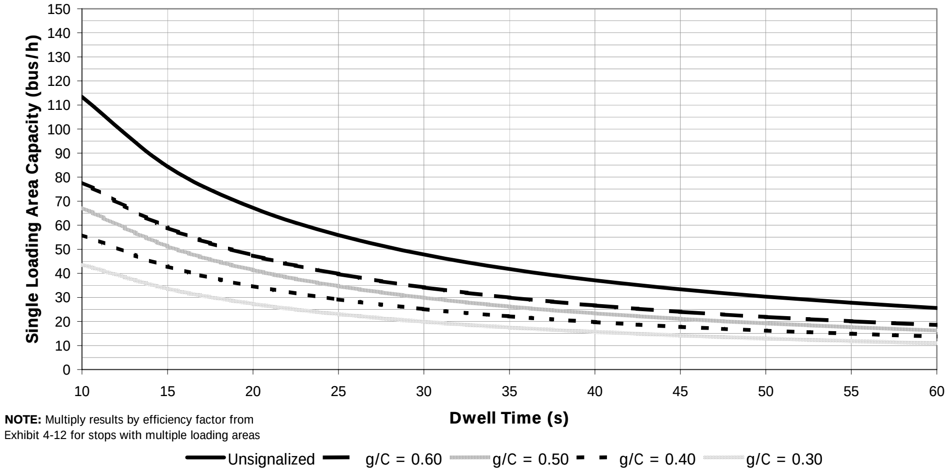
NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas


Bus Stop Capacity:
Off-line stops, 800 veh/h, Max. Capacity (25% failure rate), 60% c_v

NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

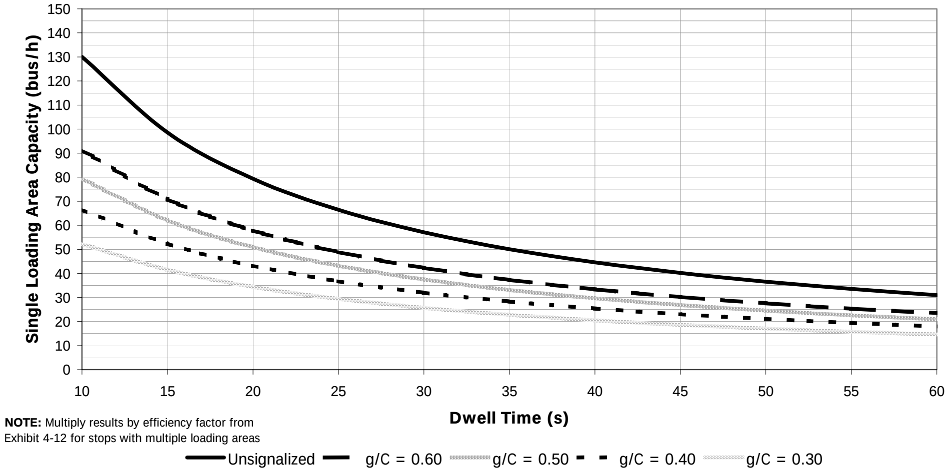
Exhibit 4-67
Bus Stop Capacity with On-Line Stops

Bus Stop Capacity:
On-line stops, Suburban area (2.5% failure rate), 60% c_v



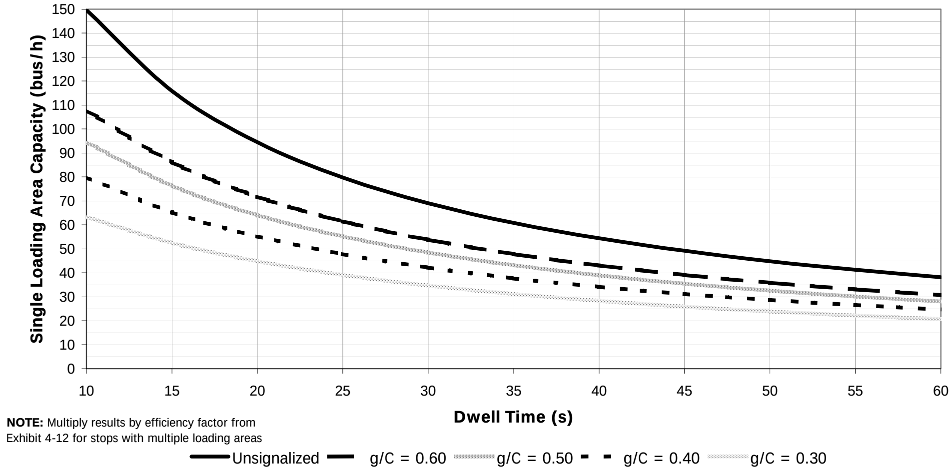
NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Bus Stop Capacity:
On-line stops, Downtown area (10% failure rate), 60% c_v



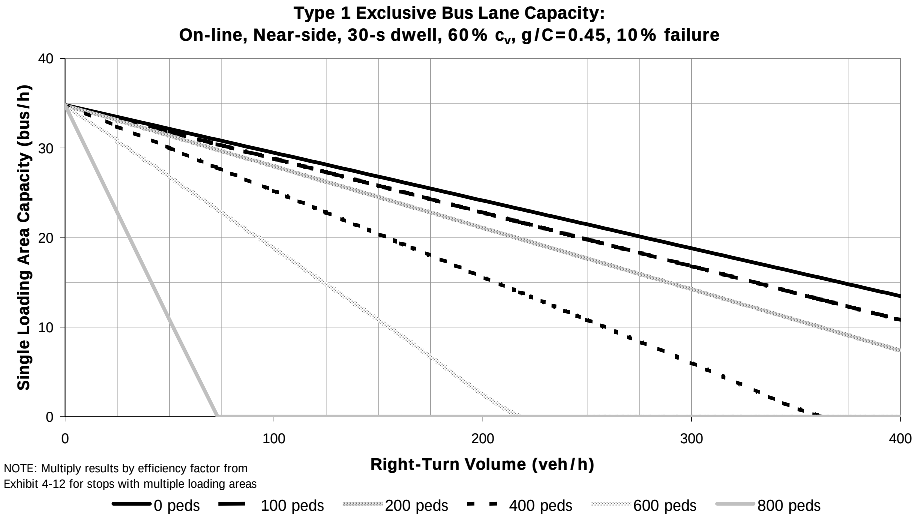
NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Bus Stop Capacity:
On-line stops, Max. Capacity (25% failure rate), 60% c_v

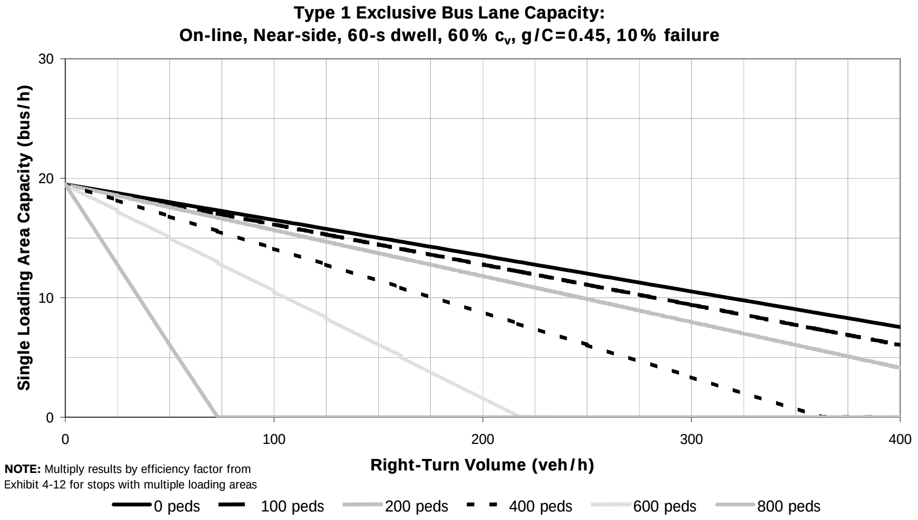


NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Exhibit 4-68
Exclusive Lane Bus Capacity:
Near-side Stops, Type 1 Lane

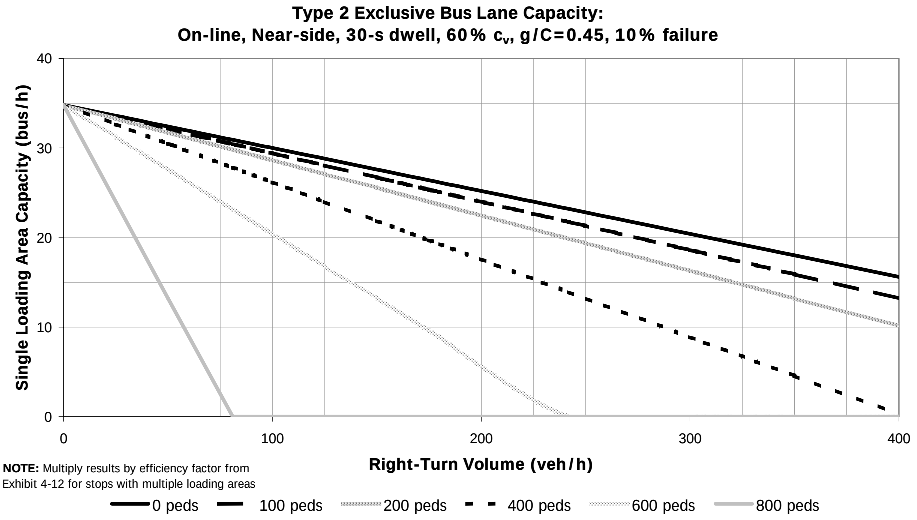


NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas



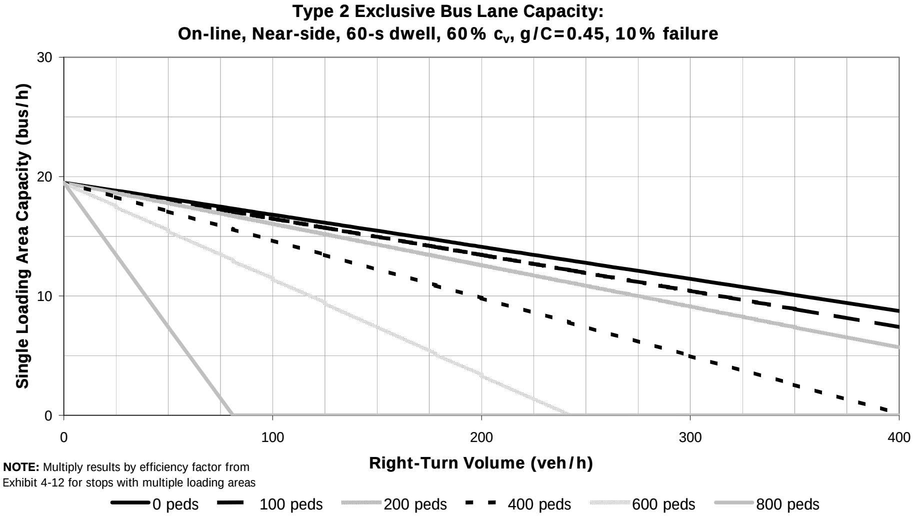
NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Exhibit 4-69
Exclusive Lane Bus Capacity:
Near-side Stops, Type 2 Lane



Type 2 Exclusive Bus Lane Capacity:
On-line, Near-side, 30-s dwell, 60% c_v, g/C=0.45, 10% failure

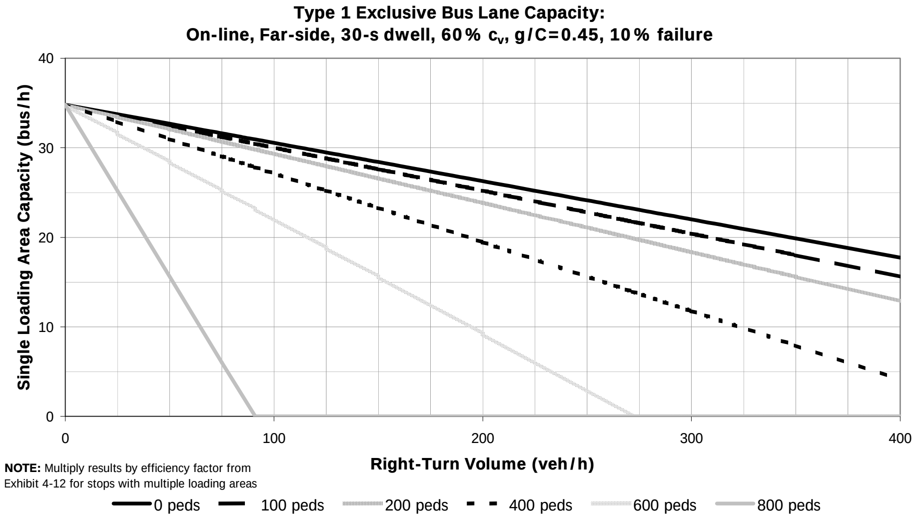
NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas



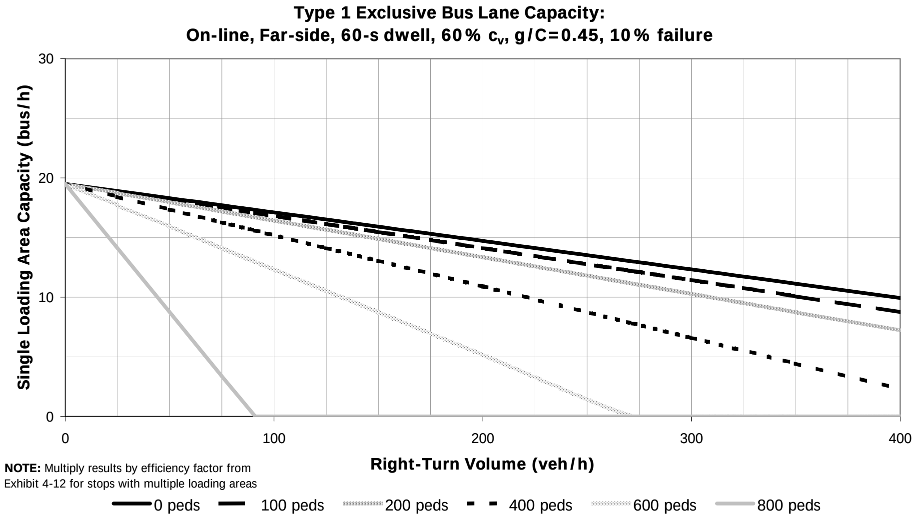
Type 2 Exclusive Bus Lane Capacity:
On-line, Near-side, 60-s dwell, 60% c_v, g/C=0.45, 10% failure

NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Exhibit 4-70
Exclusive Lane Bus Capacity: Far-side Stops, Type 1 Lane

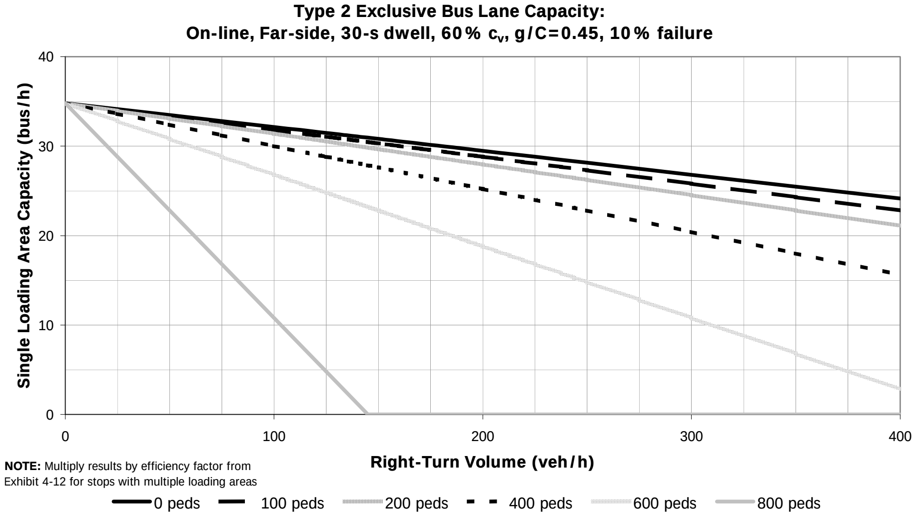


NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas



NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Exhibit 4-71
Exclusive Lane Bus Capacity: Far-side Stops, Type 2 Lane



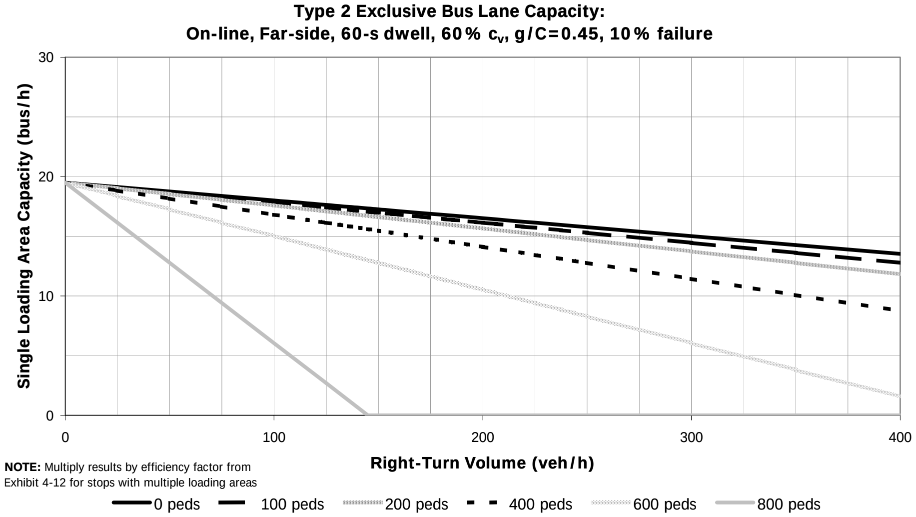
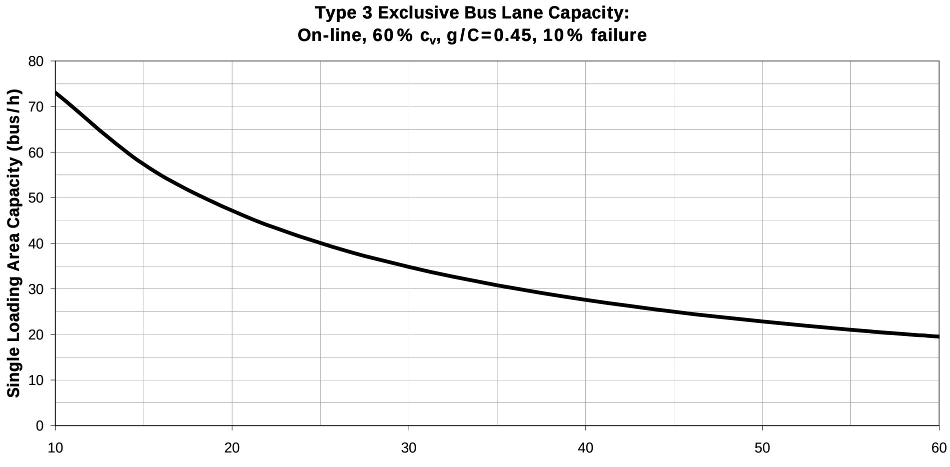
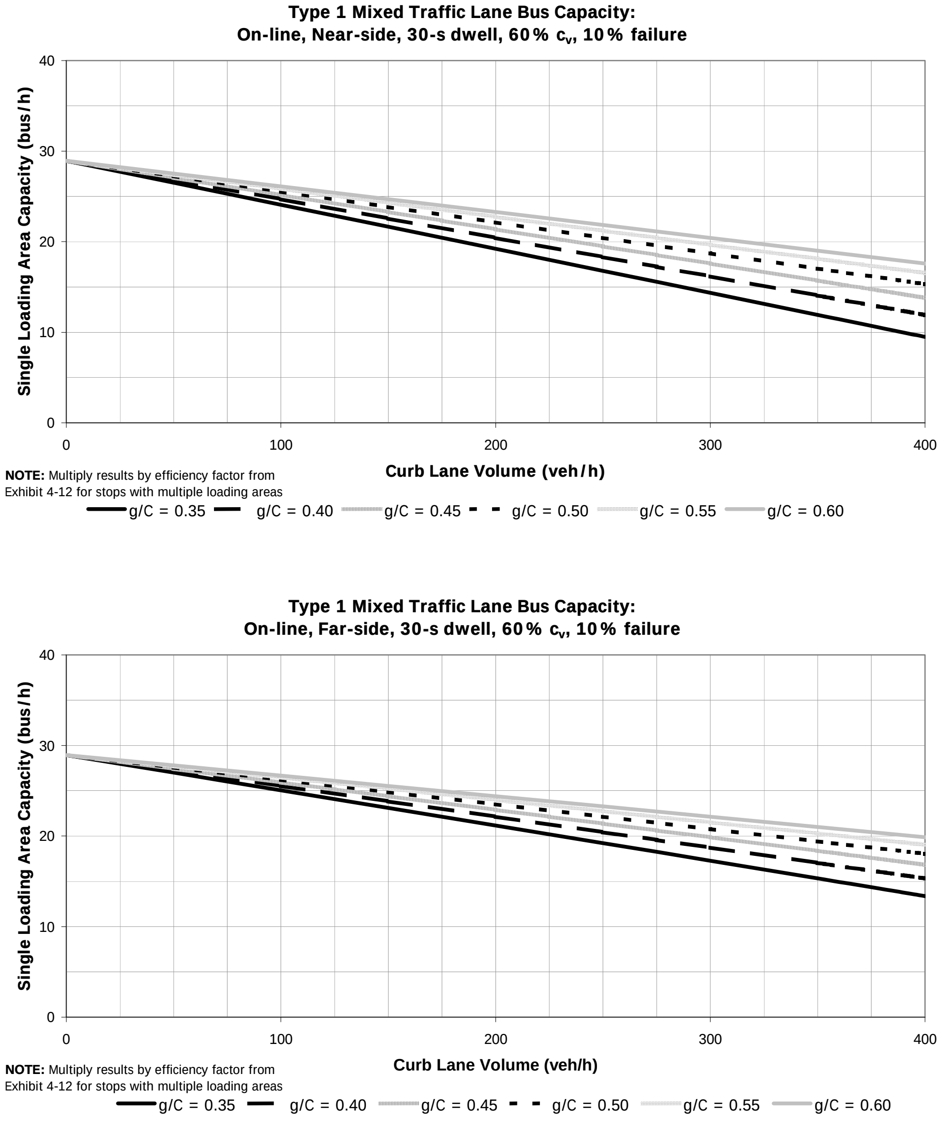


Exhibit 4-72
Exclusive Lane Bus Capacity:
Type 3 Lane



NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Exhibit 4-73
Mixed Traffic Bus Capacity:
Type 1 Lane

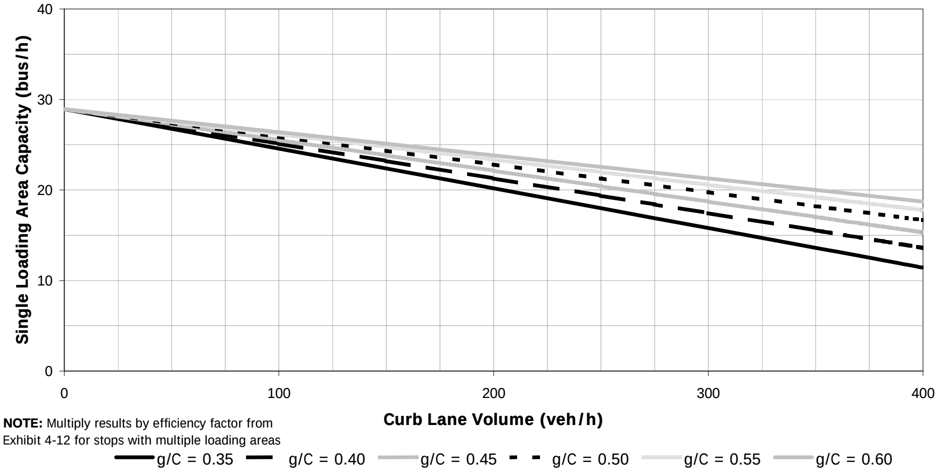


NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

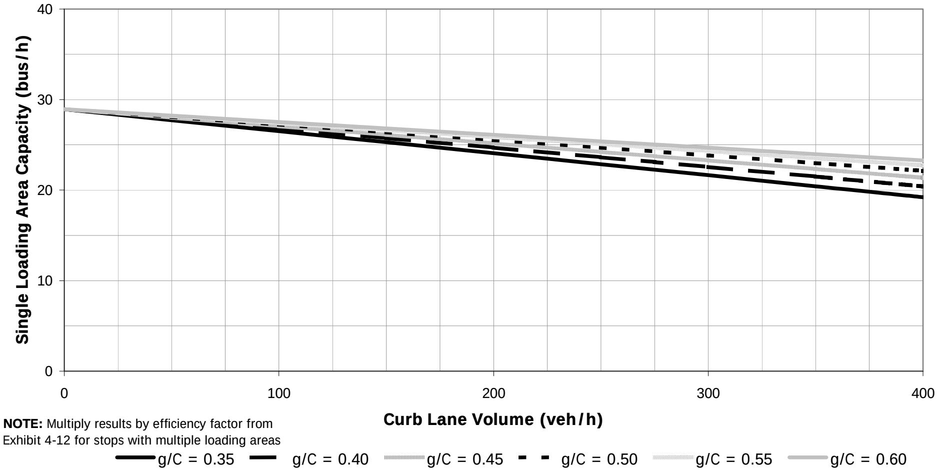
Exhibit 4-74
Mixed Traffic Bus Capacity:
Type 2 Lane

Type 2 Mixed Traffic Lane Bus Capacity:
On-line, Near-side, 30-s dwell, 60% c_v, 10% failure



NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

Type 2 Mixed Traffic Lane Bus Capacity:
On-line, Far-side, 30-s dwell, 60% c_v, 10% failure



NOTE: Multiply results by efficiency factor from Exhibit 4-12 for stops with multiple loading areas

APPENDIX E: EFFECTS OF BUS BUNCHING ON PERSON CAPACITY

Transit services are typically designed with sufficient buses to ensure that an agency's maximum schedule load is not exceeded. Agency policies differ on whether this maximum load applies to every bus or to the average load of all buses on a route during a specified time period (e.g., one-half hour), but in any event, no pass-ups should occur.

If passengers arrived evenly throughout the course of an hour, the number of buses per hour required to serve those passengers would be simply the hourly passenger demand divided by the maximum schedule load per bus. More typically, more passengers will arrive for some buses than for others, due to the normal randomness of passengers' travel from day to day and from predictable surges at certain times (e.g., from a school letting out). If passenger demand requires frequent service and if buses are scheduled as though passengers arrive at an even rate, the result will be that some buses will experience overcrowding. The number of buses per hour required to accommodate typical peak-15-minute loads can be determined by rearranging Equation 4-8 as follows:

Predictable surges in demand may be accommodated by adjusting headways or adding an extra bus. Tweaking the schedule is less effective for handling random surges.

$$f_{\min} = \frac{P_h}{P_{\max}(PHF)}$$

Equation 4-21

where:

f_{min} = minimum frequency to accommodate peak-15-minute passenger demands without overcrowding (bus/h);

P_h = hourly passenger volume (p/h);

P_{max} = maximum schedule load per bus (p/bus); and

PHF = peak hour factor.

For example, if 600 passengers must be served during the peak hour and if the maximum schedule load is 60 passengers per bus, 10 buses per hour would be needed if passengers arrived at an even rate (i.e., a peak hour factor of 1.00). If the peak-15-minute passenger demand were 20% higher than the average demand over the peak hour (i.e., a peak hour factor of 0.83), the number of buses required to avoid overcrowding would be 12.

The peak hour factor concept could be extended to address crowding issues on routes experiencing a moderate amount of bunching. If, as a simplified example, buses are scheduled to arrive every 10 minutes, passengers arrive at an even rate, and one bus operates 5 minutes late, that bus will pick up all of its normal passengers at a stop, plus half of the passengers that would normally take the following bus. The late bus will experience overcrowding, carrying more passengers than the schedule assumes, while the following bus will pick up half of its normal load, and some of its offered capacity will go unused.

In practice, the extra passengers would cause dwell times to be longer than normal, the first bus will fall further and further behind schedule, and the following bus will tend to run early.

As an extreme example, imagine that buses are scheduled to arrive every 5 minutes but that actually two arrive in close succession every 10 minutes. The effective frequency of the route in this case is 10 minutes, as that is the average interval between bus arrivals. The effective frequency can be determined from the following:

Equation 4-22

$$f_{eff} = \frac{f}{(1 + c_{vh})}$$

where:

f_{eff} = effective frequency (bus/h);
f = scheduled frequency (bus/h); and
c_{vh} = coefficient of variation of headways, from Equation 3-7.

The coefficient of variation of headways should be calculated using the population standard deviation; this produces a c_{vh} of 1.0 when two buses always arrive together and a c_{vh} of 0.5 when buses are consistently one-half headway off-headway, as in the previous examples.

The average loading of late buses during the peak 15 minutes can be calculated as shown in Equation 4-23. Dividing the average hourly passenger demand by the peak hour factor gives the average peak 15-minute load; dividing the result by the effective frequency gives the average load per late bus during the peak 15 minutes.

Equation 4-23

$$P_l = \frac{P_h}{(PHF)\, f_{eff}}$$

where:

P_l = average load per late bus during the peak 15 minutes (p/bus).

Research is required to develop procedures to estimate the effects of various factors (e.g., traffic, transit priority, bus operator experience) on headway adherence. Adding additional buses to address overcrowding may not have an effect on the most crowded buses, if the added buses end up bunched as well. Since the added buses entail added operating costs for an agency, measures to improve reliability could prove to be more cost-effective for relieving overcrowding.

PART 5
RAIL TRANSIT CAPACITY

CONTENTS

LIST OF EXHIBITS

CHAPTER 1. RAIL CAPACITY FUNDAMENTALS

OVERVIEW

Rail transit systems encompass a variety of technologies, vehicle sizes, and applications. Despite these variations, a few basic factors—in particular, dwell time and the train signal control system—typically control the number of trains that can be operated along a section of a line during an hour. The number of cars per train and the diversity of passenger demand control how many people those trains can carry.

Organization of Part 5.

Part 5 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents methods for calculating the capacity of a variety of rail modes and right-of-way types. The majority of the material in this part has been condensed from *TCRP Report 13*, "Rail Transit Capacity."(R15) The accompanying CD-ROM includes spreadsheets originally developed by TCRP Project A-8 for calculating grade-separated and single-track rail capacity using the procedures described in Part 5.

- *Chapter 1* introduces the fundamental concepts and factors associated with rail capacity.
- *Chapter 2* describes the basic operation of train control and signaling systems and their relationship to the minimum train headway.
- *Chapter 3* examines the factors that influence station dwell time and presents methods for estimating dwell time.
- *Chapter 4* discusses passenger space requirements and methods for estimating passenger design loads based on the length of a rail car.
- *Chapter 5* presents operating and system design issues that influence capacity.
- *Chapter 6* provides planning-level capacities for rail modes, based on typical U.S. and Canadian operations.
- *Chapter 7* develops a procedure for calculating the capacity of grade-separated rail systems; this procedure forms the basis for many of the procedures presented in subsequent chapters.
- *Chapter 8* gives procedures for calculating the capacity of sections of light rail lines that are not grade-separated.
- *Chapter 9* identifies the factors that influence the capacity of commuter rail lines that either use diesel locomotives or are not grade-separated.
- *Chapter 10* adapts the basic grade-separated capacity procedure for use with automated guideway transit systems.
- *Chapter 11* covers the capacity of surface and aerial ropeway modes.
- *Chapter 12* is a list of references used in Part 5.
- *Chapter 13* provides example problems demonstrating the procedures covered in Part 5.
- *Appendix A* provides substitute exhibits in metric units for Part 5 exhibits that use U.S. customary units only.
- *Appendix B* lists characteristics of U.S. and Canadian rail transit routes.

Exhibits that also appear in Appendix A are indicated by a margin note like this.

LINE CAPACITY

Line capacity and vehicle capacity, both relating to the number of trains that can be operated per hour, are equivalent terms for rail.

Ideally, station dwell time and the minimum train separation produced by the signaling system will control line capacity, but other factors may need to be considered.

Line capacity is the maximum number of trains that can be operated over a section of track in a given period of time, typically 1 hour. Ideally, the combination of the train signaling system being used and the station with the longest dwell time will control the line capacity. However, under less-than-ideal conditions, any of a number of other factors may control line capacity. These include

- Signaling systems designed for the minimum planned train headway, rather than maximum capacity,
- Speed restrictions due to sharp curves or steep downgrades on the approach to the station with the longest dwell time,
- Line crossings and merges, particularly at-grade track junctions,
- Time required to turn back a train at a terminal station, and
- Mode-specific issues, such as light rail trains operating in mixed traffic or commuter rail trains sharing tracks with freight trains.

Power supply limitations can also constrain line capacity.

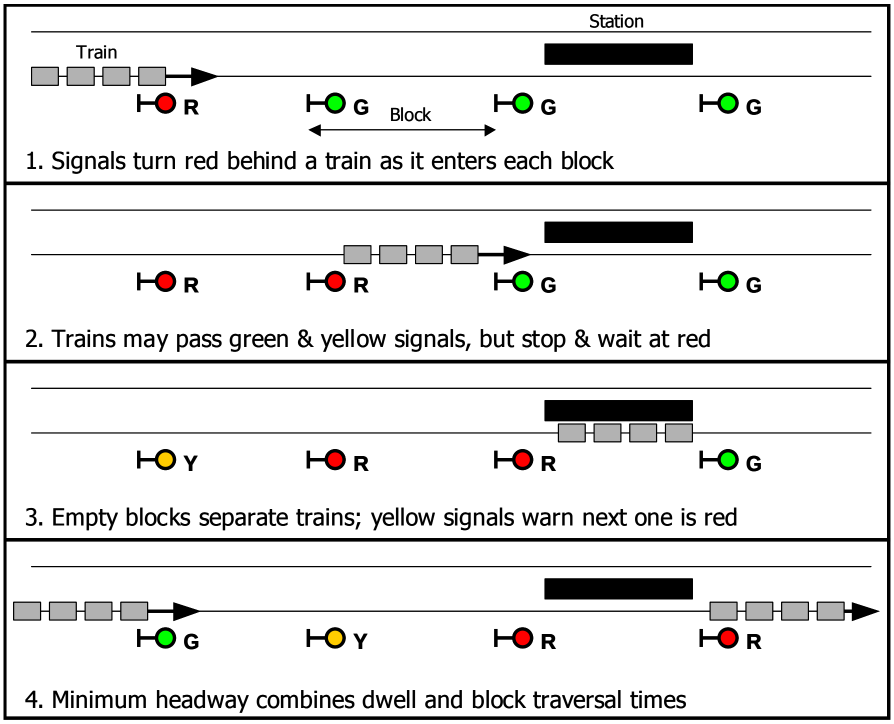
The factor providing the lowest capacity—the weakest link—will constrain the capacity of a given section of a line.

Train Control and Signaling

Streetcars and portions of some light rail systems that operate at low speeds do not use train signals. Multiple trains may be allowed to berth at stations where space permits.

Most major rail modes rely on signaling systems to, among other things, maintain safe separation between trains. The minimum distance between trains must be long enough for a train to come to a complete stop, with a suitable safety margin between it and the train ahead. All urban rail transit train control systems are based on dividing the track into sections known as *blocks* and ensuring that trains are separated by a suitable and safe number of blocks. The longer the time required for a train to traverse (pass through) a block—whether due to long block lengths, low train speeds, or station dwell time—the longer the minimum headway between trains, and the lower the line capacity. Train control is discussed in detail in Chapter 2. Exhibit 5-1 illustrates the operation of a typical three-aspect (red/yellow/green) signal system.

Exhibit 5-1
Basic Train Signal Operation



Dwell Time

Dwell time is frequently the dominant factor in determining the minimum train headway and, thus, the line capacity. The three main components of dwell time are

- Door open and close time, and time waiting to depart once the doors close,
- Passenger flow time, and
- Time the doors remain open after passenger flow ceases.

Dwell time at the station with the highest passenger volumes often will control line capacity.

Of these three factors, passenger flow time is the largest and the hardest to control. It is dependent on passenger volumes at stations, the number of doors on a train, the door widths, the level of crowding inside the train and on the platform, and congestion between boarding and alighting passengers at the train door. The other two factors are, to a great degree, under an agency's control. Minimizing the time spent in a station without passenger flows occurring is important in maintaining reliable train operations, particularly when a line is operating near capacity. The calculation of dwell times is described in Chapter 3.

Operating Margin

When a rail system is operating close to its capacity, small irregularities in service can lead to delays, as a train is not able to approach a station until the train ahead departs. These irregularities can be caused by variations in station dwell times, variations in train performance, and—on manually driven systems—variations between operators. To compensate for these variations, when creating a minimum headway, most rail systems add an operating margin to the combination of the signal system's minimum train separation time and the critical station dwell time. The operating margin is, in effect, the amount of time a train can run behind schedule without interfering with the following trains and, consequently, is an important component of line capacity. Operating margins are discussed in Chapter 5.

An operating margin is "slack time" built into the minimum headway to accommodate small irregularities in service. If a train is late by more than the operating margin, following trains will be delayed.

Turnbacks

A typical terminal station will have a center (island) platform, allowing passengers to board trains on either side. A number of designs are possible, but a common, lower-cost (but also potentially capacity-constraining) design is to locate a crossover in advance of the station. This crossover allows entering trains to be sent to either platform, and exiting trains to be sent to the correct departure track. When a line operates at short headways, the amount of time required to load and unload passengers, and for the operator to change ends, inspect the train, and check train integrity and braking will be longer than the headway between trains. As a result, a second train will arrive and occupy the other platform while the first train is still preparing to depart. A capacity constraint will result if the first train is unable to clear the crossover before a third train arrives to use the platform that the first train is vacating. Exhibit 5-2 shows this process.

Alternative terminal station designs are discussed in Chapter 2.

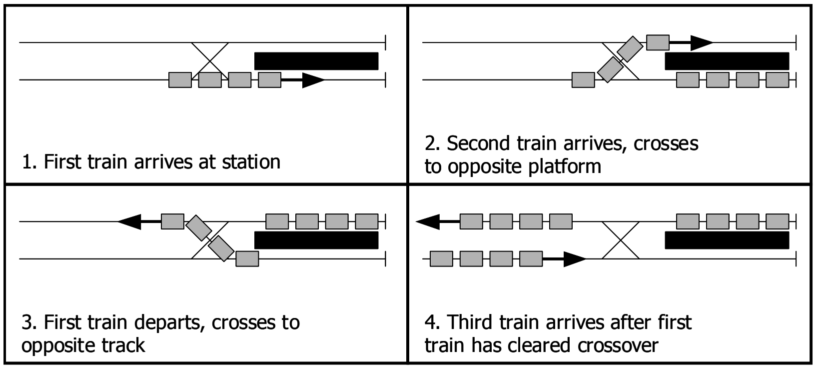


Exhibit 5-2
Turnback Operation with Crossover Located in Advance of Station

As described in Chapter 2, when turnbacks are correctly designed and operated, they should not control capacity on a new rail system. However, turnbacks can be a constraint on older systems, where physical constraints—particularly in subways—may have resulted in less-than-optimal designs, or when passenger demand has generated the need for more service than the system was originally designed for.

Junctions

Locations where lines merge, diverge, or cross at-grade can constrain capacity, or introduce the likelihood of interference, when scheduled headways approach 2 to 2.5 minutes. Two trains may need to use the space where the tracks cross, but only one train can occupy that space at a time. The minimum interval between trains on a given line at an at-grade ("flat") junction is a combination of

1. The time required for an opposing train to move through the junction,
2. The time required to move ("throw") and lock the switches,
3. The delay incurred in decelerating from and accelerating to line speed, and
4. The minimum headway imposed by the signaling system on the line.

Conceptually, the process is similar to that used for calculating headway based on dwell time at a station, in that both headways are based on the minimum train separation on the lines plus the time a train is stopped. In this case, time stopped is spent waiting for another train at a junction rather than waiting to serve passengers.

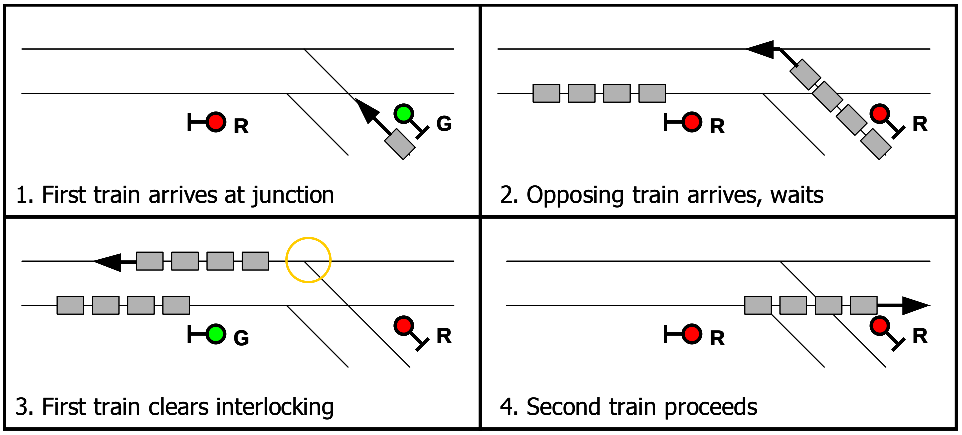
It is not desirable for one train to have to wait for another. When more capacity is required, grade-separated ("flying") junctions are typically used. Exhibit 5-3 depicts the two types of junctions. Exhibit 5-4 illustrates the operation of a flat junction. Chapter 2 discusses junctions in more detail.

Exhibit 5-3
Types of Rail Junctions

(a) Flat (Pittsburgh)

(b) Flying (Paris)

Exhibit 5-4
At-grade ("Flat") Junction Operation



Mode-Specific Issues

The capacity factors discussed thus far are applicable to most major rail modes, particularly heavy rail (rail rapid transit), and one of these factors will generally control line capacity. Sometimes, though, issues unique to a particular mode may need to be considered as well. Chapters 8 through 11 discuss the following issues:

- *Light Rail*—single-track operations, on-street operations (either in mixed traffic or in an exclusive right-of-way).
- *Commuter Rail*—mixed freight and passenger operations, limits on the number of trains imposed by the owner of the tracks being used, differences in locomotive power, single-track operations.
- *Automated Guideway Transit*—widely varying technology, potential for off-line stations that allow trains to bypass stations and other trains.
- *Ropeway*—line length, line speed, vehicle or carrier spacing.

PERSON CAPACITY

Person capacity defined.

Person capacity is the maximum number of people that can be carried in one direction over a section of track in a given period of time, typically 1 hour, under specified operating conditions without unreasonable delay, hazard, or restriction, and with reasonable certainty.

The definition of person capacity is less absolute than the definition of line capacity, as it depends on the number of trains operated, the length of those trains, passenger loading standards, and variations in passenger demand between trains and between individual cars of a given train.

The *theoretical capacity* is the number of cars per hour per direction, times the maximum design load of each car.

Person capacity accounts for variations in passenger arrivals and distribution, and is lower than the theoretical capacity.

This last factor, known as *loading diversity*, provides an important distinction between a line's theoretical capacity and a more realistic person capacity that can actually be achieved on a sustained basis. The theoretical capacity assumes that all the offered capacity can be used by passengers. In practice, this only occurs when a constant queue of passengers exists to fill all available seats and standing room—a situation that is undesirable in a transit operation, as it leads to crowded platforms and passenger delay. Transit passengers generally do not arrive at an even rate over the course of an hour, and generally do not distribute themselves evenly among the cars of a train. Accounting for loading diversity allows one to determine the number of people that can be accommodated during an hour without pass-ups occurring.

How many people *can* be carried vs. how many people *could* be carried.

Constraints on staff and equipment resources must also be considered. Line capacity considers how many trains *could* be operated, assuming no constraints on the supply of cars to form trains, nor any constraints on the number of operators available to drive those trains. Knowing, and designing for, the ultimate person capacity of a line is often important in long-term planning. However, it may be just as important to know in the short term how many trains *can* be operated and the person capacity of those trains, given existing resources.

Loading Diversity

Passengers do not load evenly into cars and trains over the peak hour. Three different types of loading diversity have to be considered: (1) loading diversity within a car, (2) loading diversity among cars of a train, and (3) unevenness of passenger demand during the peak hour.

Loading diversity within a car.

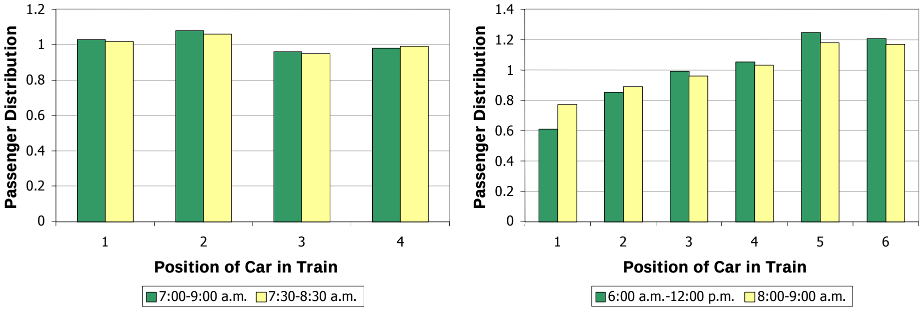
The first type of loading diversity is within a car. In individual cars, the highest standing densities occur around doorways while the lowest densities occur at the ends of the cars. Several European urban rail systems add doors, sometimes only single-stream, at the car ends to reduce this unevenness.

Loading diversity within a train.

A second type of diversity occurs in uneven loading among cars of a train. Cars that are closer to station exits and entrances will be more heavily loaded than more remote cars. This inefficiency can be minimized by staggering platform entrances and exits between ends, centers, and third points of the platforms. This is not always possible or practiced. Even so, relatively even loading often occurs due to the duress factor that encourages passengers to spread themselves along the platform during heavily traveled times—or risk being unable to get on the next arriving train.

Few systems count passengers by individual cars when the cars are *crush* loaded. This is difficult to do with any accuracy and the results differ little from assigning a set *full* load to each car of a fully loaded train. BC Transit has measured car loadings at a station where passengers are regularly passed up, as shown in Exhibit 5-5.

Exhibit 5-5
Average Peak Hour Passenger Distribution Between Cars of Trains[R15]



(a) Vancouver, SkyTrain (Broadway Station) (b) Toronto, Yonge Subway (Wellesley Station)

NOTE: 1.0 represents an individual car load equal to the average load of all cars in the train.
Vancouver data collected inbound direction Oct. 27, 1994, 50 trains, 6,932 passengers.
Toronto data collected southbound direction Jan. 11, 1995, 99 trains, 66,263 passengers.

In Vancouver, there is no significant variation in the average loading diversity between cars of a train in either the peak hour or the peak 2-hour period, both of which are within the range of +5% of an average (mean) load to -6%. However, the imbalance between cars on individual trains ranges from +61% to -33%. The average evenness of loading can be attributed to four factors: short trains, wide platforms, close headways, and dispersed entrance/exit locations among the system's stations.

Toronto's Yonge Street subway shows a more uneven average loading between cars. During the morning peak period, the rear of the train is consistently more heavily loaded. This pattern reflects the dominance of the major transfer station at Bloor Street, with the interchange occurring at the rear (northern) end of the Yonge subway platform. As would be expected, there is less variation in the average car loading diversity between the peak hour and the peak morning period due to the pressures on passengers to spread along the platforms at busy times. The average diversity of individual car loading over the peak period has a range of +26% to -39%. The imbalance for cars on individual trains ranges from +156% to -89%.

Loading diversity within the peak hour.

The third and most important type of diversity is the unevenness of passenger demand over the peak hour. This aspect of diversity is measured by the *peak hour factor,* which is defined as:

Equation 5-1

$$PHF = \frac{P_h}{4P_{15}}$$

The PHF ranges from 0.25 (all volume occurs during the peak 15 minutes) to 1.00 (volumes are even throughout the hour).

When 30-minute peak periods are used, P should represent 30-minute volumes, and $2P_{30}$ should be substituted for $4P_{15}$.

where:
PHF = peak hour factor;
P_h = passenger volume during the peak hour (p); and
P_{15} = passenger volume during the peak 15 minutes (p).

Passengers do not arrive evenly and uniformly on any rail transit system, as shown dramatically over the extended peak period in Exhibit 5-6 for Toronto's Yonge Street subway. This exhibit shows the realities of day-to-day rail transit operation. The morning peak 15 minutes has a pronounced abnormality at 8:35 a.m. following a short gap in service. The different loading, train by train, is significant, and it is difficult to visually pick out the peak hour or the peak 15 minutes.

Exhibit 5-7 shows an a.m. peak period for Vancouver's SkyTrain that, although without major delays, shows the irregular loading from train to train due to the interlace of short-turn trains with regular service from 7:30 a.m. onward.

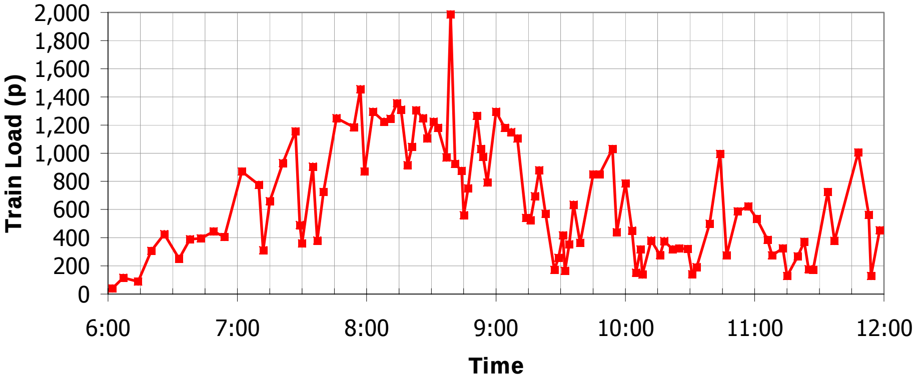


Exhibit 5-6
Individual A.M. Train Loads, Toronto Yonge Subway, Wellesley Southbound (Jan. 11, 1995)(R15)

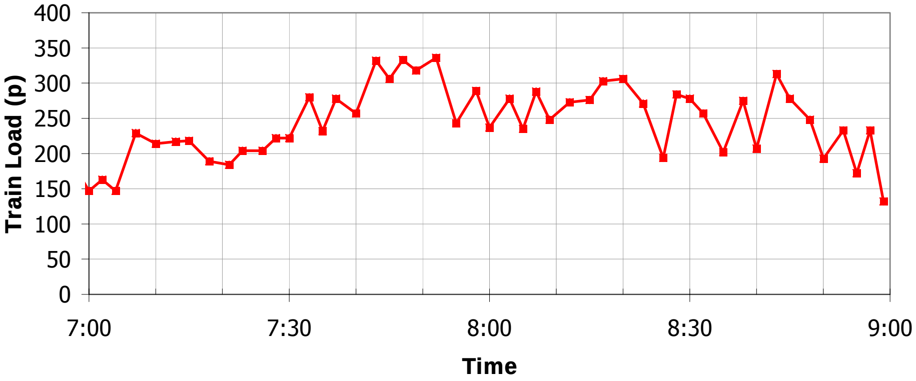


Exhibit 5-7
Individual A.M. Train Loads, Vancouver, SkyTrain Broadway Station Inbound
(October 27, 1994)(R15)

Peak hour factors observed at many U.S. and Canadian rail systems are tabulated in Exhibit 5-8. Recommended values for the peak hour factor for specific modes are presented in the mode-specific chapters later in Part 5.

Number of Cars

The number of cars in a train is a major determinant of person capacity—the longer the train, the more people it can carry. However, there are limits to how many cars can be added to a train, set by the lengths of platforms, the supply of cars, and (for light rail) city block lengths.

Platform Lengths

Station platforms are designed for the longest train the system plans to operate. When platforms are located above or below grade, they are difficult to lengthen once constructed. In some instances, for example at New York's South Ferry subway station and at some older commuter rail stations, the platform is shorter than the train length, and passengers wishing to exit trains must do so from the front cars only. However, this kind of operation is not generally desirable and is not typical practice for new systems.

Exhibit 5-8
Observed Peak Hour Factors (1994-95)(R15)

System (City)	# of Routes	Peak Hour Factor
Commuter Rail		
AMT (Montréal)	2	0.71
CalTrain (San Francisco)*	1	0.64
GO Transit (Toronto)*	7	0.49
Long Island Rail Road (New York)	13	0.56
MARC (Baltimore)*	3	0.60
MBTA (Boston)*	9	0.53
Metra (Chicago)	11	0.63
Metro-North (New York)	4	0.75
NICTD (Chicago)	1	0.46
New Jersey Transit*	9	0.57
SCRRA (Los Angeles)*	5	0.44
SEPTA (Philadelphia)	7	0.57
VRE (Washington, D.C.)*	2	0.35
Light Rail		
CTS (Calgary)	2	0.62
RTD (Denver)	1	0.75
SEPTA (Philadelphia)	8	0.75
TriMet (Portland)	1	0.80
Rapid Transit		
SkyTrain (Vancouver)	1	0.84
CTA (Chicago)	7	0.81
MARTA (Atlanta)	2	0.76
Metrorail (Miami)	1	0.63
NYCT (New York)	23	0.81
PATH (New Jersey)	4	0.79
STM (Montréal)	4	0.71
TTC (Toronto)	3	0.79

*Mainly diesel-hauled—not electric multiple unit.

Car Supply

Even when the platform design allows for longer trains, a shortage of cars may preclude operating longer trains. For example, the Washington, D.C., Metro platforms can accommodate up to eight-car trains, but the supply of cars has limited typical train lengths to four to six cars. This kind of constraint is typically financial—new rail cars averaged $1.2 to 2.5 million each in 2000-2001, depending on the type of car,(R4) and additional staff are required to maintain the additional cars.

Street Block Lengths

Street block lengths can be a major limitation for at-grade systems which operate on-street. Most jurisdictions are unwilling to allow stopped trains to block intersections and so require that trains not be longer than the shortest street block where a stop is likely. This issue is especially noteworthy in Portland, Oregon, where unusually short street blocks of 200 ft (65 m) in the downtown area limit trains to two cars. The San Diego Trolley also faced this issue when it operated four-car trains on the East (Orange) Line for a time. Since three cars is the maximum that can be accommodated by the downtown city blocks, trains were split into two sections before entering downtown.

Sacramento is an exception to the street block length rule and can operate four-car trains in the peak hours. These long trains block one intersection when stopped. This situation was almost a necessity as the original extensive single-track nature of the Sacramento line (now being addressed by double-tracking) imposed a minimum headway of 15 minutes on the service. The capacity limitation of this headway restriction was therefore partially made up by the operation of relatively long trains.

Exclusive lanes can mitigate street block length constraints.

Street block length is also an issue when another vehicle occupies the lane used by light rail trains. If a vehicle in the lane would cause the rear of the train to protrude into an intersection, then the train would need to wait for the lane to clear before advancing. This issue provides a strong argument for providing an exclusive light rail transit lane where street running with long trains occurs. Indeed, as a result of this concern, operation with mixed traffic is very rare on new light rail transit systems. (An exception to this rule, the Portland Streetcar, operates one-car trains.) Where buses and light rail transit trains operate alongside each other on transit malls in Baltimore and Calgary, the rail stations, bus stops, and lanes are laid out to cause minimum interference between the modes.

Number of Trains

The maximum number of trains that can be operated during an hour is generally set by the line capacity. However, power supply limitations can also constrain the number of trains that can use a given section of a line. For example, the downtown section of the Portland, Oregon, light rail line has a line capacity of 30 trains per hour (2-minute headways), based on the downtown traffic signal cycle, but the existing power system was designed for 3-minute headways. Outer portions of Pittsburgh's light rail lines have power system upgrades planned in order to accommodate 28 additional cars by 2004.(R0)

Electrically powered trains require a considerable amount of energy, particularly when accelerating: the San Diego Trolley's vehicles, for example, use 500 to 550 kW when accelerating from a stop, and 150 to 165 kW while in motion.(R20)

Calculation Procedure

The person capacity of a rail route at its maximum load section *under prevailing conditions* is determined by multiplying the number of cars operated during the peak hour by the agency's scheduled design load for each car and by a peak hour factor:

Equation 5-2

$$P = P_c C_h (PHF)$$

where:

P = person capacity (p/h);
P_c = maximum design load per car (p/car);
C_h = cars operated per hour (car/h); and
PHF = peak hour factor.

Maximum design load can be determined using the procedures in Chapter 4.

The person capacity of a rail route at its maximum load section *when operated at line capacity* is determined by multiplying the number of trains per hour by the number of cars per train, the agency's scheduled design load for each car, and a peak hour factor, as shown in Equation 5-3. Line capacity, assuming no power supply constraints, can be determined from the procedures given later in Part 5.

Equation 5-3

$$P = TN_c P_c (PHF)$$

where:

P = person capacity (p/h);
T = line capacity (train/h);
N_c = number of cars per train (car/train);
P_c = maximum schedule load per car (p/car); and
PHF = peak hour factor.

P_c is set by agency policy and is less than the car's "crush" or maximum load.

This page is intentionally blank.

CHAPTER 2. TRAIN CONTROL AND SIGNALING

INTRODUCTION

Functions of signaling.

The role of signaling is to safely separate trains from each other and protect specific paths through interlockings (switches) at junctions and crossovers. Additional functions include automatic train stops, should a train run through a stop signal, and speed control to protect approaches to junctions, sharp curves, and approaches to terminal stations where tracks end at a solid wall.

Signaling technology is very conservative.

Signaling cannot protect from every eventuality.

Rail transit signaling maintains high levels of safety based on brick-wall stops and fail-safe principles ensuring that no single failure—and often multiple failures—should allow an unsafe event. The rigor with which fail-safe principles have been applied to rail transit has resulted in an exceptional safety record. However, the safety principles do not protect against all possibilities, including possible human error. An increasing inability to control the human element—responsible for three-quarters of rail transit accidents or incidents—has resulted in new train control systems using automation to reduce or remove the possibility of human error.

Automatic train control.

Automatic train control adds further features to the train protection of basic signaling, including automatic driving and train supervision that regulates service.

This chapter describes and compares the separation capabilities of the following types of rail transit train control systems: fixed-block, cab, and moving-block. The chapter is applicable to the main rail transit grouping of electrically propelled, multiple-unit, grade-separated systems.

FIXED-BLOCK SYSTEMS

Track circuits.

Fixed-block systems provide a coarse indication of train location.

In a fixed-block system, trains are detected by the wheels and axles of a train shorting a low-voltage current inserted into the rails. The rails are electrically divided into blocks. The blocks will be short where trains must be close together (e.g., in a station approach), and can be longer between stations where trains operate at speed.

The signaling system only knows the position of a train by the simple measure of block occupancy. It does not know the position of the train within the block; it may have only a fraction of the train, front or rear, within the block. At block boundaries, the train will occupy two blocks simultaneously for a short time.

A minimum of two empty blocks is required between trains for a two-aspect system.

In the simplest two-aspect (red/green) block system, the signals display only stop (red) or go (green). A minimum of two empty blocks must separate trains and these blocks must be long enough for the braking distance plus a safety distance. The simplest system can accommodate a throughput approaching 24 trains per hour. This does not provide sufficient capacity for some high-volume rail lines. Higher capacity can be obtained from combinations of additional signal aspects (three is typical: red/yellow/green), shorter block lengths, and overlay systems that electronically divide blocks into shorter "phantom" sections—for trains equipped for this overlay.

Conventional train control systems can support a throughput of 30 trains/track/hour.

In this way, conventional train control systems can support a throughput of up to 30 trains per hour with typical train length, performance, station dwells, and operating margins. Overlay systems can increase this throughput by 10 to 15%. A notable exception to this is in Russia where conventional signaling routinely handles 40 metro trains per hour. This is achieved by tightly controlling station dwells to a maximum of 25 seconds and rigorous adherence to schedule using digital clocks in each station to display the seconds from the departure of the previous train. New Moscow metro lines are being designed for 44 and 48 trains per hour—by far the closest train spacing on any rail—irrespective of technology.

Requiring a driver to control a train's speed and commence braking according to multiple-aspect color light signaling requires considerable precision to maximize throughput. Cab signaling provides assistance in this regard and reduces capital and maintenance costs.

CAB SIGNALING

Cab signaling sets authorized, safe train speeds.

Cab signaling uses codes inserted into each track circuit and detected by an antenna on each train. The code specifies the maximum allowable speed for the block occupied and may be termed the *reference* or *authorized* speed. This speed is displayed in the driver's cab—often so that the authorized speed and actual speed can be seen together.

A trip stop is a mechanical device next to the track that activates a train's emergency brakes when a train passes a red signal.

The authorized speed can change while a train is in a block, as the train ahead proceeds, allowing drivers to adjust train speed close to the optimum with less concern about overrunning a trip stop. Problems with signal visibility on curves and in inclement weather are reduced or eliminated. Cab signaling avoids much of the capital and maintenance costs of multiple-aspect color light signals, although it is prudent and usual to leave signals at interlockings and occasionally on the final approach to and exit from each station.

Reducing the number of color light signals makes it economically feasible to increase the number of aspects and it is typical, although not universal, to have the equivalent of five aspects on a cab signaling system. A typical selection of reference speeds would be 50, 40, 30, 20, and 0 mph (80, 70, 50, 35, and 0 km/h).

MOVING-BLOCK SYSTEMS

Moving-block signaling systems are also called *transmission-based* or *communication-based* signaling systems. A moving-block signaling system can be compared to a fixed-block system with very small blocks and a large number of aspects. However, a moving-block signaling system has neither blocks nor aspects. The system is based on continuously or frequently calculating the clear (safe) distance ahead of each train and then relaying the appropriate speed, braking, or acceleration rate to each train.

Moving block signaling is based on the use of target points.

This system requires continuous or frequent two-way communication with each train, and precise knowledge of a train's location, speed, and length, and of fixed details of the line—curves, grades, interlockings, and stations. With this information, a computer can calculate the next stopping point of each train—the *target point*—and command the train to brake, accelerate, or coast accordingly. The target point will be based on the normal braking distance for that train plus a safety distance.

The safety distance is the maximum distance a train can travel after it has failed to act on a brake command before automatic override (or overspeed) systems implement emergency braking.

Without track circuits to determine block occupancy, a moving-block signaling system must have an independent method to accurately locate the position of the front of a train, and then use look-up tables to calculate its end position from the length associated with that particular train's identification. The first moving-block systems used a wire laid alongside or between the running rails, periodically transposed from side to side. The wire transmitted signals to and from antennas on the train, while counting the transpositions determined location.

The use of exposed wayside wires is a maintenance problem and refinements use inert transponders located periodically along the track. These are interrogated by a radio signal from each train and return a discrete location code. Positioning between transponders relies on the use of a tachometer. Communications to and from the train are then radio-based, with protocols to ensure safety and reliability and that messages are received by, and only by, the train they are intended for.

Communication can be made secure.

The computers that control a moving-block signaling system can be located on each train, at a central control office, dispersed along the wayside, or a combination of these. The most common arrangement is a combination of on-board and central control office locations.

Safety Issues

Safety on rail transit is a relative matter. It encompasses all aspects of design, maintenance, and operations. In fixed-block signaling, electrical interlockings, switch, and signal setting are controlled by relay logic. A rigorous discipline has been built around this long-established technology which the use of processor-based controls is now infiltrating.

A moving-block signaling system is inherently processor-controlled. Processor-based train control systems intrinsically cannot meet the fail-safe conventions of traditional signaling. Computers, microprocessors, and solid-state components have multiple failure opportunities and cannot be analyzed and tested in the same way as conventional equipment. Instead, an equivalent level of safety is provided based on statistical failure modes of the equipment. Failure analysis is not an exact science. Although not all failure modes can be determined, the statistical probability of an unsafe event can be predicted.

HYBRID SYSTEMS

Hybrid systems can allow equipment not equipped for moving block operation to operate on lines signaled with moving blocks.

There are times when an urban rail transit system shares tracks with other services, such as long-distance passenger trains, whose equipment is impractical or uneconomic to equip with the moving-block signaling system. Hybrid or overlay systems are available that allow use by unequipped trains—with longer separation—while still obtaining the close headway of the moving-block system for the urban or short-distance trains.

AUTOMATIC TRAIN OPERATION

Automated train operation systems often also provide for manual operation.

Automatic acceleration has long been a feature of rail transit, where relays, and more recently microprocessors, control the rate of acceleration smoothly from the initial start to maximum speed. Linking this feature to on-board commands from the signaling system provides automatic train operation.

The acceptance of driverless trains in transit service has been slow.

The driver or attendant's role is typically limited to closing the doors, pressing a train start button, and observing the line ahead, with limited manual operating capabilities to deal with certain failures. Dispensing entirely with a driver or attendant is controversial but has demonstrated its economy and safety on numerous automated guideway transit (AGT) systems, and on rail systems in Europe and Vancouver, B.C.

Automated train operation may provide a 2 to 4% capacity increase.

Automatic train operation (ATO), with or without attendants or drivers, allows a train to follow the optimum speed envelope more closely and commence braking for the final station approach at the last possible moment. This reduces station-to-station travel times, and, more importantly, from the point of capacity, it minimizes the critical station *close-in time*—the time from when one train starts to leave a station until the following train is berthed in that station. This can increase total line capacity by 2 to 4%.

AUTOMATIC TRAIN SUPERVISION

Automatic train supervision (ATS) is generally not a safety-critical aspect of the train control system. At its simplest, it does little more than display the location of trains on a mimic board or video screen in the central control or dispatcher's office. Increasing levels of functionality are available.

Corrective measures to correct late running trains.

In more advanced systems where there is ATO, computer algorithms are used to attempt to automatically correct lateness. These are rare in North America and are generally associated with the newer moving-block signaling systems.

Predictive control.

A further level of ATS strategies is possible: predictive control, where a computer looks ahead to possible conflicts (for example, a merge of two branches at a junction). The computer can then adjust terminal departures, dwell times, and train performance to ensure that trains merge evenly without holds.

The non-vital ATS system can also be the host for other features such as on-board system diagnostics and the control of station and on-board information through visual and audio messages, including those required by the Americans with Disabilities Act (ADA).

TRAIN THROUGHPUT

One of the difficulties in determining commuter rail capacity when tracks are shared with freight trains is that passenger and freight trains operate at varying intervals and speeds.

Determining the throughput of any rail transit train control system relies on the repetitive nature of rail transit operation. In normal operation, trains follow each other at regular intervals traveling at the same speed over the same section of track. All modern heavy rail rolling stock has comparable performance.

Stations are the principal limitation on the maximum train throughput. In a well-designed and operated modern system, junction or turnback constrictions or bottlenecks should not occur. A flat junction can theoretically handle trains with a consolidated headway approaching 2 minutes. However, delays may occur and systems designed for such close headways will usually incorporate grade-separated (flying) junctions. Moving-block signaling systems provide even greater throughput at flat junctions.

A two-track terminal station with either a forward or rear scissors cross-over can also support headways below 2 minutes. In this chapter, the limitations on headway will be calculated for all three possible bottlenecks: station stops, junctions, and turnbacks.

Station Close-In Time

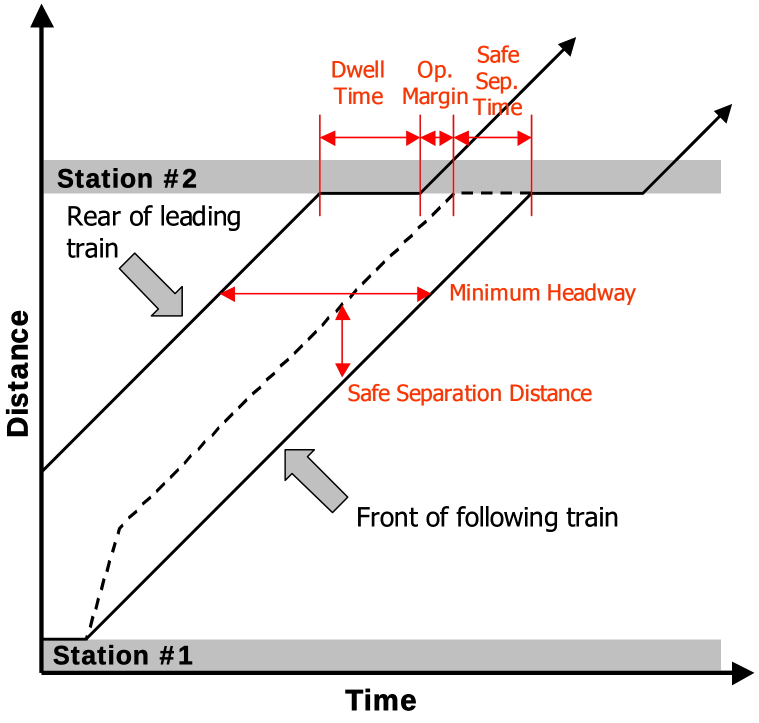
The close-in time is the main constraining factor on rail transit lines.

The time between a train pulling out of a station and the next train entering—referred to as *close-in*—is the main constraining factor on rail transit lines. This time, also known as the *safe separation time*, is primarily a function of the train control system, train length, approach speed, and vehicle performance. The approach speed—and thus capacity—can be reduced by sharp curves or downgrades on station approaches. Close-in time, when added to the dwell time and an operating margin, determines the minimum possible headway achievable without regular schedule adherence impacts—referred to as the *non-interference headway*. Exhibit 5-9 shows a distance-time station stop diagram.

Computer simulations often provide the basis for accurate estimations of capacity.

The best method to determine the close-in time is from the specifications of the system being considered, from existing experience of operating at or close to capacity, or from a computer simulation model. Such models can provide an accurate indication of the critical headway limitation—whether a station close-in maneuver, a junction, or a turnback. If a model or actual operating data are not available, then the minimum headway can be calculated from the procedures in Chapter 7.

Exhibit 5-9
Distance-Time Plot of Two Consecutive Trains(R15)



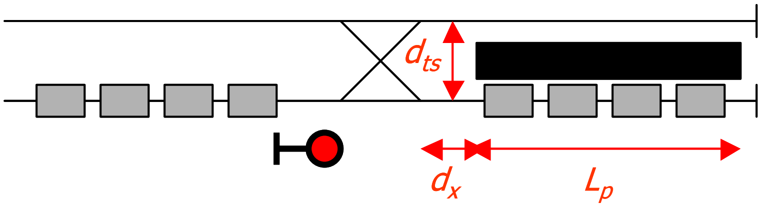
NOTE: Acceleration and braking curves omitted for clarity.

Turnbacks

Turnbacks should not be a constraint on capacity.

Correctly designed and operated turnbacks should not be a constraint on capacity. Key dimensions of a typical terminal station arrangement with the preferred[1] center (island) platform are shown in Exhibit 5-10.

Exhibit 5-10
Key Turnback Dimensions(R15)



The worst case is based on the arriving train (lower left) being held at the crossover approach signal while a train departs. It must, moving from a stop, traverse the crossover and be fully berthed in the station before the next exiting train (lower right) can leave. The exiting train must then clear the crossover and the interlocking switches must be reset before another train can enter the station. The difference between the scheduled headway and the time required to make these maneuvers, doubled for a two-berth station such as the one illustrated, is available for terminal layover. The terminal layover time must be sufficient to accommodate passenger movements, and allow time for the driver to change ends, inspect the train, and check train integrity and braking. The maximum time available per track for terminal layover is given by Equation 5-4.

---

[1] While side platforms reduce the track-to-track centers and so reduce the maneuver time, they require passengers to be directed to the correct platform for the next departing train. This is inherently undesirable and becomes more so when a train cannot depart due to a defect or incident and passengers must be redirected to the other platform.

Equation 5-4

$$t_l \le 2\left(h - t_s - \sqrt{\frac{2(L_p + d_x + f_{sa} d_{ts})}{a+d}} - \sqrt{\frac{(L_p + d_x + f_{sa} d_{ts})}{2a}} \right)$$

where: *[typical heavy rail values shown in brackets]*

t_l = terminal layover time (s);

h = train headway (s); *[120 s]*

t_s = switch throw and lock time (s); *[6 s]*

L_p = platform length (ft, m); *[660 ft, 200 m]*

d_x = distance from cross-over to platform (ft, m); *[65 ft, 20 m]*

d_{ts} = track separation (ft, m),
= platform width + 5.25 ft (1.6 m); *[33 ft, 10 m]*

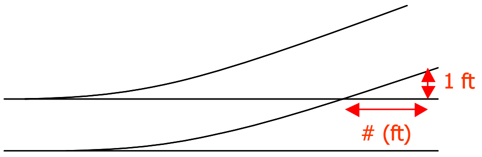
f_{sa} = switch angle factor (see also Exhibit 5-11):
— 5.77 for #6 turnout,
— 6.41 for #8 turnout, and
— 9.62 for #10 turnout;

a = initial service acceleration rate (ft/s², m/s²); and *[4.3 ft/s², 1.3 m/s²]*

d = service deceleration rate (ft/s², m/s²). *[4.3 ft/s², 1.3 m/s²]*

Exhibit 5-11
Turnout Numbers(R23)

Turnout numbers are based on the ratio of the number of feet moved longitudinally per foot moved out at the "frog" (device located where the tracks cross). The higher the number, the smaller the departure angle and the higher the permitted speed.



A typical terminal layover time can be calculated using the typical parameters given in the brackets above, including a headway of 120 seconds. The terminal layover time, t_l, is less than or equal to 175 seconds per track. This would increase by 9 seconds if the incoming train did not stop before traversing the crossover. While this is not a generous amount of time, particularly to contain a schedule recovery allowance, many systems maintain such close headways with minimal delays.

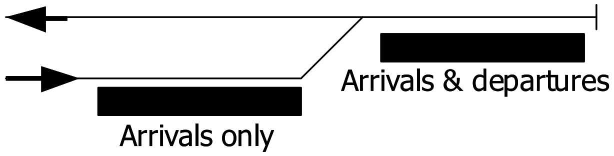
This analysis assumes that any speed restrictions in the terminal approach and exit are below the speed a train would reach in the calculated movements—approximately 21 mph (34 km/h) on a stop-to-stop approach, and 29 mph (47 km/h) as the end of the train leaves the interlocking on exit. Normally there would be no restrictions so low but following London Transport's Moorgate disaster—when a fully loaded train accelerated into the wall at the end of a terminal station—some systems have imposed low entry speeds, occasionally enforced with speed control signaling.

The maximum permitted terminal time can be calculated for the specific system and terminal parameters. There are numerous corrective possibilities where the time is insufficient. These include moving the crossover as close to the platform as possible; however, structures can restrict the crossover location in subways.

Toronto's streetcars face terminal design problems where two or more routes share a common terminal and single-track turning loop. This is the case at the Broadview and Dundas West subway stations where there is heavy transferring activity between the subway and streetcars. The high volumes of transit vehicles and passengers can cause delays to the following streetcars while passengers board and alight from the preceding car. Scheduled recovery time for the streetcar operator is hard to accommodate in these conditions as the volume of the following cars precludes layover time.

The Baltimore light rail line also uses single-track termini but the train frequency (17-minute headways) is not high enough for these to be a capacity limitation. However, some terminals are designed to allow an arriving train to unload passengers before the departing train ahead leaves. This is accomplished through the use of an extra platform as shown in Exhibit 5-12. This arrangement allows the location of a station in a relatively narrow right-of-way since the platforms are not adjacent to each other and a wider center platform is not required.

Exhibit 5-12
Light Rail Single-Track Terminus with Separate Unloading Platform (Baltimore)(R15)



If passenger dwell is a limiting factor, then this issue can be reduced with the use of dual-faced platforms. At terminals with exceptionally heavy passenger loading, multiple-track layouts may be needed. Another alternative, used at SEPTA's 69th Street, New York's South Ferry, and Chicago's Howard and Forest Park termini, are loops—however, these are rare luxuries for heavy rail transit. However, some older streetcar-based light rail lines still incorporate terminal loops.

Dual-faced platforms and loops can reduce dwell times.

Crew turnaround time can be expedited with *set-back crewing*, where a crew from a previous train is pre-positioned at the far end of the train. At a leisurely walking pace of 3 ft/s (1 m/s), it would take 200 seconds for an operator to walk the length of a 650-ft (200-m) heavy rail train, more if the operator were expected to check the interior of each car for left objects or passengers. Obviously, this could not be accommodated reliably in a 175-second terminal layover time.

Terminal arrangements should accommodate some common delays. An example would be the typical problems of a train held in a terminal for a door sticking problem, waiting for police to remove an intoxicated passenger, or for a cleaning crew to perform minor cleaning. Alternatively, one track may be pre-empted to store a bad order train. On these occasions, the terminal is temporarily restricted to a single track and the maximum terminal layover time is reduced to 61 seconds with the above parameters (70 seconds without an approach stop). This may be sufficient for the passenger dwell but cannot accommodate changing ends on a long train and totally eliminates any schedule recovery allowance.

Allowances should be made to prevent common delays from disrupting terminal operations.

More expensive ways to improve turnbacks include extending tracks beyond the station and providing crossovers at both ends of the station. This permits a storage track or tracks for spare and disabled trains—a useful, if not essential, failure management facility. With crossovers at both ends of the station, on-time trains can turn beyond the station with late trains turning in front of the station—providing a valuable recovery time of some 90 seconds at the price of additional equipment to serve a given passenger demand.

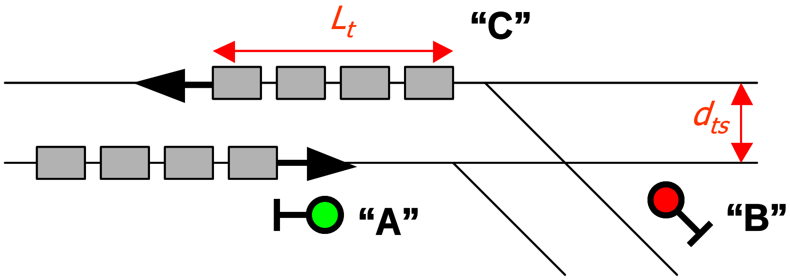
Junctions

Correctly designed junctions should not be a constraint on capacity. Where a system is expected to operate at close headways, high-use junctions will invariably be grade-separated. At such *flying junctions*, the merging and diverging movements can all be made without conflict and the only impact on capacity is the addition of the switch throw and lock times, typically 3 to 6 seconds. Speed limits, imposed in accordance with the radius of curvature and any superelevation, may reduce the schedule speed but should not raise the minimum headway—unless there is a tight curve close to a headway limiting station.

Junctions should not constrain capacity.

The capacity of a flat junction can be calculated in a similar manner to the terminal station approach. The junction dimensions are shown in Exhibit 5-13.

Exhibit 5-13
Flat Junction Dimensions(R15)



The worst case is based on a train (lower left) held at signal "A" while a train of length L_t moves from signal "B" to clear the interlocking at "C." The minimum operable headway is the line headway of train "A" (imposed by the line's signaling system), plus the time required for the conflicting train to clear the interlocking, plus the extra time for train "A" to brake to a stop and accelerate back to line speed. Ignoring specific block locations and transition spirals, this can be expressed approximately as:

Equation 5-5

$$h_j = h_l + \sqrt{\frac{2(L_t + 2 f_{sa} d_{ts})}{a}} + \frac{v_l}{a+d} + t_s + t_{om}$$

where: *[typical heavy rail values shown in brackets]*

h_j = limiting headway at junction (s);

h_l = line headway (s); *[32 s]*

L_t = train length (ft, m); *[650 ft, 200 m]*

d_{ts} = track separation (ft, m); *[33 ft, 10 m]*

f_{sa} = switch angle factor (see also Exhibit 5-11):

- 5.77 for #6 turnout,
- 6.41 for #8 turnout, and
- 9.62 for #10 turnout;

Higher-speed turnouts have smaller angles between the diverging tracks. They require a longer distance for the tracks to separate from each other, but trains can move onto the branch at a higher speed.

a = initial service acceleration rate (ft/s^2 ,m/s^2); *[4.3 ft/s^2 ,1.3 m/s^2]*

d = service deceleration rate (ft/s^2 ,m/s^2); *[4.3 ft/s^2 ,1.3 m/s^2]*

v_l = line speed (mph, km/h); *[60 mph = 91 ft/s, 100 km/h = 27.8 m/s]*

t_s = switch throw and lock time (s); and *[6 s]*

t_{om} = operating margin time (s).

Although 120-second headways are possible, junctions generally should be grade-separated for headways below 150-180 seconds.

Substituting the typical values shown above into the equation results in a junction limiting headway of 102 seconds. An operating margin should then be added to this headway. While in theory a flat junction should allow a 120-second headway, it does not leave a significant operating margin and there is a probability of interference headways. General guidance in rail transit design is that junctions should be grade-separated for headways below 150 to 180 seconds.

Advantage of sophisticated supervision to reduce junction conflicts.

An exception is with a moving-block signaling system incorporating an automatic train supervision system with the capability to look forward. This system adjusts train performance and station dwells to avoid conflicts at the junction. That is, trains will not have to stop or slow down at the junction except for the interlocking's track design speed limit. In this case, the junction interference headway drops to 63 seconds, allowing 120-second, or slightly lower, headways to be sustained on a flat junction—a potentially significant cost savings associated with a moving-block signaling system.

CHAPTER 3. STATION DWELL TIMES

INTRODUCTION

Station dwell times are a major component of headway.

Controlling dwells.

Station dwell times are the major component of headways at short frequencies. The controlling station dwell time is the combination of dwell time and a *reasonable* operating margin—the dwell time during a normal peak hour that controls the minimum regular headway. Controlling dwell takes into account routine perturbations in operations—but not major or irregular disruptions. The sum of controlling dwell and the train control system's *minimum train separation time* produces the maximum train throughput without headway interference. In this chapter, the components of dwell time will be examined and procedures provided to determine dwell times.

DWELL TIME COMPONENTS

Peak period dwell times on four selected systems.

Regularity of fully automated systems.

Dwell time consists of the time passenger flow occurs, the time before the doors are closed, and the time waiting to depart with the doors closed. Exhibit 5-14 shows these dwell components for the peak period of four selected rail transit stations. Each of the rail transit systems serving the particular stations has a different operating philosophy. BART in the San Francisco Bay Area is automatically driven with door closure and departure performed manually, the latter subject to override by the automatic train control. MTA-NYCT in New York and the TTC in Toronto are entirely manual, subject only to a permissive departure signal. The TTC has a safety delay between door closure and train departure. SkyTrain, in Vancouver, B.C., is an entirely automatic system with unattended cars; door closing and departure times are pre-programmed. This is evident from Exhibit 5-14(c), which shows two services, including a short-turn service with shorter dwells that ends about halfway down the graph. All data represent the heaviest-used doorway(s) on the train.

There is great variance in dwell times between doors of a train and between stations in a system—the data shown are from doors with the heaviest flow at the busiest station.

Dwell reductions made possible by automation are often offset by slack operating procedures.

The proportion of dwell time productively used for passenger movements ranges from 31 to 64% of the total dwell time. This presents a challenge in determining dwell times from the passenger volumes. Dwells also vary depending on the operating practices of each system. Several North American light rail and heavy rail systems are notably more expeditious at station dwells than their counterparts, contributing to a faster—and so more economic and attractive—operation. Ironically, several automatically driven systems have sluggish station dwells in which expensive equipment and staff sit and wait—long after all passenger movement has ended. The high-capacity rail systems in Europe and Asia, particularly those of Russia and Japan, are noted for their efficient management and control of station dwells.

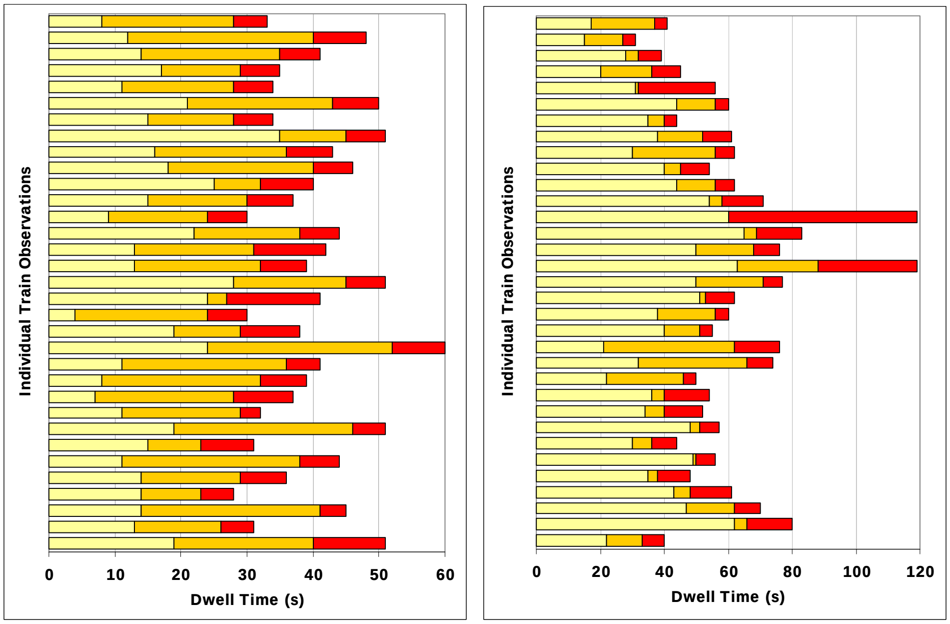
DOORWAY FLOW RATES

Flow time is the time in seconds for a single entering or exiting passenger to cross the threshold of the rail transit car doorway, per single stream of doorway width. Extensive rail transit door flow rate data collection took place in 1995 as part of TCRP Project A-8, Rail Transit Capacity. Data were collected from a representative set of high-use systems and categorized by the type of entry—level entry being the most common, followed by light rail with door stairwells, with and without fare collection at the entrance. The data sets were partitioned into mainly boarding, mainly alighting, and mixed flows. The results are summarized in Exhibit 5-15.

Exhibit 5-14
Dwell Time Components of Four Rail Transit Stations(R15)

🟨 Doors Open, Passenger Flow
🟧 Doors Open, No Passenger Flow
🟥 Doors Closed, Waiting to Depart

Note that the scale of the Grand Central Station chart is twice that of the other charts in this series.

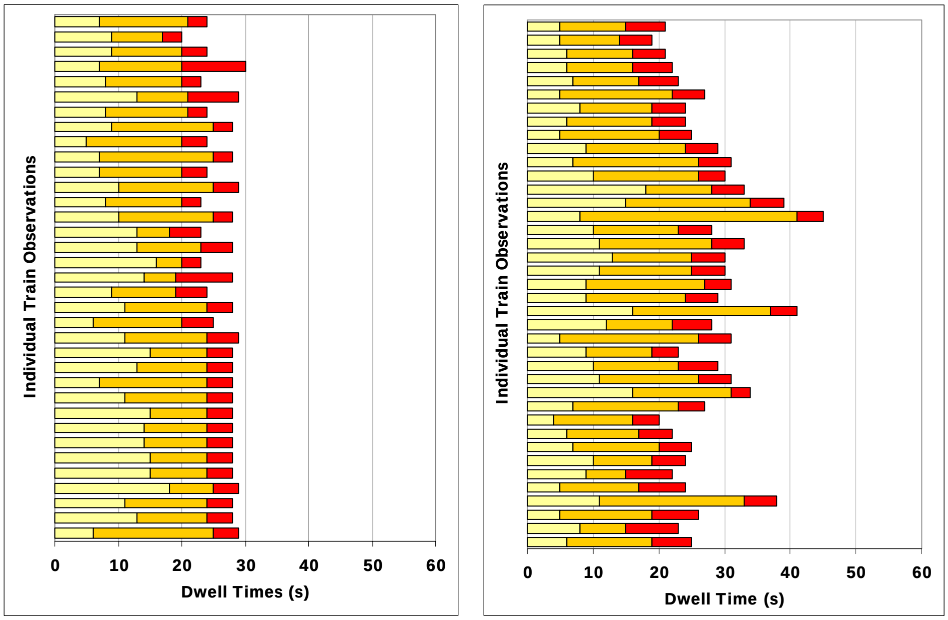


Average headway: 153 seconds
Number of passengers observed: 586
Flow time averages 38% of total dwell

(a) San Francisco, BART (Montgomery Station)

Average headway: 160 seconds
Number of passengers observed: 1,143
Flow time averages 64% of total dwell

(b) New York, NYCT (Grand Central Station)



Average headway: 153 seconds
Number of passengers observed: 586
Flow time averages 38% of total dwell

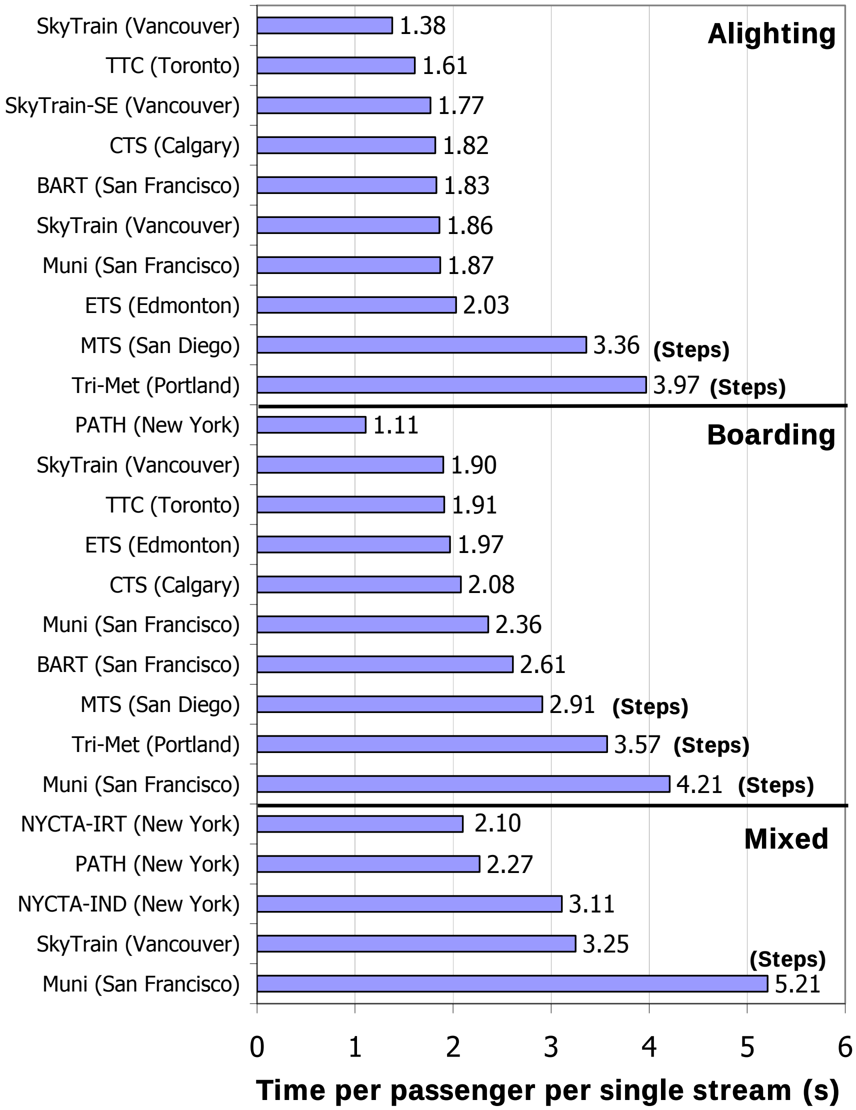
(c) Vancouver, SkyTrain (Burrard Station)

Average headway: 160 seconds
Number of passengers observed: 1,143
Flow time averages 64% of total dwell

(d) Toronto, TTC (King Station, southbound)

These four charts are representative of 61 data sets of door flows collected in early 1995 for TCRP Project A-8. Data are from systems operated at, or close to, the capacity of their respective train control systems. Each bar represents an observation of an individual train.

Exhibit 5-15
Selection of Rail Transit Door Flow Times (1995)(R15)

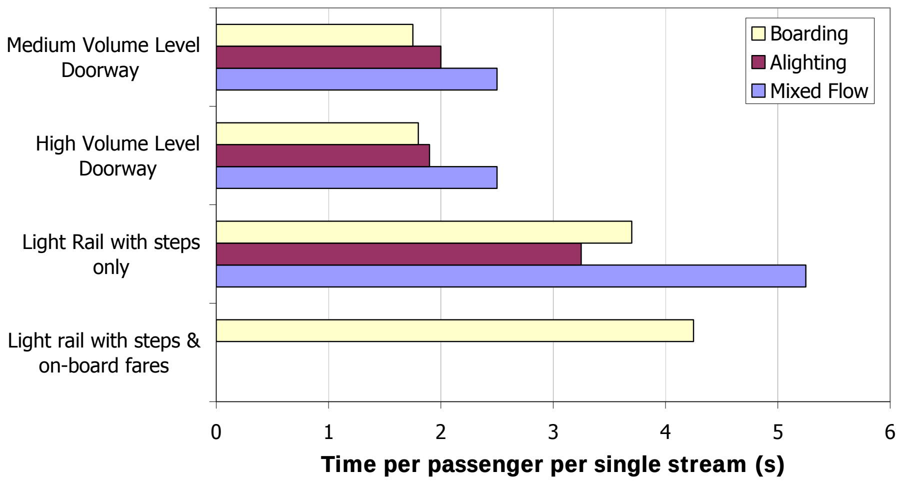


NOTE: Level boarding, except up or down steps where indicated.

Passengers ascend steps into a light rail vehicle faster than they descend them on exit.

An interesting result is that passengers enter high-floor light rail vehicles faster from street level than they exit. The overall fastest flow rate, 1.11 seconds per passenger per single stream, was observed on PATH when passengers were boarding empty trains at the Journal Square station in Newark in the morning peak. These flow data are consolidated and summarized by type of flow in Exhibit 5-16.

Exhibit 5-16
Summary of Rail Transit Average Door Flow Times(R15)

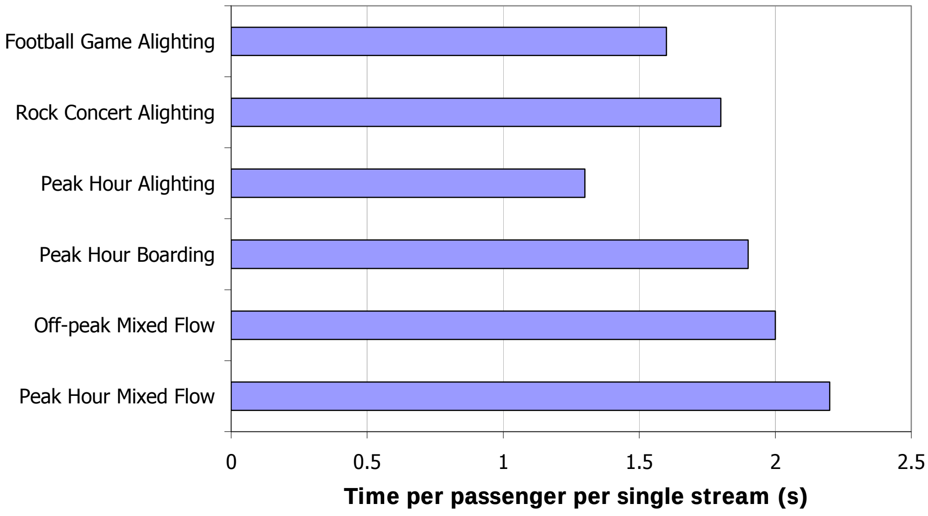


Doorway steps double boarding and alighting times.

The results show that, in these averages, there is little difference between the high-volume—older East Coast heavy rail transit—systems and the medium-volume systems—newer light rail and heavy rail transit. Doorway steps approximately double times for all three categories: mixed flow, boarding, and alighting. Exact fare collection adds an average of about 1 second per passenger.

While most of the field data collection on doorway flow rates was done during peak-periods, off-peak and special event flows were observed on Vancouver's SkyTrain and compared with peak period flows, as summarized in Exhibit 5-17.

Exhibit 5-17
SkyTrain (Vancouver) Door Flow Rate Comparisons(R15)



Special event passenger rates were found to be slower than weekday peak rates.

Special event flows were observed before a football game, before a rock concert, and on a busy suburban station in the early afternoon base period. The resultant data are contrary to the supposition that special event crowds move faster and that off-peak flows are slower than in the peak hour. BC Transit (now TransLink) has also measured car occupancy differences between normal peak hour operation and after service delays. In the ensuing pressure to travel after a delay, passenger space almost doubled from a mean of 3.8 ft^2 per passenger to 2.2 ft^2 per passenger (2.8 passengers per m^2 to 5 passengers per m^2).

Effect of Door Width on Passenger Flow Times

Door widths on observed systems seemed to have little effect on flow rates.

Extensive doorway flow data have failed to show any meaningful relationship between door width and flow rate. Within the 3.75 to 4.5 ft (1.14 to 1.37 m) range of door widths observed, all double-stream doors are essentially equal. Double-stream doors frequently revert to single stream flows and very occasionally three passengers will move through the doorway simultaneously.

All observed doors were essentially double-stream.

At some width below this range, a doorway will be essentially single stream. At widths above those surveyed, a doorway will routinely handle triple streams. There are no single- or triple-stream doors on any modern North American rail transit vehicle, although they exist on AGT systems and in other countries. JR East in Tokyo is experimenting with a quadruple-stream doorway—shown in Exhibit 5-18. Wide doors have been a characteristic of the ADtranz C100 automated guideway transit vehicle used in many airports and on Miami's MetroMover. This four-stream 8-foot (2.4-meter) door is shown below.

Exhibit 5-18
Quadruple-Stream Doorways

(a) Tokyo (b) Miami

Effect of Number of Door Channels on Dwell Times

The total number of door channels available (related to door width and the number of doors) will determine total passenger service time.

Station dwell time is related to the time required to serve all passengers through the busiest door. The greater the number of door channels, the less time required to serve a given passenger flow. Door channels can be provided through a combination of the number of doors and the width of those doors. Newer London Underground cars, for example, provide two double-width doors toward the middle of the cars and two single-channel doors at the ends of the cars, for a total of six door channels per side of the car. The greater the number of doors, the better the opportunity to spread out passengers on station platforms (and thus reduce passenger congestion around the doors), and the smaller the effect that a non-functioning door will have on passenger service times at the car's remaining doors. A tradeoff involved with having more doors or door channels is that less area is available inside the car for seats. Also, a car's design (for example, driver's compartment and wheel locations) will constrain potential door sizes and locations.

ESTIMATING DWELL TIMES

Relating passenger volumes, and flow rates and times, to dwell times.

There are three methods to estimate station dwell times. The first translates station passenger volumes and doorway flow rates into doorway flow times and then into dwell times. This involves complex mathematics involving logarithmic transformations and depends on knowledge of station passenger movements, which are often not readily available. Use of this method is limited and reference should be made to Chapter 4 of TCRP Report 13, "Rail Transit Capacity."(R15)

The second method is the traditional *Mean Plus Two Standard Deviations*. It provides a prediction interval for a new train as opposed to one for the mean of all trains. Since it is maximum capacity that is the ultimate objective, only the upper limit is of interest. This is of value for stations on existing systems where data can be collected at busy stations to allow the mean and standard deviation to be calculated.

When controlling dwell is calculated using the mean plus two standard deviations, an operating margin is usually unnecessary.

Both one and two standard deviations have been used in other work. In either case, it is necessary to ensure that the calculated controlling dwell time contains a sufficient allowance or margin to compensate for minor irregularities in operation. With the addition of one standard deviation, some additional allowance for operational irregularities is necessary. With the addition of two standard deviations, the need for any additional allowance is minor or unnecessary.

In many situations, particularly new systems, insufficient data are available to estimate the dwell standard deviation over a 1-hour or even a 15-minute peak period. In these cases, or as an alternate approach in situations where data are available, an operating allowance or margin can be added to the estimated dwell time due to a specific volume of passenger movements. The results on controlling dwell times of adding 15- and 25-second operating margins on existing systems are shown in Exhibit 5-19.

Exhibit 5-19
Controlling Dwell Limits (s) (1995)(R15)

System & City	Mean	SD	# of samples	Upper Limit (Mean+SD)		Operating margin (s)	
				One SD	Two SD	+15	+25
BART (San Francisco)	46.3	12.0	290	58.3	70.2	61.3	71.3
CTS (Calgary)	35.7	15.7	91	51.5	67.0	50.7	60.7
ETS (Edmonton)	24.7	8.8	18	33.6	42.3	39.7	49.7
NYCT (New York)	30.7	20.9	380	51.6	72.6	45.7	55.7
PATH (New Jersey)	51.3	23.0	252	64.3	97.3	66.3	76.3
TriMet (Portland)	32.0	19.4	118	51.4	70.8	47.0	57.0
MTS (San Diego)	51.1	17.9	34	69.1	86.8	66.1	76.1
Muni (San Francisco)	50.4	21.8	75	72.2	93.9	65.4	75.4
TTC (Toronto)	36.6	23.2	322	59.8	83.0	51.6	61.6
SkyTrain (Vancouver)	30.7	7.2	82	37.9	45.1	45.7	55.7

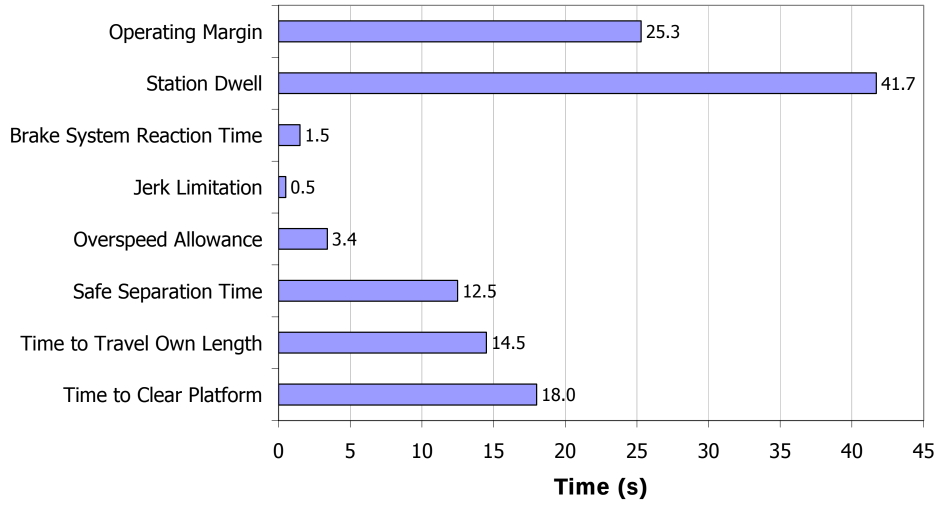
SD: standard deviation

One standard deviation provides an 84% confidence level and two provide a 97.5% confidence level (i.e., 97.5% of all dwells will be less than the average plus two standard deviations.)

The third method is often the most practical, involving selection of dwell times and operational allowances from comparable existing systems.

Exhibit 5-20 shows that dwell time is the dominant component of the minimum headway. Chapter 5 provides additional examples of existing controlling dwells; discusses the need for, and approaches to, estimating a reasonable operating margin; and discusses the time required to load wheeled mobility aids and strollers.

Exhibit 5-20
Typical Headway Components(R15)



NOTE: Based on a heavy rail system operating at 120-s headways, with cab signaling.

CHAPTER 4. PASSENGER LOADING LEVELS

INTRODUCTION

Establishing the loading level of rail transit is the final step in determining capacity. After the maximum train throughput has been calculated from the inverse of the sum of signaling separation time, dwell time, and operating margin, capacity is then based only on train length and loading level.

Loading levels vary widely by transit mode and system.

The existing loading levels on North American rail transit vary from the relaxed seating on many commuter rail lines to the denser loadings experienced on older subway and light rail systems. These loadings offer levels of passenger comfort that are inappropriate for new systems intended to compete with the automobile.

The next section reviews existing rail transit loading standards. The remainder of the chapter determines a range of loading standards that can be applied in specific circumstances for each mode.

LOADING STANDARDS

Mexico City's Metro is an exception and experiences loading that can exceed 1.8 ft^2/p (0.125 m^2/p).

Most rail transit systems have loading standards for the peak-hour, peak-point location with more relaxed standards away from entry into the city center and for off-peak times. Exhibit 5-21 shows loading standards over the peak 15 minutes for selected heavy rail systems.

Exhibit 5-21
Passenger Space on Selected North American Heavy Rail Systems During Peak 15 Minutes (1995)[R9]

	Passenger Space (based on gross floor space)	
System (City)	**(ft^2/p)**	**(m^2/p)**
NYCT (New York)	4.0 into CBD	0.38 into CBD
CTA (Chicago)	7.0 into CBD	0.67 into CBD
SEPTA (Philadelphia)	8.0 into CBD	0.77 into CBD
MBTA (Boston)	5.0 into CBD	0.50 into CBD
BART (San Francisco)	5.75-9.0	0.53-0.83
WMATA (Washington)	5.0-12.0	0.50-1.11
MARTA (Atlanta)	6.75-7.5	0.63-0.71
TTC (Toronto)	4.5-6.0	0.42-0.56
STM (Montréal)	3.4-4.0	0.31-0.38

CBD: central business district

Service standards are usually based on peak-within-the-peak loads.

Care should be taken in comparing and applying the service standards with hourly average loadings. Service standards are usually based on the peak-within-the-peak—15 minutes or less. The difference between 15-minute and peak hour flows can be represented by a peak hour factor.

Peak hour diversity is lower in New York than in most other cities.

The peak hour factor for New York subway trunk routes averages 0.82. Outside New York, the peak-within-the-peak period tends to be more pronounced and the peak hour factor is lower. This is due in part to the long-established Manhattan program to stagger work hours and the natural tendency of passengers to avoid the most crowded period—particularly on lines that are close to capacity.

Maximum standing time policies.

In addition to standards or policies for the maximum loading on peak-within-the-peak period trains and for standards based on minimum *policy* headways, at off-peak times some operators specify a maximum standing time. This is more often a goal rather than a specific standard—20 minutes is typical.

Loading levels for commuter rail are unique and uniform. Although standing passengers may be accepted for short inner-city stretches or during times of service irregularities, the policy is to provide a seat for all passengers. Capacity is usually cited at 90 to 95% of the number of seats on the train.

SPACE REQUIREMENTS

The Batelle Institute(R8) provides details of the projected body space of passengers in various situations. The most useful of these for rail transit capacity are shown in Exhibit 5-22 for males:

Exhibit 5-22
Male Passenger Space Requirements(R8)

These are suggested minimum spaces.

Situation	Projected Area (ft^2)	Projected Area (m^2)
Standing	1.6-2.2	0.15-0.20
... with briefcase	2.7-3.2	0.25-0.30
... with daypack	3.2-3.8	0.30-0.35
... with suitcases	3.8-5.9	0.35-0.55
... with stroller	10.2-12.4	0.95-1.15
... with bicycle (horizontal)	17.2-20.4	1.60-1.90
Holding on to stanchion	2.7	0.25
Minimum seated space	2.7-3.2	0.25-0.30
Tight double seat	3.8 per person	0.35 per person
Comfortable seating	5.9 per person	0.55 per person
Wheelchair space (ADA)	10.0 (30 in x 48 in)	0.93 (0.76 m x 1.22 m)

NOTE: Stroller and bicycle dimensions based on review of manufacturer specifications.

Pushkarev et al.(R17) suggest *gross vehicle floor area* as a readily available measure of car occupancy, recommending the following standards for the peak hour:

- *Adequate*: 5.4 ft^2 (0.5 m^2) per passenger provides comfortable capacity.
- *Tolerable with difficulty*: 3.8 ft^2 (0.35 m^2) is the lower limit in North America with "some touching."
- *Totally intolerable*: 2.2 ft^2 (0.2 m^2) is the least amount of space that is occasionally accepted.

Commuter rail capacity is based on the number of seats, reduced by a peak hour factor. Commuter rail cars in North America are typically 86 ft (28 m) long and, with few exceptions, have seating for 114 to 185 passengers. The higher levels relate to bi-level or gallery cars and/or cars with 2+3 ("two-by-three") seating arrangements.

Wheeled mobility aid space provisions range from 5.9 to 12.9 ft^2 (0.55 to 1.2 m^2); the ADA uses a 30-in. by 48-in. (760-mm by 1220-mm) space. This space can include folding or jump seats. Provision must also be made for wheelchair maneuvering and for any requirements to carry strollers, baggage, and bicycles. More space is required for powered wheeled mobility aids and ones whose occupants have a greater leg extension, less for compact and sports chairs.

The capacity for existing systems should be based on actual loading levels of a comparable service. Actual levels on a specific system or line should be adjusted for any difference in car size and interior layout—particularly the number of seats.

Maximum, full, and crush loads.

Manufacturer-specified passenger loading—*total*, *maximum*, *full,* or *crush load*—does not necessarily represent a realistic occupancy level. Rather, it reflects applying a set criteria—such as 5 or occasionally 6 passengers per square meter (0.45 to 0.56 p/ft^2)—to the floor space remaining after seating space is deducted. In particular, *crush load* can represent the theoretical, and often unattainable, loading used to calculate vehicle structural strength or the minimum traction equipment performance.

Vehicle-Specific Calculations

Estimating the person capacity of a vehicle.

Detailed calculations of the person capacity of individual vehicles are not recommended. Given the wide range of peak hour occupancy that is dependent on policy decisions, elaborate determination of interior space usage is generally not practical. Reasonably accurate estimates of vehicle capacity are all that are needed. The following procedures offer a straightforward method.

The first step after obtaining the interior car dimensions is to determine the length of the car side free from doorways. Deducting the sum of the door widths, plus a setback allowance of 16 in. (0.40 m) per double door,[2] from the interior length gives the interior free wall length.

Seating can then be allocated to this length by dividing by the seat pitch:

- 27 in. (0.69 m) for transverse seating,[3] and
- 17 in. (0.43 m) for longitudinal seating.

The result, in lowest whole numbers,[4] should then be multiplied by 2 for longitudinal seating or by 3, 4, or 5, respectively for 2+1, 2+2, or 2+3 transverse seating. The result is the total number of seats. A more exact method would use the specific length between door setbacks. Articulated light rail vehicles should have the articulation width deducted. Four seats can be assigned to the articulation, if desired.

Seating area.

The floor space occupied by seats can then be calculated by multiplying transverse seats by 5.4 ft^2 (0.5 m^2) and longitudinal seats by 4.3 ft^2 (0.4 m^2). These areas make a small allowance for bulkhead seating but otherwise represent relatively tight and narrow urban transit seating. Add 10 to 20% for a higher quality, larger seat such as that found on BART.

Standing area.

The residual floor area can now be assigned to standing passengers. Light rail vehicles with step wells should have half the step well area deducted. Although prohibited by many systems, passengers will routinely stand on the middle step, squeezing into the car at stops if the doors are treadle operated.

Articulated light rail vehicles should have half the space within the articulation deducted as unavailable for standing passengers, even if the articulation is wider. Many passengers choose not to stand in this space.

Standing passengers can be assigned as follows:

- 2.15 ft^2/p (5 p/m^2), an uncomfortable near-crush load for North Americans with frequent body contact and inconvenience with packages and briefcases. Moving to and from doorways is extremely difficult.
- 3.2 ft^2/p (3.3 p/m^2) a reasonable service load with occasional body contact. Moving to and from doorways requires some effort.
- 5.4 ft^2/p (2.0 p/m^2),[5] a comfortable level without body contact, reasonably easy circulation, and similar space allocation as seated passengers.

---

[2] A lower set-back dimension of 12 in. (0.3 m) may be used if this permits an additional seat/row of seats between doorways.

[3] Increase to 32 in. (0.8 m) for seats behind a bulkhead.

[4] For more accurate results, the sidewall should be divided into the lengths between each set of doors (and, when appropriate, between the door and any articulation) and checked, or adjusted, to ensure that an integer of the seat pitch is used. This can be done by dividing the interior free wall length by the number of doorways plus one. The number of integer seat pitches in each space is then determined and used to calculate the total vehicle seating.

However, this approach can result in the seating changing radically with a small change in vehicle length, articulation length, or door width, any of which are sufficient to add or remove a row of seats between each set of doors. On a four-door car with 2+2 seating, this results in the seating adjusting up or down by 20 seats at a time—five rows of four seats. Simple calculations cannot substitute for a professional interior layout design that can optimize seating with a combination of transverse and longitudinal seats. Other design criteria can also be accommodated including the provision of wheelchair spaces and maximizing circulation space around doorways.

[5] This upper level is a peak 15-minute occupancy level for standing passengers. Over the peak hour it corresponds closely to Pushkarev's(R17) and Jacobs'(R12) estimates of a U.S. rush hour loading average of 5.4 ft^2/p (0.5 m^2/p)—both seated and standing. It also corresponds to Pushkarev's and Batelle's(R8) recommendations for *adequate* or *comfortable* loading levels.

The middle level above is slightly relaxed from the often stated standard of four standing passengers per square meter. The so-called crush loads are frequently based on 5 or 6 passengers per square meter (0.45 to 0.56 p/ft^2), the latter being more common in Europe. Asian standards for both maximum and crush loads reach 7 or 8 standing passengers per square meter (0.67 to 0.77 p/ft^2). The resultant sum of seated and standing passengers provides a guide for the average peak 15-minute service loading level for the specific vehicle. Peak hour loading should be divided by the peak hour factor to get equivalent peak 15-minute loading levels. No specific allowance has been made for wheelchair, bicycle, stroller, or other wheeled device accommodation, or for reduced standing densities away from doorways. The above range of standing densities makes such small adjustments unnecessary. Cars intended for higher density loading should have a greater number of doors. Space inefficiencies at the extremities of a car are unavoidable unless the London Underground arrangement of doors at the very end of each car is adopted.

The above process can be expressed mathematically as:

Equation 5-6

$$C_c = \left[\frac{(L_c - 0.5L_a)W_c - 0.5D_n W_s D_w}{S_{sp}} \right] + N \left[\left(1 - \frac{S_a}{S_{sp}} \right) \left(\frac{L_c - L_a - D_n(D_w + 2S_b)}{S_w} \right) \right]$$

The articulated rail car schematic in Exhibit 5-23 shows the principal dimensions of this equation.

where:

C_c = car capacity—peak 15 minutes (p/car);
L_c = car interior length (ft, m);
L_a = articulation length for light rail (ft, m);
W_s = stepwell width (certain light rail only) (ft, m);
W_c = car interior width (ft, m);
S_{sp} = space per standing passenger (ft^2, m^2):
  2.15 ft^2 (0.2 m^2)—crush load,
  3.2 ft^2 (0.3 m^2)—maximum schedule load, and
  5.4 ft^2 (0.5 m^2)—comfortable standing load;
N = seating arrangement:
  2 for longitudinal seating,
  3 for 2+1 transverse seating,
  4 for 2+2 transverse seating, and
  5 for 2+3 transverse seating;[6]
S_a = area of single seat (ft^2, m^2):
  5.4 ft^2 (0.5 m^2) for transverse, and
  4.3 ft^2 (0.4 m^2) for longitudinal;
D_n = number of doorways;
D_w = doorway width (ft, m);
S_b = single setback allowance (ft, m):
  0.67 ft (0.2 m)— or less; and
S_w = seat pitch (ft, m):
  2.25 ft (0.69 m) for transverse, and
  1.42 ft (0.43 m) for longitudinal.

---

[6] 2+3 seating is only possible on cars with width greater than 10 ft (3 m), and is not applicable to light rail or automated guideway transit.

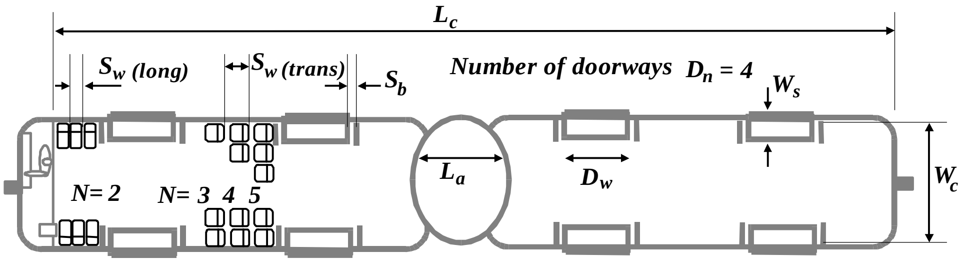


Exhibit 5-23
Schematic LRT Car Showing Dimensions(R15)

Default Method

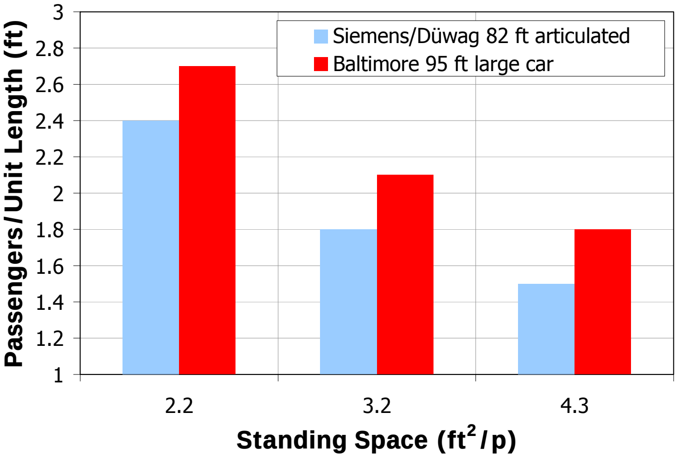
A default method is to divide the gross floor area of a vehicle (exterior length multiplied by exterior width) by 5.4 ft² (0.5 m²) and use the resultant number of passengers as the average over the peak hour—without applying a peak hour factor. An average space over the peak hour of 5.4 ft² (0.5 m²) per passenger is the comfortable loading level on U.S. rail transit systems recommended in several reports and is close to the average loading on all trunk rail transit lines entering the CBD of U.S. cities.

LENGTH

Train length as a surrogate for capacity.

Another default method to approximate loading levels is to assign passengers per unit length. Applying Equation 5-6 to two typical light rail vehicles produces the loading levels in passengers per unit length shown in Exhibit 5-24. As would be expected, the wider and longer Baltimore car has proportionately higher loadings per meter of length. The almost generic Siemens-Düwag car used in nine systems (with some dimensional changes) has a range of 1.5 to 2.4 passengers per foot of car length (5.0 to 8.0 p/m length). The lower level of 1.5 passengers per foot length (5.0 p/m length)—with a standing space per passenger of 4.3 ft² (0.4 m²)—corresponds closely with the recommended *comfortable* loading of an average of 5.4 ft² (0.5 m²) per passenger.

Exhibit 5-24
Linear Passenger Loading—Articulated LRVs(R15)



An alternative figure using metric units appears in Appendix A.

Applying Equation 5-6 to selected heavy rail cars produces the loading levels in passengers per unit length shown in Exhibit 5-25. As would be expected, the smaller and narrower cars in Vancouver and Chicago have lower loadings per unit length.

The more generic 75-ft (23-m) cars used in more than 12 U.S. and Canadian cities have a remarkably close data set for each of the three variations of door and seating configurations, with a range of 2.1 to 3.5 passengers per foot of car length (7.0 to 11.5 p/m of car length). The higher end of this range approaches that of crush loaded conditions.

The lower end of the range, at 2.1 to 2.4 passengers per foot length (7 to 8 p/m length)—with a standing space per passenger of 4.3 to 3.2 ft² (0.4 to 0.3 m²)—is an appropriate and tight range for higher use systems. A lower figure of 1.8 p/ft length (6 p/m length) corresponds closely with the recommended *comfortable* loading of an average of 5.4 ft² (0.5 m²) per passenger and is appropriate for a higher level of service on new systems. In either case, a reduction by 0.3 p/ft length (1.0 p/m length) should be used for smaller, narrower cars.

Exhibit 5-25
Linear Passenger Loading—Heavy Rail Cars(R15)

An alternative figure using metric units appears in Appendix A.

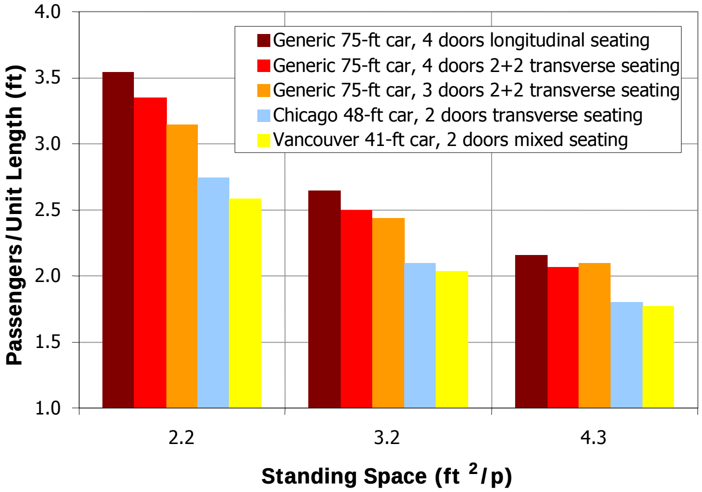


Exhibit 5-26 summarizes the average loading level in passengers per foot length for typical U.S. and Canadian rail transit cars.

Exhibit 5-26
Summary of Linear Passenger Loading (p/ft) (1995)(R15)

An alternative table using metric units appears in Appendix A.

	Average	Median	Standard Deviation
All Systems	2.0	1.8	0.6
Commuter Rail	1.5	1.4	0.2
Heavy Rail	2.1	1.9	0.6
Heavy Rail less New York	1.7	1.7	0.5
MTA-NYCT alone	2.4	2.4	0.5

SUMMARY

Passenger space can be designed on a per-person or more generic per-unit-vehicle-length basis. When designing for a new system, an average of 5.4 ft² (0.5 m²) per passenger over the peak hour is appropriate to provide a higher (i.e., more comfortable) level of service. This recommended passenger space corresponds to a linear loading level of 1.8 passengers per foot length (6 passengers per meter length) for heavy rail cars and 1.5 passengers per foot length (5 passengers per meter length) for light rail cars, which are somewhat narrower.

Passengers with luggage, daypacks, strollers, and other items will take up more space than unencumbered passengers and may need to be accounted for in design in certain circumstances. A recommended minimum space is 3.2 ft² (0.3 m²) per passenger, corresponding to 2.4 passengers per foot (8 passengers per meter) for heavy rail and 2.1 passengers per foot (7 passengers per meter) for light rail.

CHAPTER 5. OPERATING ISSUES

INTRODUCTION

Allowance for operating variables.

The previous three chapters have introduced the three major factors that control rail transit capacity: *Train Control and Signaling, Station Dwell Times,* and *Passenger Loading Levels.* Operating issues, discussed in this chapter, affect all three factors.

Uniformity of train performance.

There is considerable uniformity of performance of the electrical multiple-unit trains that handle more than 90% of all U.S. and Canadian rail transit, assisted by the widespread introduction of electronic controls and automatic driving. However, there still can be up to a 10% difference in performance between otherwise identical trains due to manufacturing tolerances, aging of components, and variances in set-up parameters, and—particularly on manually driven systems—due to variations in driving techniques between drivers.

Operating margins.

To accommodate these routine irregularities, two allowances are made in rail transit operations planning and scheduling. An *operating margin* is added to the minimum train separation time and maximum load point station dwell time to create a minimum headway. This operating margin is, in effect, the amount of time a train can run behind schedule without interfering with the following trains. The operating margin is an important component in determining the maximum achievable capacity.

Schedule recovery.

The second allowance is *schedule recovery,* an amount of time added to the terminal turn-around time to allow for recovery from accumulated delays on the preceding trip. Schedule recovery time has some effect on achievable capacity and also has economic implications, as it can increase the number of trains and staff required to transport a given volume of passengers.

OPERATING MARGINS

Operating margin examples.

As a starting point for recommending a suitable operating margin, the operating margins incorporated into the schedules of existing systems can be reviewed. The maximum load point, peak-period, station dwell time, and headways for several rail transit lines are presented in Exhibit 5-27.

The headways in Exhibit 5-27 for Calgary are all multiples of the 80-second traffic signal cycle. The seemingly erratic headways in Calgary are misleading as three routes, forming two interlaced services, share this downtown bus and light rail mall. The exhibit also shows the dwell and headway regularity of interlaced services on Vancouver's fully automatic SkyTrain.

The lower four charts in Exhibit 5-27 show the range of dwell and headway irregularities on manually driven systems. These are not typical of most heavy rail lines throughout the day, but represent lines at or near capacity at the peak-point in the peak period. It is at these times that operating margin and schedule recovery times are most needed to correct service irregularities.

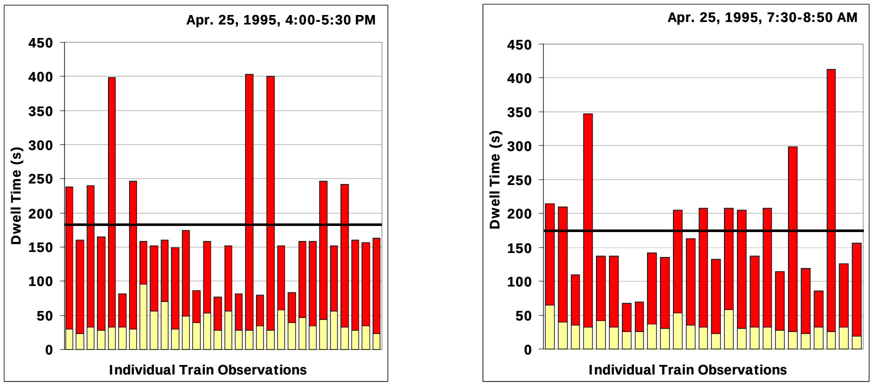
Exhibit 5-28 shows the headway components with the final column indicating the residual time that is a surrogate for the operating margin. [7]

---

[7] The operating margin is estimated to be:
Operating margin = (average headway) – (avg. station dwell) – 2(standard deviation of station dwell) – (train control separation)

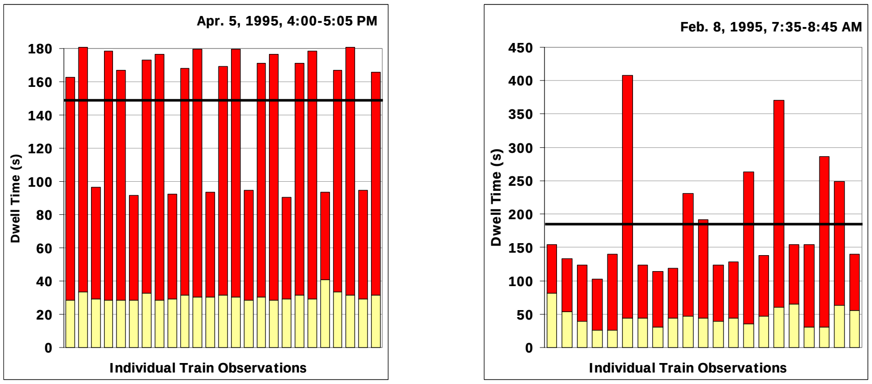
Exhibit 5-27
Observed Rail Headways and Dwell Times(R15)

Light rail headways on observed systems were generally sufficiently long that any irregularities reflected problems other than schedule interference between trains. One of the closest on-street headways is in Calgary, shown at the top. Note that the scales of the graphs vary.



(a) CTS 3rd St. SW EB (Calgary)

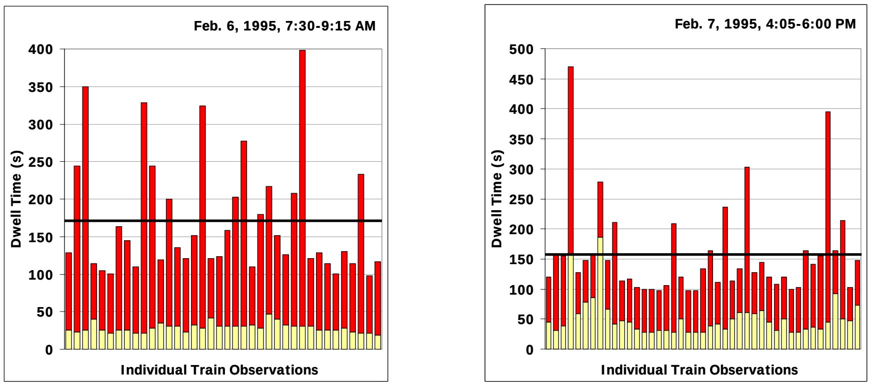
(b) CTS 1st St. SW WB (Calgary)



(c) SkyTrain Broadway EB (Vancouver)

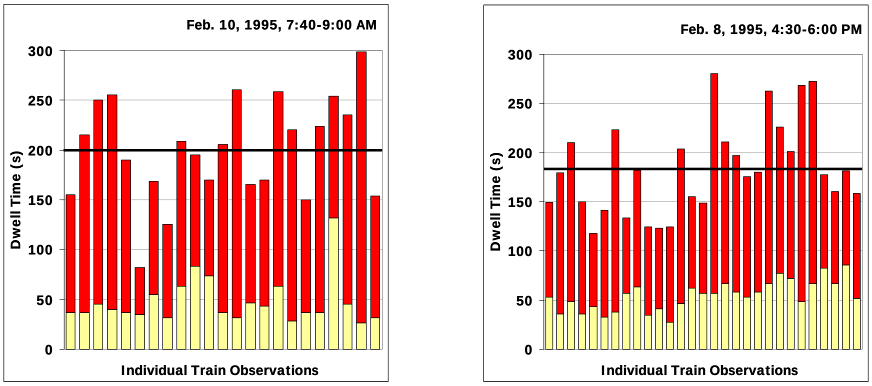
(d) BART Embarcadero WB (San Francisco)

Additional examples of these dwell/headway charts are contained in Chapter 6 of *TCRP Report 13*, "Rail Transit Capacity."(R15)



(e) TTC King SB (Toronto)

(f) TTC Bloor NB (Toronto)



(g) PATH Journal Square WB (Newark)

(h) NYCT Grand Central NB Express (New York)

🟨 Dwell Time (s)
🟥 Headway (s)
— Average headway (s)
NB: northbound
SB: southbound
EB: eastbound
WB: westbound

Exhibit 5-28
Dwell and Headway Data Summary of Surveyed Rail Transit Lines Operating at or Close to Capacity (1995)(R15)

System & City	Station & Direction	Avg. Station Dwell (s)	Dwell SD (s)	Avg. Hdwy. (s)	Dwell as % of Hdwy.	Train Control Separation (s)	Estimated Operating Margin (s)
BART San Francisco	Embarcadero WB	49.9	15.7	201.7	24.7	90.0	30.4
CTS Calgary	1st St. SW WB	34.6	11.1	176.6	19.6	80.0	39.9
CTS Calgary	3rd St. SW EB	40.0	16.2	181.4	22.1	80.0	28.9
CTS Calgary	City Hall EB	36.8	20.6	191.4	19.2	80.0	33.4
Muni San Francisco	Montgomery WB	34.4	11.0	146.0	23.6	60.0	29.6
NYCTA New York	Queens Plaza WB	40.7	17.3	134.7	30.2	53.0	6.4
NYCTA New York	Grand Central SB	64.3	16.7	164.7	39.0	53.0	14.1
NYCTA New York	Grand Central NB	53.9	14.8	184.1	29.3	53.0	47.5
PATH Newark	Exchange Place EB	23.3	7.4	115.8	20.1	55.0	22.6
PATH Newark	Journal Square WB	47.3	23.4	199.7	23.7	55.0	50.6
SkyTrain Vancouver	Broadway EB	30.2	2.6	145.6	20.7	40.0	70.2
SkyTrain Vancouver	Burrard WB	26.7	2.5	150.7	17.7	40.0	79.0
SkyTrain Vancouver	Metrotown EB	37.8	10.4	241.3	15.7	40.0	142.8
TTC Toronto	Bloor NB	43.0	15.3	145.5	29.4	55.0	17.0
TTC Toronto	King SB	28.1	5.9	168.3	16.7	55.0	73.4

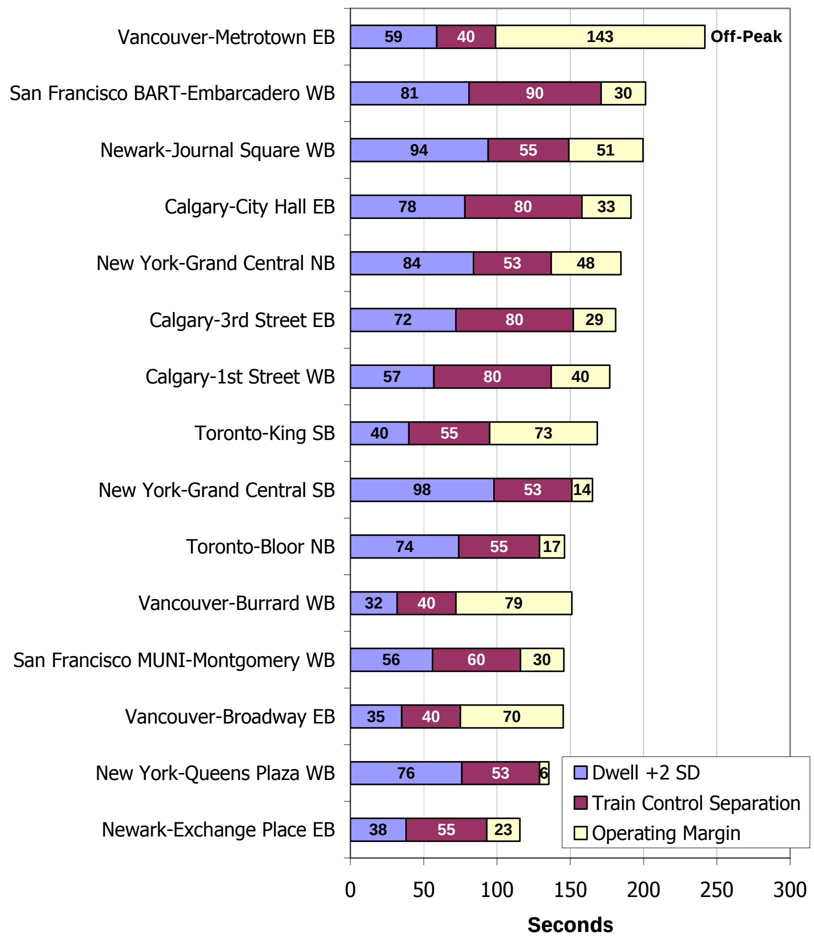
NB: northbound, SB: southbound, WB: westbound, EB: eastbound
SD: standard deviation, Hdwy.: headway

Exhibit 5-29 shows the headway components graphically, with the operating margin as the end component of each bar. The bars are arranged in order of increasing headway. Note that the bar at the top is the only off-peak data set. It is included only for comparison and shows the large operating margin available when a system is not at capacity. The operating margins range widely and bear little relationship to system, technology, or loading levels.

Headway coefficient of variation.

A proxy for service reliability is the headway coefficient of variation—the standard deviation divided by the mean. There could be expected to be a relationship between operating margin and service reliability; however, *TCRP Report 13*(R15) found no such relationship. Some inference can be drawn in that the system with the best headway adherence identified in *TCRP Report 13,* Vancouver's SkyTrain, also has the most generous operating margins.

Exhibit 5-29
Headway Components of Surveyed Heavy Rail Transit Lines Operating at or Close to Capacity(R15)



NOTE: NB = northbound, SB = southbound, WB = westbound, EB = eastbound

Estimating Operating Margins

Although there is no clear relationship between existing rail transit operating margins and other operating criteria, this important factor, and the related terminal recovery or layover time, cannot be discounted. The inevitable headway irregularities and the need for reasonable operating flexibility require the greatest possible operating margin and recovery time to ensure reasonably even service and to achieve maximum capacity. Selecting a recommended operating margin is a dilemma, as too much reduces achievable capacity, but too little incurs sufficient irregularity that it may also serve to reduce capacity.

It is recommended that a range be considered for an operating margin. A reasonable level for a system with more relaxed loading levels, where all of the capacity is not needed, should be 35 seconds. On systems where headways prohibit such margin, a minimum level of 10 seconds can be used with the expectation that headway interference is likely.

Suggested operating margin range.

In between these extremes is a tighter range of 15, 20, or 25 seconds that is recommended. This range is used in estimating achievable capacity in this manual and is recommended as a default value for computations using the detailed procedures.

SKIP-STOP AND EXPRESS OPERATION

Skip-stop operation increases speed but not capacity.

Skip-stop service (where a given train stops at every other station) is used on several of the heavy rail transit operations in Japan, New York, Philadelphia, and, until recently, Chicago. Skip stops provide faster travel times for most passengers, and require less equipment and fewer staff. They do not increase capacity as the constraint remains the dwell time at the maximum load point station at which all trains must stop. In fact, capacity can be slightly reduced as the extra passengers transferring between *A* and *B* trains at common stations can increase dwell times. Skip-stop operation is only applicable if the headways are sufficiently short that the "up to two-headway wait" at minor stations is acceptable to passengers.

The common stations on the Japanese skip-stop operations have multiple platforms, typically two island platforms allowing passengers to transfer across the platform between *A* and *B* or between local and express trains.

Four light rail lines (Philadelphia's 100-series lines and New Jersey's Hudson-Bergen line) operate a form of express service, where a following train skips stops to catch up to—but not pass—the train in front.

Light rail operations may also skip stations when an *on-demand* operating policy is adopted. This requires that an on-board passenger signal to stop the train. Drivers must observe whether there are any waiting passengers as they approach each station. This is a particularly efficient way to increase line schedule speed and reduce operating costs. However, at higher capacity levels all trains will stop at all stations and so the practice has no effect on line capacity. Demand stops are rare on new North American light rail systems, even where there are clearly some low-volume stations where during off-peak times on-demand stops could contribute to lower energy consumption, lower maintenance costs, and a faster, more attractive service.

Directional capacity with express service.

New York's Lexington Avenue express tracks carry 80% the number of trains of the local tracks.

Most trunk routes in New York[8] have three or four tracks, while the Broad Street subway in Philadelphia and the North Side elevated in Chicago have four tracks. The capacity of four-track lines is not a simple multiple of two single tracks and varies widely with operating practices such as the merging and diverging of local and express services and trains holding at stations for local-express transfers. The result is that four tracks rarely increase capacity by more than 50% over a double-track line—and often less. A third express track does not necessarily increase capacity at all when restricted to the same station close-in limitations at stations with two platform faces.

PASSENGER-ACTUATED DOORS

The majority of new light rail systems have passenger-actuated doors, which increase comfort by retaining interior heat or air conditioning and reducing wear and tear on door mechanisms. The practice can extend station dwell time but is of little value at higher frequencies or busy stations where the use of all doors is generally required. Consequently, some systems use the feature selectively and allow the train operator to override passenger actuation and control all doors when appropriate.

Door cycle times.

A typical heavy rail transit car door will open and close in 5 seconds. Certain light rail doors, associated with folding or sliding steps, can take double this time to operate. A door opening initiated at the end of a station dwell will extend the dwell time by the door opening and closing time, plus any added passenger movement time. A system approaching its capacity could not tolerate such dwell extensions but would, in any event, be using all doors which might just as well be under driver control—avoiding any last-minute door opening and closing.

---

[8] All but two New York three- and four-track trunks merge or split into double-track sections, tunnels, or bridges, crossing the Harlem and East Rivers, often with one crossing used for local trains and a second used for express services. The Concourse line used by the B and D trains, and the Seventh Avenue-Broadway line used by the 1 and 9 trains are the only three-track river crossings. The Manhattan Bridge carries four tracks, but only two are in service.

OTHER STATION CONSTRAINTS

Inadequate platform exit capacity can reduce line capacity, as dwell times of following trains increase.

Many station-related factors can influence demand. Poor location, inconvenient transfers to connecting modes, and inadequate or poorly located kiss-and-ride or park-and-ride facilities may all deter usage. However, the only factor that has a potential effect on the line capacity of a rail transit line is the rate of exiting from a platform. Adequate passageways, stairways, and escalators must be provided to ensure that a platform can clear before the arrival of the next train. Inadequacies in passenger access to a station may reduce demand but not capacity.

Part 7 of the TCQSM covers NFPA station exit requirements in greater detail.

Station exiting requirements are specified by the U.S. National Fire Protection Association (NFPA) rapid transit standard 130.(R14) Exits, emergency exits, and places of refuge must be adequate to allow a platform with one headway's worth of passengers plus the entire complement of a full-length fully loaded train to be able to be evacuated to a safe location within 4 minutes—without using elevators and treating escalators as a single-width stairway. These regulations ensure that in all but the most unusual circumstances—where there is a disproportionate reliance on emergency exits—full capacity loads can leave the platform before the next train arrives.

NFPA 130 requirements may not be met on older systems. Additional exits must be provided to ensure that achievable capacity is not constrained by platform back-ups. Rates of flow are established for passageways, and up and down stairs and escalators according to width. In emergencies, exit fare payment devices can be placed in a free passage mode. This is not the case in normal operation when adequate exit fare control checks must be provided on those systems with distance-related fares.

Out-of-service fare gates and escalators have the potential to create station platform congestion, if the remaining in-service equipment does not have sufficient capacity.

Even when NFPA 130 requirements are met, constraints posed by out-of-service fare gates, escalators, or other station components can potentially create congestion that could cause passenger queues to back up onto station platforms, if these components are being operated close to their capacity. Part 7 of the TCQSM provides procedures for calculating the passenger-handling capacity of various station components.

On-board light rail fare payment.

Fare payment is a particular factor on the few light rail systems that still use manual on-board payment. Exhibit 5-16 showed that exact fare payments add an average of 1.5 seconds per boarding passenger. This is an inefficiency that increases running time, station by station, day by day.

However, the far more drastic impact of manual on-board fare collection is the restriction of boarding to a single staffed door. Not only do all passengers take more time to board individually, the efficiency of loading several passengers at once through multiple doors is lost, resulting in dwell times that are potentially three to four times as long as they would be without on-board fare collection. Exhibit 5-30(c) shows an extreme case of platform congestion resulting from manual on-board fare collection and a surge of passengers from a nearby tourist attraction. A system using manual on-board fare collection, and restricting boardings to driver-attended doors only, cannot achieve its maximum capacity.

A few systems provide on-board fare machines, combined with random fare checks. These machines allow passengers to board through all doors and then make their way inside the car to the fare machine. This addresses the dwell time issue, but can substitute a crowding and circulation issue inside the car, in the vicinity of the fare machine. On low-volume or mainly pre-paid lines such as the Portland Streetcar (which operates mainly within a fare-free area), congestion within the car may not be an issue. However, on high-volume systems with on-board fare machines, such as trams in Melbourne, Australia, it can be an issue.

Exhibit 5-30
On-Board Fare Collection

(a) Farebox (Pittsburgh)

(b) Self-service machine (Portland Streetcar)

(c) Farebox, with passenger surge (Cleveland)

(d) Smart card reader (San Francisco)

Platform width.

Stations with high mixed flows must also have platforms of adequate width to accommodate the flows. Platform width is also a factor in making it easy for passengers to distribute themselves along the length of a train and so improve the peak hour factor.

WHEELCHAIR ACCOMMODATIONS

With dwell times being one of the most important components of headway, the time for wheelchair movements is important. Measured lift times run 2 to 3 minutes, with some as low as 60 seconds. The movement of wheelchairs on level surfaces is generally faster than walking passengers except where the car or platform is crowded. Level loading is essential to achieve high capacity. Where high platforms or low-floor cars cannot be provided, mini-high or high-block loading arrangements for wheelchairs, described later in this section, have the least impact on capacity. The vertical and horizontal gap between the edge of platform and the door is often a major problem for passengers in wheeled mobility aids.

Wheelchair boarding rates.

An unknown is the number of wheelchairs that will elect to use mainstream rail transit when all ADA measures have been implemented. A 1995 survey of heavily used rail transit systems indicated an average of 1 wheelchair use per 20,000 passengers.(R15) Other estimates range from 1 in 5,000 to 1 in 10,000. However, usage is usually dependent on other streetscape amenities and demographic factors as well. The usage of lifts can be three to five times higher than these rates due to use by other passengers not using wheeled mobility aids.

In addition to any boarding and alighting delays, the time for a wheelchair to move to a securement position and use any required securement or restraint systems can be considerable, particularly if the rail car is crowded. However, experienced users can be remarkably quick in boarding and alighting, and passenger movement times are often lower than for lift-equipped buses, as there is more room to maneuver wheelchairs, walkers, and scooters within rail vehicles. Off-vehicle fare collection also helps to speed loading for mobility limited and able-bodied passengers alike. The least loss of time is when the wheelchair position is close to the doorway and requires neither a folding seat nor the use of a securement system. Some systems have experienced passenger conflicts over mobility device seating priority when other passengers occupy the folding seats provided to create space for wheelchairs and other mobility devices.

Some agencies are overly cautious in adapting bus securement procedures to light rail service. Consideration of wheelchair securement is necessary for light rail vehicles operating on-street, due to the possibility of rapid braking as a result of traffic. However, many systems' experience indicates that wheelchair securement systems are not necessary for off-street rail service, as braking and acceleration is closely controlled and ride quality is smooth.

Impact of wheelchairs on line capacity.

There are many other types of boarding and alighting delays from passengers, other than those in wheelchairs, and generally these are accommodated in the operating margins and schedule recovery times. There is insufficient information to quantify the impact of wheelchair accessibility on line capacity. Indications are that in the short term, wheelchair lift and bridging plate use on light rail may cause delays, but this use is generally on systems with long headways (6 minutes and above) and have minimal impact on capacity at these levels. In the longer term, other accessibility requirements of the ADA and the move to level boarding with low-floor cars, or mini-high and profiled platforms, should sufficiently improve boarding and alighting movements to offset any negative impact of wheelchair use.

Wheelchair Boarding Methods

High-level loading is invariably used on heavy rail systems and is typically used on automated guideway transit systems. The relative rarity of level loading with high level platforms on other rail modes has resulted in a variety of methods to allow wheelchair access to rail vehicles. Each of the methods is outlined by mode in the sections that follow.

It should be noted that both mobility-impaired passengers and transit agencies prefer access methods which do not single out people with mobility impairments for special treatment. Lifts and special ramps cause delays which reduce the reliability of the service, while isolating people with mobility impairments from other passengers. Mechanical devices such as lifts can also fail and put a train out of service. For these reasons, the popularity of lifts and other special devices for use by people with mobility impairments is decreasing in favor of more reliable and less exclusionary methods such as low-floor cars.

Light Rail

High Platforms

High platforms allow level movement between the platform and the car floor. This allows universal access to all cars of a train and removes the reliability and exclusionary effects associated with lifts, ramps, and special platforms. Passenger flow is speeded for all passengers since there are no steps to negotiate on the car. High-platform stations can be difficult to fit into available space, because of the need for an ADA-accessible sloped ramp to get between street level and platform level, which can increase costs. Nevertheless, high platforms are used exclusively on a number of systems, including Los Angeles, St. Louis, and Calgary. The use of high platforms on the transit mall portion of Calgary's light rail lines illustrates the difficulty accommodating this preferred loading method in on-street locations.

The Los Angeles Waterfront vintage trolley uses high platforms, in combination with a platform bridge across the gap for use by wheeled mobility aids.

Mixed use of high and low platforms.

High platforms are also used at stations in Buffalo, Pittsburgh, and San Francisco; in combination with low-level loading at other stops.[9] Buffalo is unusual in that a subway, with high platforms, serves the outer portion of the line, while the downtown segment is on a transit mall with low-level loading using fold-out steps, combined with high-platform stubs for wheelchair access. Pittsburgh has separate doors for each platform level, while the San Francisco Muni uses cars fitted with steps that can be mechanically raised to floor height at high-platform stations.

Examples of high-platform stations and vehicles used in mixed high- and low-platform environments are shown in Exhibit 5-31.

Exhibit 5-31
High-Platform Station and Adjustable Door Height Examples

(a) On-street station in median (San Francisco) (b) Partial platform (Buffalo)

(c) Adjustable vehicle steps (San Francisco) (d) Separate door levels (Pittsburgh)

Low-Floor Cars

Low-floor cars improve access for everyone, not just persons using mobility aids.

Low-floor cars[10] offer a straightforward solution to the need for universal access to light rail vehicles. By bringing the floor height down to just above the railhead, boarding is simplified for all passengers, as steps are no longer required. Small, extendible ramps and slight increases in platform edge height allow passengers using wheeled mobility aids to board without the aid of lifts or special platforms. Boarding

---

[9] Low-level surface stops on Pittsburgh's light rail lines are not accessible. The Port Authority is constructing high platforms on the renovated Overbrook Line and at selected other stops as part of its light rail reconstruction project. In San Francisco, the Market Street subway and stations along the Mission Bay extension have high platforms. Stations along the historic streetcar "F" line Embarcadero extension and selected on-street stops on other lines have mini-high platforms. Where neither high nor mini-high platforms exist, the Muni system is not accessible.

[10] Note the difference between the terms *low-floor car* and *low-level loading*. The former states that the majority of the car floor is slightly above curb height, while the latter describes cars (low-floor cars included) where passengers can enter from street level without the need for platforms.

by persons with strollers, bicycles, and luggage, and by persons who have difficulty climbing steps is also greatly simplified. Exhibit 5-32 presents examples of low-floor cars used in North America.


(a) Portland, Oregon (light rail)   (b) Jersey City, New Jersey

Exhibit 5-32
Low-Floor Cars

On-street stations used by low-floor vehicles are more compact than high-platform stations would be.

Low-floor cars provide much of the benefit of level loading without the need for high platforms. The typical floor height is 14 in. (350 mm),[11] about double the height of a normal curb. Medium- or intermediate-height platforms are therefore still required for no-step boarding, but long ramps are unnecessary. Buttons located at a lower height than the separate passenger-actuated door buttons on the inside and outside of the car allow wheelchair users to deploy the ramp on demand to bridge the gap between the car and the platform.

Low-floor cars in North America.

While low-floor cars have operated in Europe for more than a decade, the first North American operation began on the Portland light rail system in 1997. Portland's cars are compatible with its existing high-floor fleet, allowing two-car trains formed from one high-floor and one low-floor car. Low-floor cars have subsequently been placed in service on New Jersey Transit's Hudson-Bergen and Newark City Subway lines, the Portland Streetcar, and the Tacoma Link, and low-floor cars are on order for lines in Houston, Minneapolis, and Boston.

Drawbacks of 100% low-floor designs.

Full and partial low-floor designs.

Low-floor cars have some drawbacks which have yet to be fully resolved. Although purchase prices have been falling, cars with a 100% low floor are more expensive to buy and maintain. Certain designs are technically complex and have suffered extensive teething problems. Most low-floor designs are intended for city streetcar or tramway applications and have neither the top speeds nor the ride quality suitable for U.S. and Canadian light rail operations and track standards. These restrictions can be overcome or reduced by hybrid or partial low-floor cars with up to 70% of the floor at the low height. This design results in a lower cost, higher top speed, and better ride quality on open track. The ends of the car and the driving (end) trucks can be of conventional construction and can retain component and maintenance commonality with conventional high-floor light rail equipment.

Steps inside the car provide access to the high-floor sections. Cars with 100% low-floor designs require the use of stub axles, hub motors, and other space-saving components. These items add to costs and have not yet been satisfactorily proven for high-speed use or on the lower quality of tracks typical of the United States and Canada, compared with Western Europe. As a result, the cars purchased in North America to date are of the partial low-floor type. Despite high costs and technical challenges, the substantial benefits of low-floor cars have made them a popular choice in Europe. Many European light rail systems have extensive on-street operation and recent new vehicle procurements have been predominantly low-floor. Manufacturers are rationalizing production to fewer, modular designs. Vehicles

---

[11] Certain low-floor designs ramp down the doorways to achieve a 13- to 14-in. (280- to 300-mm) floor height.

designed for on-street operation still remain less than ideal for typical U.S. and Canadian light rail systems with their extensive open, segregated trackage.

Mini-High Platforms

The most common wheelchair loading arrangement.

The most common wheelchair access method to high-floor light rail cars are *mini-high* or *high-range* platforms that provide level loading to the accessible door of the train. This method is mechanically simple and often uses a folding bridgeplate, manually lowered by the train operator, to provide a path over the stepwell between the platform edge and vehicle floor. The mini-high platform is reached by a ramp or, where space limitations require, a small lift. A canopy is sometimes provided over the ramp. In Sacramento, one of the pioneers of mini-high platforms, these lifts are passenger-operated and the boarding passenger must be on the mini-high platform for the train operator to board them. The Sacramento system handles about 1,200 wheelchairs and five times as many strollers per month on the mini-high platforms. Mini-high platforms also have been adopted for the light rail lines in Baltimore, Denver, and Salt Lake City, and for Cleveland's Waterfront Line. Exhibit 5-33 provides examples of mini-high platforms used in North America.

Exhibit 5-33
Mini-High Platforms

(a) Sacramento

(b) Denver

(c) San Francisco

(d) Baltimore

Second train stops for mini-high platforms.

The San Francisco Municipal Railway has also installed mini-high platforms at key locations on its surface light rail lines.[12] The cars must make a special stop to board and alight passengers using the mini-high platforms, as the moveable steps on the car must be raised and the center door aligned with the platform in order for level loading to take place. The steps are usually raised before the car has come to a stop. An elastic gap filler is used between the platform edge and car doorway. No bridge plate is needed and the train operator does not have to leave the cab. This arrangement, aside from the need for a second stop, is very efficient, with the time required for a passenger movement being as low as 10 seconds.

---

[12] Muni's historic streetcar fleet also requires a second stop at mini-high platforms because the mini-high platform ramps block the doors of the relatively short streetcars. (See Exhibit 5-33c.)

Profiled platform as an alternative to mini-high platforms.

An alternative to the mini-high platform is the Manchester-style profiled platform, shown in Exhibit 5-34. This platform has an intermediate height and is profiled up to a section that is level with one doorway for wheelchair access. Maximum platform slopes are shown in Exhibit 5-35.

Exhibit 5-34
Profiled Light Rail Platform Providing for One Accessible Door(R15)

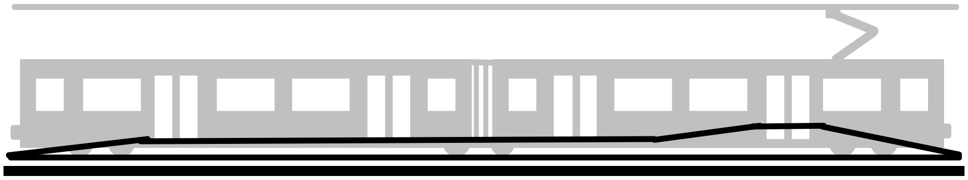


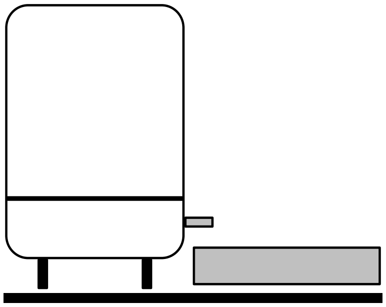
Exhibit 5-35
ADA Maximum Platform Slopes

Maximum Rise		Maximum Slope	
Rise ≤ 3 in.	Rise ≤ 7.5 cm	1:4	14.04°
3 in. < Rise ≤ 6 in.	7.5 cm < Rise ≤ 15 cm	1:6	9.46°
6 in. < Rise ≤ 9 in.	15 cm < Rise ≤ 22.5 cm	1:8	7.13°
Rise > 9 in.	Rise > 22.5 cm	1:12	4.76°

Folding steps and profiled platforms.

Most of the platform is only slightly higher than a sidewalk. Where the street arrangement permits, the profiled platform can be raised so that its mid-section—taking up most of the length—is raised one step, providing single-step entry to most doors. Alternatively, cars can have a slide or fold-out step as shown in Exhibit 5-36.

Exhibit 5-36
Profiled Light Rail Platform with Slide-Out or Fold-Down Step(R15)



Car-Mounted Lifts

Car-mounted lifts, illustrated in Exhibit 5-37, were introduced on the San Diego Trolley, one of the first light rail transit systems to be wheelchair accessible. In San Diego, lifts are mounted in the cars so that the first door on the right side of every train is lift-equipped. When not in use, the lift is stored in a vertical position that blocks the doorway from use by other passengers. While the lift model used initially was prone to failure, the current installation is reliable with a failure rate of about 1 in 400 operations.[13] The Kenosha, Wisconsin, vintage trolleys use a car-mounted lift that folds flat against the side of the door when not in use, which allows other passengers to use the door when the lift is not in use. Trains used on New Orleans' Waterfront and Canal Street lines use car-mounted lifts located at a high-level door not used by other passengers.

Dwell times with car mounted lifts.

Boarding and alighting times with the car-mounted lifts are around 1 minute for each passenger movement. However, the need for the train operator to leave the cab to operate the lift adds to the time required and can mean the total station dwell time extends to 1.5 to 2 minutes when the lift is used. If the operator is required to assist in securing the wheelchair, the dwell can be further extended.

---

[13] Based on San Diego Trolley data for May 1994. Out of 1,069 lift passengers carried (2,138 lift cycles) only 6 failures were recorded—giving a failure rate of 0.28%.

(a) San Diego (b) Kenosha, Wisconsin (c) New Orleans

Exhibit 5-37
Car-Mounted Lifts

Platform-Mounted Lifts

Platform mounted lifts are used on the San Jose light rail system.[14] They offer advantages over car-mounted lifts in that all car doors are left available for other passengers when the lift is not required, the lift is not subject to car vibration, and the failure of a lift need not remove a car from service. Disadvantages include increased susceptibility to vandalism and an increase in the distance that the train operator must walk to operate the lift.

Dwell times with wayside lifts.

Wheelchair loading is slow in San Jose because of the wayside lift arrangement. The lift is stored vertically in an enclosed housing at the front of each platform. To operate the lift, the train operator must raise sliding steel doors on each side of the lift housing, lower the car side of the lift to floor level, lower the platform side to ground level, have the passenger board the lift, raise the lift and board the passenger, store the lift, and secure the housing. This procedure takes 2 to 3 minutes, giving a total train delay (including loading and unloading) of 4 to 6 minutes per passenger requiring the lift. These delays can easily consume the train's scheduled terminal recovery time. In 1995, an average of 25 wheelchairs and scooters were carried each weekday on the San Jose light rail line, but this increased to as many as 50 per day for special events.

Portland removed its platform lifts in 1997 after adding a low-floor car to each train. Under normal circumstances, the Portland lift, illustrated in Exhibit 5-38(b), was at ground level ready to receive boarding passengers. The presence of the passenger on the lift signaled the passenger's intention to board to the train operator. The train operator then aligned the first door of the train with the lift and boarded the passenger. The car's steps were bridged by a folding plate on the lift. This configuration speeded the use of the lift but did not prevent it from having an effect on punctuality, as the time for each mobility device movement averaged 1 minute 50 seconds.

---

[14] A few streetcar stops on Market Street in San Francisco also use curbside lifts, due to space limitations preventing installation of a mini-high platform.

Exhibit 5-38
Platform-Mounted Lifts

(a) San Jose (b) Portland, Oregon (before low-floor cars)

Commuter Rail

Bridgeplates are often used to span the gap between platform and train.

Commuter rail systems use many of the same kinds of access methods as light rail systems. The main difference is that these methods are often supplemented with a bridgeplate to span the gap between platform and train when a form of level boarding is used. The vertical and/or horizontal gap between the train and platform for "level" boarding typically is greater for commuter rail than for light rail. The bridgeplate can be portable or built into the train.

High-level platforms are usually not possible on lines shared with freight trains.

High-level platforms provide the easiest and fastest boarding for all passengers. The Electric Division of Chicago's Metra, MTA-Long Island Rail Road, MTA-Metro North Railroad, and Vancouver's West Coast Express are among the commuter rail lines that use high-level platforms. However, it is often not possible to provide high-level platforms on lines that are shared with freight trains, as freight wide-loads will need to be accommodated.(R11)

Mini-high platforms, combined with a bridgeplate, are a frequently used option on lines with low-level platforms. Toronto, Los Angeles, San Diego, and Tri-Rail in South Florida are examples of systems using this method. Platform lifts are used by CalTrain in the San Francisco Bay Area and at some New Jersey Transit commuter rail stations. Metra's diesel-powered lines in Chicago provide cars with on-board lifts. Exhibit 5-39 provides examples of commuter rail wheelchair loading treatments.

Exhibit 5-39
Commuter Rail Wheelchair Loading Examples

(a) San Diego (b) Tracy, California

Ropeway Modes

Inclined Planes

Because each inclined plane in North America is unique, so are the means of providing access; due to their age, many inclined planes are inaccessible as a result of the vehicle and/or station design.

Access is much easier to provide when the car floor is level, rather than when the seats are tiered (as is the case on most inclined planes). Johnstown, Pennsylvania, has level loading from each end. The Horseshoe Curve funicular, near Altoona, Pennsylvania, provides level loading from each side of the car.

Several access methods have been developed for tiered cars. The funicular at the Industry Hills Resort in California was designed to carry golf carts and has a series of terraced ramps leading to each car tier. Pittsburgh's Monongahela Incline has an elevator inside the lower station to take wheelchairs to the top tier loading area; wheelchairs exit on the level at the top station. Los Angeles' Angels Flight (closed as of 2001) used an inclined platform lift (like those used on stairways) to bring wheelchairs to the top car level; wheelchairs exited on the level at the top station.

Aerial Ropeways

In the past, gondola access required that the entire system be brought to a stop to load and unload wheelchairs because boarding normally occurred as the carriers circulated through the station while moving (typically at 50 ft/min or 15 m/min) and there was a vertical gap between the cabin floor and the platform that needed to be overcome. Newer designs provide a trench in the platform floor that the gondola passes through, allowing level loading. Clutching equipment allows an individual carrier to be brought to a near-stop to load wheelchairs, without stopping the entire system. Aerial tramways provide level boarding from the platform into the cabin; however, elevators or ramps may be needed to access the platform.

SYSTEM DESIGN

Although the procedures in Part 5 are focused on normal operating conditions, it is prudent to consider the impacts of abnormal conditions. Three areas in particular to consider are (1) the potential impacts of disabled trains on system operation, (2) routine track maintenance, and (3) handling special event crowds.

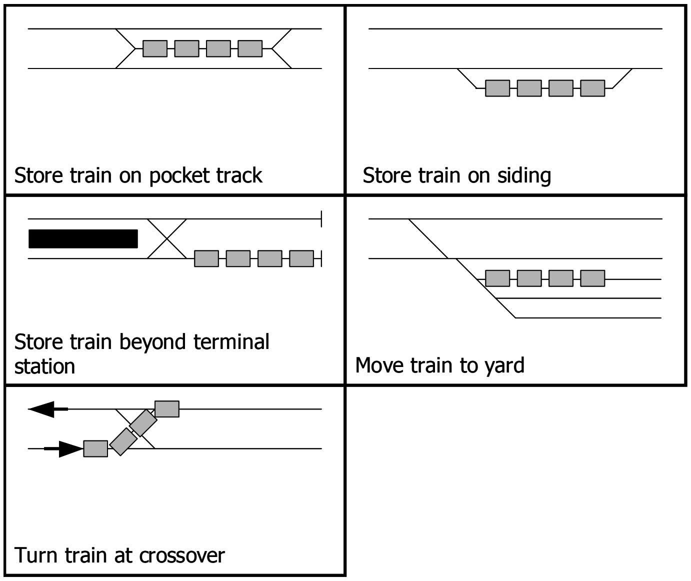
Disabled Trains

When a train needs to be taken out of service, it is desirable to get it off the main line as quickly as possible. In a typical two-track operation, this means moving it to a place where it can be temporarily stored, moving it into a yard, or turning it back on the opposite track. The train will likely not be able to move at its normal speed, which means that the trains following it will catch up to it and be delayed. The longer the disabled train remains on the line, the more trains will be delayed. Because the disabled train, and the ones delayed behind it, will occupy signal blocks for longer periods of time, train headways will increase and line capacity will decrease. The longer headways mean that more passengers will accumulate on platforms between trains, potentially leading to platform crowding. In addition, passengers on a disabled train will need to be off-loaded; the station where they off-load will have passengers of its own on the platform waiting to board the train, and the platform should be designed to accommodate all of those passengers. Finally, when a system operates close to capacity, any significant delay will use up a train's terminal recovery time, resulting in potential delays later on in the reverse direction. As can be imagined, a disabled train can quickly cause delays and crowding that ripple along the line, and which may take a long time to clear up.

Crossovers can be used to short-turn trains to help recover from delays.

Exhibit 5-40 shows examples of ways that a rail system can be designed to accommodate disabled trains. Trains can be stored off the main line in a pocket track accessible to both main tracks (allowing the train to be reversed later if needed), on a siding accessible to only one direction, or in a storage track beyond a terminal station. If a yard is convenient to the train's location, it can be removed from the line altogether. Finally, a train can be turned back at a crossover—either to get to a storage track or to move it in a direction where it will delay fewer people. Crossovers can also be used to short-turn trains in advance of their scheduled terminus—this can help to fill a gap in the sequence of trains in the reverse direction, helping to reduce the time needed to recover from the delay, at the expense of further delaying passengers traveling beyond the station where the train makes its short turn.

Exhibit 5-40
System Design Features for Accommodating Disabled Trains



Guidance on estimating line capacity with a disabled train.

The spacing of storage tracks and crossovers requires balancing initial capital costs when constructing the system with the amount of delay a system is willing to tolerate when a train breaks down. Physical constraints, particularly when tracks are elevated or underground, must also be considered. Train headways and the resulting line capacity as a result of a disabled train can be estimated from agency experience, or by using an assumed disabled train operating speed, the resulting block traversal time, and increased dwell times for subsequent trains resulting from the longer headways and greater passenger accumulations in stations.

Track Maintenance

Many rail systems do not operate 24 hours a day, in order to provide a window of time to conduct routine track maintenance when the tracks are out of service (e.g., from 1 a.m. to 4 a.m.). However, some projects may require more time than this window allows, or an agency may have a need for 24-hour operation. An alternative means of moving passengers must be developed when a track needs to be taken out of service during regular service hours.

Single-track rail operation.

If passenger demand is low, the remaining in-service track can be used in single-track operation to move trains around the work area if signaling is provided for the wrong-side direction. However, the capacity of both directions will be greatly reduced. The single-track capacity procedures in Chapter 8 can be used in these circumstances, given a known distance between crossovers.

Bus bridges.

If single-track operation does not provide sufficient capacity to meet passenger demand, another alternative is to provide a bus bridge. In this situation, trains are turned back on either side of the work area, and passengers transfer to buses to meet a train on the other side of the work area or to reach a destination station within the work area.

Use of express tracks.

MTA-New York City Transit is able to take advantage of the third and fourth tracks that exist on many of its major lines to close tracks for maintenance and maintain two-direction operations.

Special Events

Special events—such as sporting events, concerts, and community festivals—can generate very large passenger demands during a short span of time. While passengers are willing to tolerate longer delays and greater levels of crowding under these circumstances than they might otherwise, system design should still consider any special train storage needs in order to make sure that crowds can be transported away from the event site in a reasonable period of time. San Diego, for example, designed its Qualcomm Stadium station with storage for 18 cars—enough room for five 3- to 4-car trains. For Super Bowl XXXII, San Diego closed the Mission San Diego station, a terminal station one station east of the stadium, which allowed storage on the main tracks for twenty-one 3- to 4-car trains. Light rail was able to transport 29,800 passengers—30% of the Super Bowl's attendance—within 2 hours following the end of the game.(R22)

Train storage needs.

Crowd management.

Crowd management is another issue requiring consideration. Security personnel are usually needed to keep passengers off tracks and to limit platform access to avoid overcrowding problems. Providing pre-sold return tickets and/or providing mobile ticket sales outlets minimizes crowds and delays at ticket machines. Platforms should be sized to accommodate expected special event crowds, and additional temporary space may be required to queue passengers when there are constraints on platform space. For example, Muni's 2nd & King light rail station, adjacent to San Francisco's baseball stadium, is located in a street median and has little platform room for large event crowds. Instead, passengers are queued using portable fences in the adjacent closed-off street following games, and are allowed onto the platform when a train arrives. San Diego's Qualcomm Stadium station has three platforms, allowing trains to be loaded from both sides, minimizing dwell time.

Demand management.

Demand management measures can be used to spread out passenger demand following sporting events, and thus minimize platform crowding. During the sold-out first season at Safeco Field, for example, the Seattle Mariners provided post-game trivia contests and a ceremonial closing of the stadium's retractable roof to encourage a portion of the fans to linger after the game.

This page is intentionally blank.

CHAPTER 6. PLANNING APPLICATIONS

INTRODUCTION

Growth and Capacity

"Capacity," as defined in this manual, is the maximum achievable capacity when the system is saturated and provided with a full complement of rolling stock. It is not the capacity that a rail transit line will provide on opening day or reach after a decade. Instead, it is the long-range design capacity after decades of growth.

A difficult question is what ultimate capacity a rail transit system should be designed for. Certain transportation models can predict passenger demand for several decades ahead. However predictions beyond 10 to 15 years are of decreasing accuracy—particularly in areas without an existing rail transit system or good transit usage. The resulting uncertainty makes the modal split component of the model difficult to calibrate.

Design for mature capacity.

When modeling does not provide a reasonable or believable answer, it is possible to fall back on an old rail transit rule-of-thumb, namely, to design for three times the initial mature capacity. Mature capacity occurs 5 to 10 years after a system opens, when extensions and branches are complete, modal interchanges—bus feeders and park-and-ride—have matured, and some of the rail transit-initiated land-use changes, including development and densification around stations, have occurred.

The line capacity determined from this manual can be used to establish the train and station platform lengths and the type of train control that will allow this long-term demand to be met—whether the demand is obtained from a long-range model or by rule-of-thumb. This long-term demand may be 30 to 50 years ahead. If this suggests that 600-ft (180-m) trains and platforms will be required, it does not mean they have to be built initially. Stations can be designed to have platforms expanded in the future. However, underground stations should have the full length cavity excavated—otherwise it can be difficult and expensive to extend platforms while the rail line is operating.

Planning Assumptions

With the relative uniformity in the performance of electric multiple-unit trains in urban rail transit service, a simple procedure can be applied to estimate a range of achievable peak hour passenger capacities for grade-separated lines at their maximum capacity.

The planning procedures require two main inputs: (1) train control system and (2) train length

The necessary choices are only two, the type of train control system and the train length. The range is provided by assigning (1) a range centered around a typical dwell time plus operating margin and (2) a small loading range centered around the recommended peak hour average space per passenger of 5.4 ft^2 (0.5 m^2). As this is a peak hour average, no peak hour factor is required.

Key assumptions are:
- Flying junctions or no junctions
- No turnback constraints
- The sum of dwell time and operating margin at the critical station is no more than 70 s
- No speed-restrictive curves or grades on the critical station approach
- Adequate supply of rolling stock

This procedure assumes system and vehicle characteristics that are close to the industry norms listed in Exhibit 5-41. It also assumes that there are no speed-restrictive curves or grades over 2% on the approach to the station with the longest dwell time, and that the power supply voltage is regulated within 15% of specifications. Finally, it assumes an adequate supply of rolling stock, and a system design that ensures that junctions (including multiple line merges) and turnbacks will not be the capacity constraint.

If any of these assumptions are not met, then the planning procedures should be used only as guidelines and the detailed procedures in the following chapters should be used to determine capacity.

Exhibit 5-41
Rail Transit Performance Assumptions for Planning Applications(R15)

Description	Default
Grade into headway critical station	< ± 2%
Distance from front of train to station exit block	<35 ft (<10 m)
% service braking rate	75%
Time for overspeed governor to operate	3.0 s
Time lost to braking jerk limitation	0.5 s
Service acceleration rate	4.3 ft/s^2 (1.3 m/s^2)
Service deceleration rate	4.3 ft/s^2 (1.3 m/s^2)
Brake system reaction time	1.5 s
Maximum line velocity	60 mph (100 km/h)
Dwell time	35-45 s
Operating margin	20-25 s
Line voltage as % of normal	>85%
Moving block safety distance	165 ft (50 m)
Average peak hour passenger loading level—light rail	1.5 p/ft length (5 p/m)
Average peak hour passenger loading level—heavy rail	1.8 p/ft length (6 p/m)
Car length—light rail	100 ft (30 m)
Car length—heavy rail	80 ft (25 m)

Capacity Analysis Categories

For capacity analysis, heavy rail, light rail, commuter rail, AGT, and ropeway modes are grouped into unique categories based on alignment, equipment, train control, and operating practices. Each of these categories has its own detailed procedures within the subsequent chapters. Because of the uniformity of equipment used by heavy rail, light rail, and commuter rail using electric multiple-unit vehicles, default values can be applied to the detailed procedures for these modes to develop planning-level capacity estimates. Planning-level capacities for ropeway modes are also provided in this chapter.

Commuter rail that uses diesel locomotives or shares tracks with other types of trains is not covered by the planning-level procedures, because of the wide range of locomotive performance, and because of the significant influence of location-specific characteristics, such as infrastructure design and the mix and volume of other trains. As an alternative, Appendix B can be consulted to identify the number of trains per hour per direction currently operated by North American commuter rail systems during the peak hour.

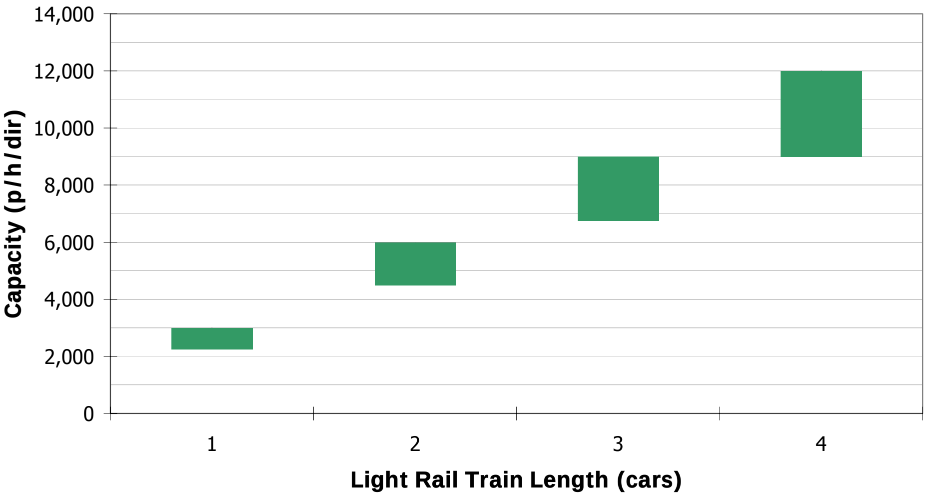
AGT uses proprietary designs and widely varying vehicle sizes. In addition, the use of off-line stations on certain AGT systems is unique to this mode and requires separate examination. Consequently, no planning-level procedures are provided. However, Chapter 10 can be consulted for detailed methods on calculating AGT capacity.

GRADE-SEPARATED RAIL CAPACITY

Systems Designed for Economy

Systems that are designed economically for the minimum *planned* train headway, rather than the minimum *possible* train headway—typically, light rail systems—will design the signal and power system to accommodate this minimum planned headway. In these cases, line capacity is directly related to the signaling constraint built into the system (assuming no significant single-track sections), and person capacity is then directly related to the line capacity and the train length. Exhibit 5-42 shows the hourly directional person capacity of light rail systems designed for a particular minimum planned headway and a particular maximum train length.

Exhibit 5-42
Capacity of Light Rail Systems Designed for Minimum Planned Headway



NOTE: Signal system design headway ranges from 3 minutes (upper bound) to 4 minutes (lower bound).

This exhibit assumes no significant (longer than 0.25 mi or 400 m) single-track sections.

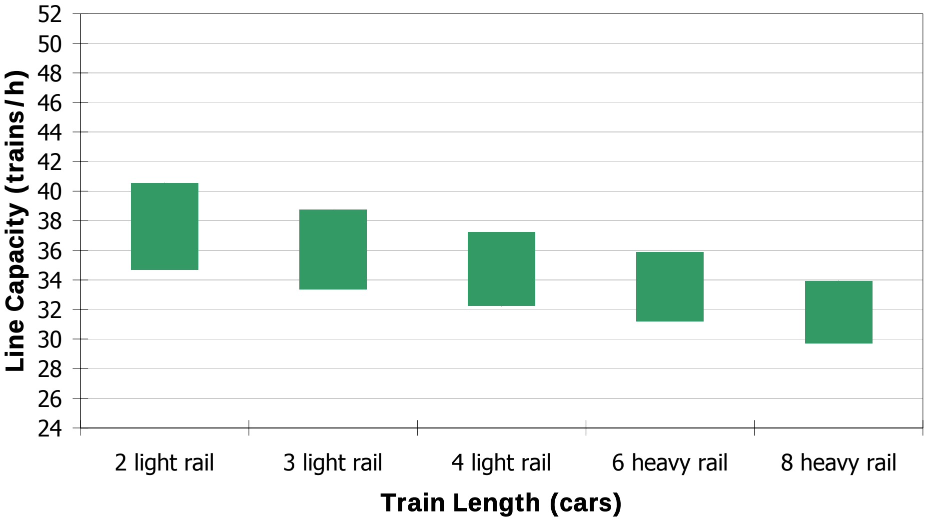
Systems Designed for Maximum Capacity

As described in Chapter 2, three types of signaling systems are possible: fixed-block, cab, and moving-block. New systems that are designed for maximum capacity would not use the more limited and more expensive (due to the number of signal installations required) three-aspect fixed-block signaling system. A fixed-block system may be used for systems designed for less than maximum throughput, in which case Exhibit 5-42 should be used. Consequently, the choice of train control system is limited to cab and moving-block signaling. Exhibits 5-43 through 5-46 give line capacity and person capacity for both cab and moving-block signaling systems, based on the assumptions given in Exhibit 5-41.

A three-aspect fixed-block system typically can support no more than 30 trains per hour—and less if a line has flat junctions or a station with extended dwell times.

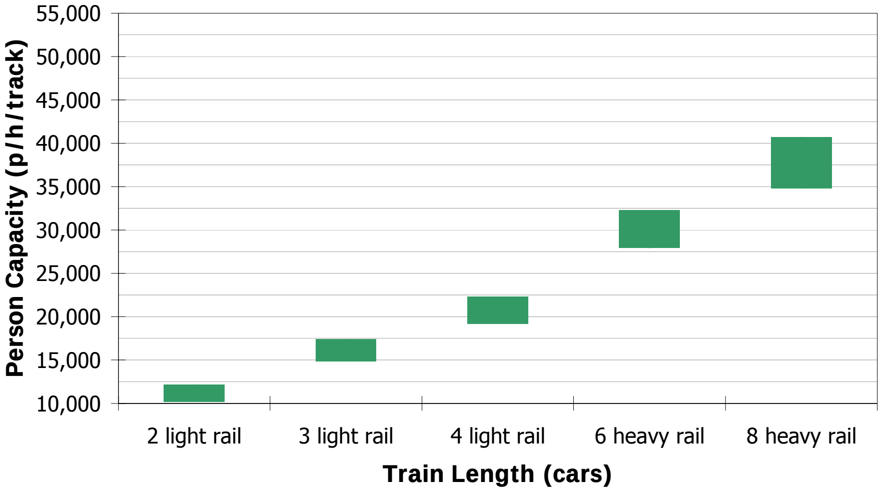
Note that with the exception of San Francisco's Muni Metro, signaled grade-separated light rail lines are rarely provided with the minimum headway capabilities represented by the capacity ranges in Exhibit 5-43 and Exhibit 5-45. Also, operating experience in North America suggests a maximum of 30 trains per hour for conventional rapid transit lines. It is apparent from the observed operating experience in New York and Washington that higher dwell times at critical stations prevent the achievement of capacities greater than 30 trains per hour.

Exhibit 5-43
Grade-Separated Line Capacity—Cab Signaling



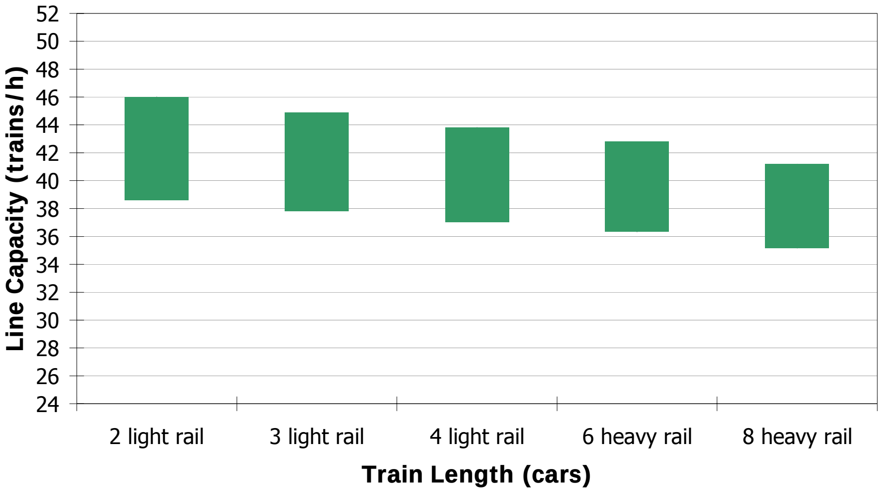
NOTE: Combination of dwell time and operating margin ranges from 55 s (upper bound) to 70 s (lower bound).

Exhibit 5-44
Grade-Separated Person Capacity—Cab Signaling



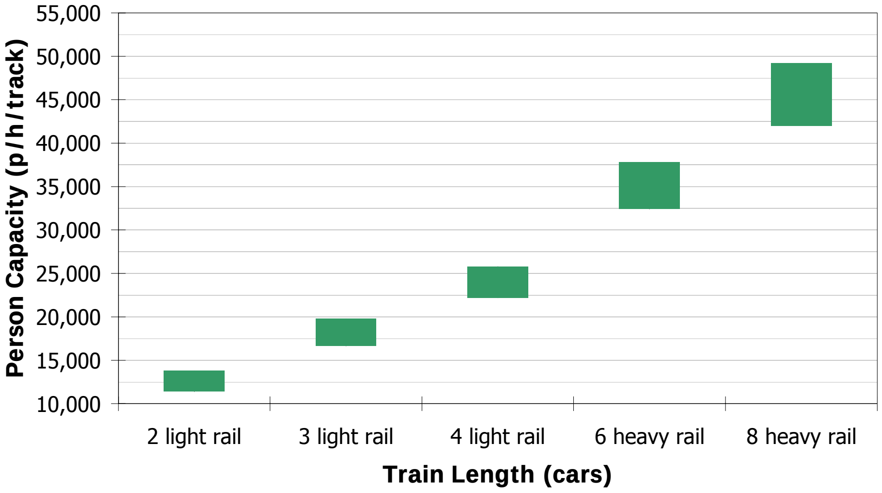
NOTE: Combination of dwell time and operating margin ranges from 55 s (upper bound) to 70 s (lower bound).

Exhibit 5-45
Grade-Separated Line Capacity—Moving-Block Signaling



NOTE: Combination of dwell time and operating margin ranges from 55 s (upper bound) to 70 s (lower bound).

Exhibit 5-46
Grade-Separated Person Capacity—Moving-Block Signaling



NOTE: Combination of dwell time and operating margin ranges from 55 s (upper bound) to 70 s (lower bound).

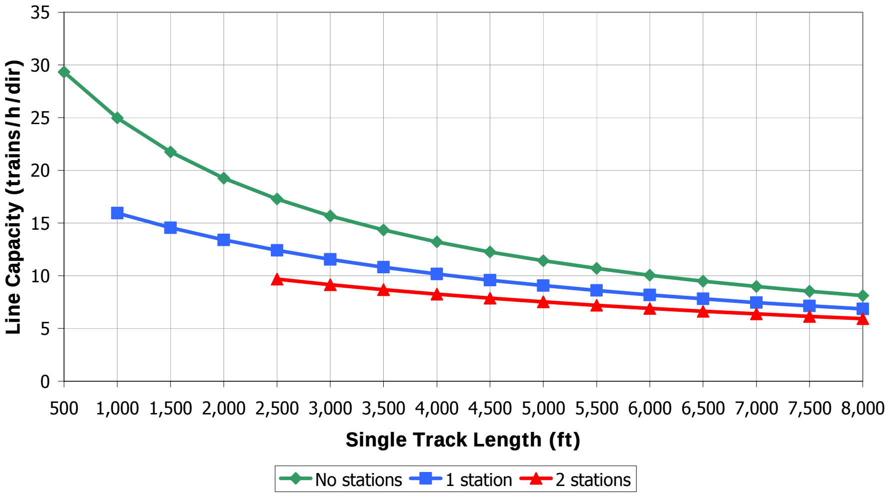
LIGHT RAIL CAPACITY

Light rail can operate in a variety of rights-of-way, each of which can potentially control capacity. The first of these types, grade-separated, was covered in the previous section. The remaining types—single-track, exclusive lane, and private right-of-way with grade crossings—are covered in this section. Definitions and examples of each right-of-way type can be found in Chapter 8. The lowest capacity of the various right-of-way types along the line will control the overall capacity.

Single Track

Single-track sections with two-way operation will typically be the capacity constraint when they are present. Exhibit 5-47 provides the directional line capacity of single-track sections of various lengths, with and without stations within the single-track section. Exhibit 5-48 provides the directional person capacity. The exhibits are for 2-car trains. The line capacity for longer trains will be slightly lower for short single-track sections with no stations (approximately 5% lower for a 650-ft [200-m] long section), but nearly the same for long sections, or when stops are made within the single-track section.

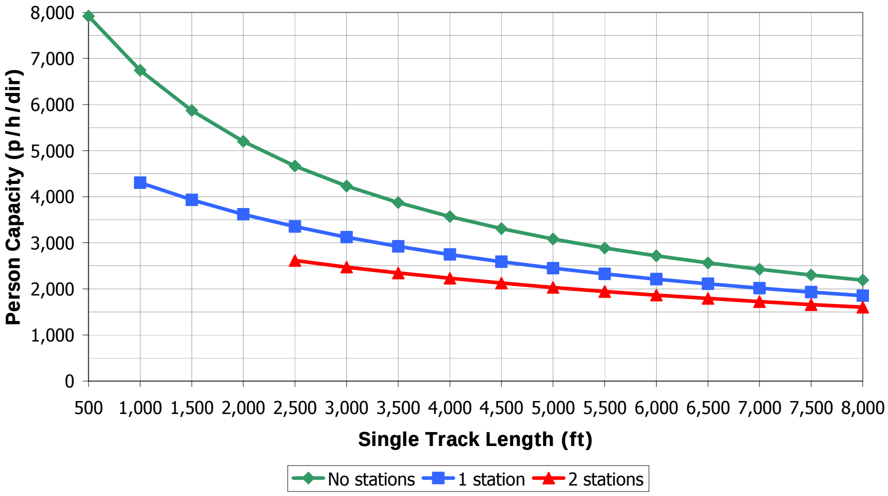
Exhibit 5-47
Single-Track Line Capacity—Two-Car Light Rail Trains



NOTE: Assumes 35-mph speed limit, 180-ft train length, 20-s dwell time, and 20-s operating margin.

An alternative figure using metric units appears in Appendix A.

Exhibit 5-48
Single-Track Person Capacity—Two-Car Light Rail Trains



NOTE: Assumes 35-mph speed limit, 180-ft train length, 20-s dwell time, and 20-s operating margin.

An alternative figure using metric units appears in Appendix A.

Exclusive Lane Operation

The minimum sustainable headway in exclusive lane on-street operations is typically twice the longest traffic signal cycle length. When cycle lengths are long and no signal priority is provided for light rail, exclusive lane operation may constrain capacity. Exhibit 5-49 provides the line capacity for a variety of signal cycle lengths, and Exhibit 5-50 provides the corresponding person capacity. These exhibits are not applicable to streetcar operation where more than one streetcar can occupy a station or stop at a time or where streetcars operate in mixed traffic.

Exhibit 5-49
Light Rail Line Capacity—Exclusive Lane Operation

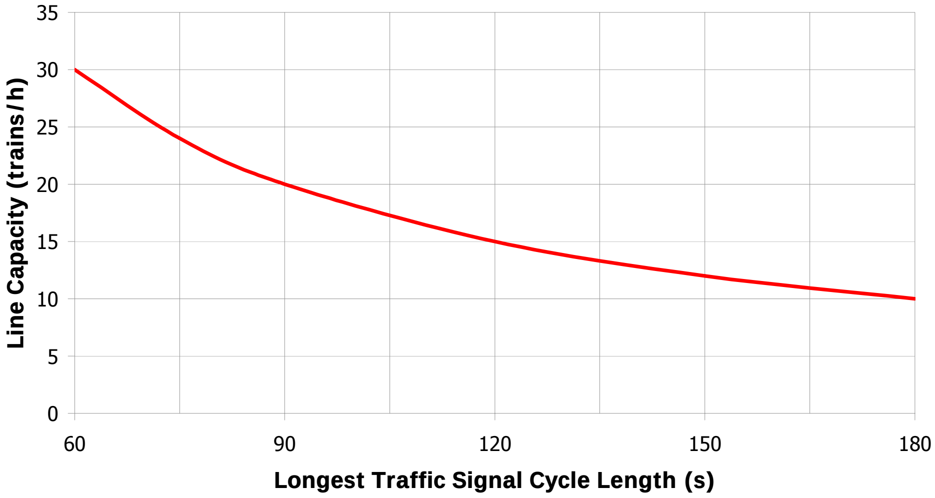
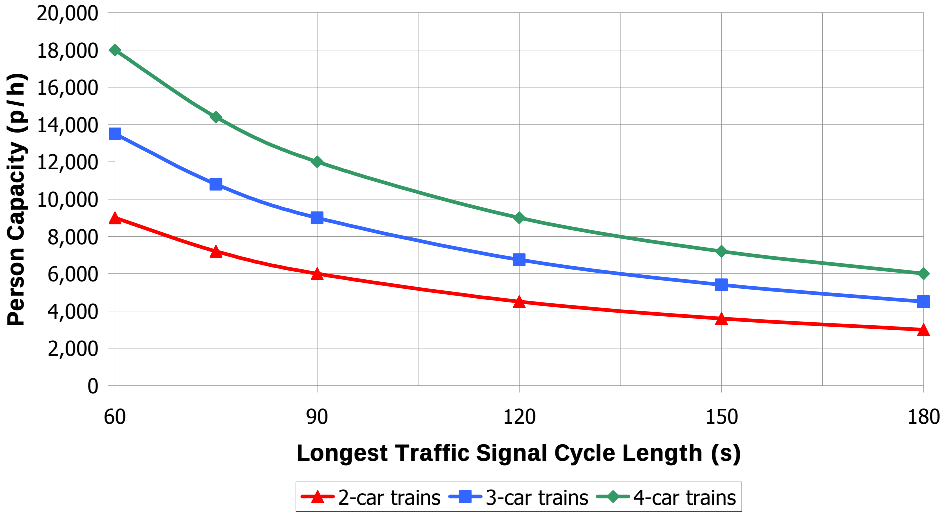


Exhibit 5-50
Light Rail Person Capacity—Exclusive Lane Operation

Exclusive lane, on-street operation is unlikely to be the capacity constraint when traffic signal cycle lengths are relatively short.



Private Right-of-Way with Grade Crossings

This category includes railroad-type operations, with street crossings controlled by gates, and operations within street medians, with street crossings controlled by traffic signals. When trains have full pre-emption of traffic (e.g., at gated crossings, or when full signal pre-emption is provided at traffic signals), use the grade-separated capacity charts. Additional dwell time may need to be allowed when station exits are located near grade crossings and pre-emption of the crossing is not allowed until passenger movements have ceased and the train is ready to leave the station. When trains do not have full pre-emption of traffic, use the exclusive-lane charts above.

COMMUTER RAIL CAPACITY

The capacity of commuter rail systems operated with electric multiple-unit trains on exclusive rights-of-way can be determined using the procedures for grade-separated systems given earlier in this chapter. The capacity of other types of commuter rail systems—those using diesel locomotives and/or sharing tracks with other types of trains—is best determined using simulation. The factors that prevent the development of either planning-level or detailed capacity methodologies for the latter types of commuter rail are discussed in Chapter 9. Appendix B can be consulted to find out the number of trains currently being operated by various North American commuter rail systems.

Commuter rail capacity often is best determined using simulation.

AUTOMATED GUIDEWAY TRANSIT CAPACITY

AGT systems often operate with electrically powered vehicles and always on exclusive rights-of-way. However, there are a number of different proprietary designs for AGT systems, each with its own vehicle performance characteristics, minimum train separations, and vehicle sizes. These variations prevent the description of a “typical” AGT system, and therefore no planning-level methodology is provided. Consult Chapter 10 for detailed capacity procedures for AGT.

No planning method is provided for AGT due to wide variations in system characteristics.

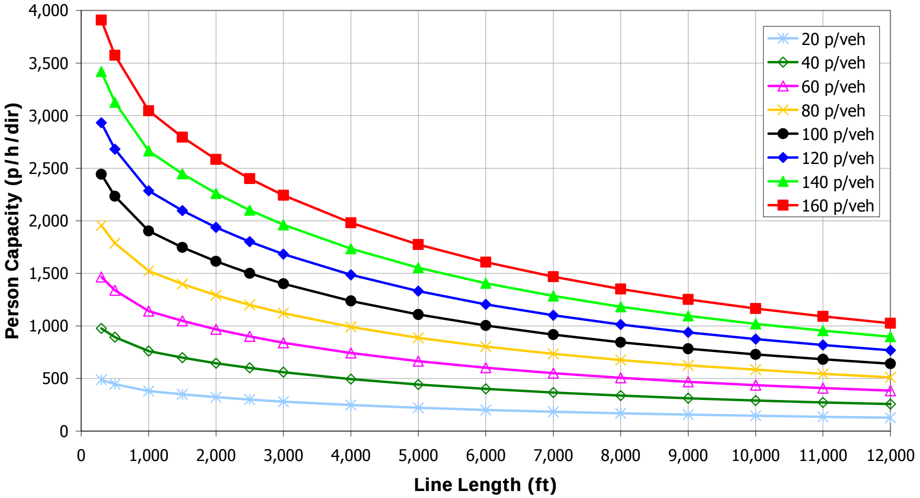
ROPEWAY CAPACITY

Ropeway systems can be classified into two categories for capacity analysis: (1) reversible systems, where one or two vehicles shuttle back and forth along a line, and (2) continuously circulating systems, where vehicles or cabins circulate around a loop. Reversible modes include aerial tramways and inclined planes. Circulating modes include gondolas and cable-hauled automated people movers.

Reversible System Capacity

The line capacity of a reversible system is dependent mainly on the length of the line and the speed at which a vehicle (train or cabin) can move from one end of the line to the other. Acceleration and deceleration delays and station dwell time are also major components of line capacity for shorter systems. Exhibit 5-51 provides the person capacity of reversible systems of various lengths and vehicle sizes, assuming two-vehicle operation and line speeds toward the upper end of modern aerial tramways and inclined planes.

Exhibit 5-51
Reversible Ropeway Person Capacity



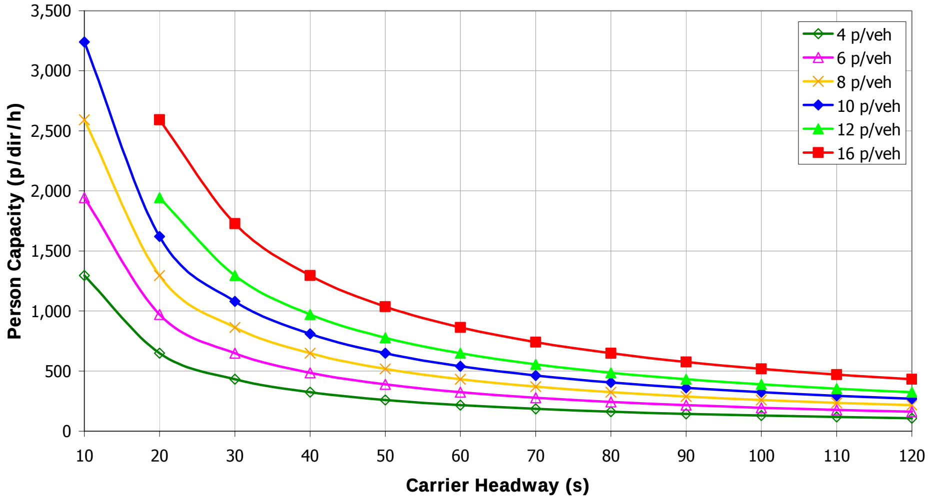
NOTE: Assumes 33 ft/s line speed, 0.66 ft/s^2 acceleration, two-vehicle operation, no intermediate stations, 90-s dwell time, and 0.90 PHF.

An alternative figure using metric units appears in Appendix A.

Continuously Circulating System Capacity

The line capacity of a continuously circulating system is dependent solely on the spacing of carriers or vehicles on the line. Person capacity, therefore, is simply a function of line capacity, vehicle size, and passenger arrival characteristics. Exhibit 5-52 provides the person capacity of detachable-grip gondola systems with different cabin sizes and headways.

Exhibit 5-52
Gondola Person Capacity



NOTE: Assumes a peak hour factor (PHF) of 0.90.

CHAPTER 7. GRADE-SEPARATED SYSTEMS

INTRODUCTION

Earlier chapters developed the methodologies for each of the components affecting rail transit capacity. Chapter 6 provided planning-level estimates of rail capacity. Chapter 7 now brings the prior methodologies together by developing detailed capacity calculations for the principal category of grade-separated rail, which accounts for almost 80% of rail transit passenger trips in North America.

Grade-separated rail defined.

Grade-separated rail transit is operated by electrically propelled multiple-unit trains on fully segregated, signaled, double-track right-of-way. This category encompasses all heavy rail transit, all AGT, some of the heaviest-volume commuter rail lines, and sections of most light rail systems.

Light rail transit.

Light rail transit operates in a variety of rights-of-way, each of which has specific line capacities. Chapter 8 contains the procedures to determine capacity for the sections of light rail that are not double-track grade-separated sections. Single-track sections, when present, are usually the capacity limitation. However, these are rare and line capacity is usually controlled by the signaling throughput of grade-separated sections—determined by the procedures of this chapter.

This control on line capacity is due to two possible reasons. First, several light rail systems converge surface routes into a signaled grade-separated section operating at, or close to, capacity. Second, other less busy systems have the signaled grade-separated sections designed economically, rather than for maximum train throughput. Typically, this signaling is designed for 3- to 4-minute headways, rather than minimum 2-minute headways, and will usually prove to be more restrictive than the headway limitations of on-street operation, with or without varying forms of traffic signal priority. However, signaled grade-separated sections may not always be the prime headway limitation, and Chapter 8 explains how to calculate and determine the weak link in the capacity chain for light rail.

Rail capacity is determined by the weak link in the capacity chain—whether dwell time, turnback time, junction constraints, signaling type, or right-of-way type.

Determining the weak link in the capacity chain is also the starting point in this chapter with respect to grade-separated rail transit.

DETERMINING THE WEAKEST CAPACITY LINK

Chapter 2 developed the methodology for the train control system maximum throughput in two special situations: junctions and turnbacks.

Junctions and turnbacks.

In new grade-separated rail systems, capacity should not be limited by junctions or turnbacks. Both can be designed to avoid constraints. Chapter 2 shows that a flat junction can handle 650-ft (200-m) trains with standard rail transit performance, under fixed-block train control, on non-interference headways down to 102 seconds plus an operating margin. The equivalent time for the same length trains with a moving-block signaling system is 63 seconds plus an operating margin. Chapter 2 recommends that junctions controlled by a three-aspect signaling system should be grade-separated where trains combine to a joint headway below 3 minutes. Only where there are flat junctions with headways for their respective train control systems below these levels, plus a 20-second operating margin, is it necessary to utilize Equation 5-5 to determine the junction throughput limitation.

Chapter 2 similarly shows that a two-track terminal station can turn 650-ft (200-m) trains every 120 seconds with a terminal time of 175 seconds—that is, the time required for passenger flows and for the driver to change ends on each train. Chapter 2 suggests a number of measures to maximize capacity. First, where passenger flows are heavy, dual-faced platforms can be provided. Second, where changing ends is a limitation, then crew set-backs should be used. Third, greater operational flexibility and improved failure management is obtainable by providing turn-back capability both ahead of and behind the station with a storage track for spare or out-of-service rolling stock. Fourth and finally, a three-track terminal station can handle exceptional passenger flows from trains on headways below 90 seconds.

On new systems, turnbacks can be disregarded as a capacity constraint unless economic circumstances or labor practices prevent an optimal terminal design. Only in such exceptional circumstances is it necessary—after determining the minimum headway from this chapter—to apply Equation 5-4 to ensure that adequate terminal time is provided to allow for the anticipated passenger flows and the train operator to change ends.

On older systems, terminal station design may be less than optimal and Equation 5-4 should be checked with the actual station cross-over geometry to ensure there is adequate terminal time. This calculation should then be cross-checked with actual field experience.

The close-in movement at the busiest station is commonly the weakest link.

In either case, a turn-back constraint is only likely if all trains use the terminal station. If peak-period short turns are operated such that only a proportion of trains use the terminal station, then a rail line's capacity limitation can be assumed to be the close-in movement at the busiest station.

GRADE-SEPARATED CAPACITY CALCULATION PROCEDURE

When junctions and turnbacks are not the capacity constraint, the combination of station close-in and dwell time will be the constraint. Should a junction or turnback appear to be the limitation on train throughput, then the first recourse is to consider design or operating practice changes that will remove or mitigate such limitations.

Constraints at the maximum load point station.

In all but the most exceptional situations, the limitation will be the close-in, dwell, and operating margin time at the maximum load point station. The capacity procedure requires that the following values be calculated:

1. The close-in time at the maximum load point station,
2. The dwell time at this station,
3. A suitable operating margin,
4. The peak 15-minute train passenger load, and
5. The peak hour factor to translate from the peak 15 minutes to peak hour.

A spreadsheet that implements the grade-separated capacity procedure is provided on the accompanying CD-ROM.

Consider using the planning graphs in Chapter 6 when input variables must be defaulted.

These values can be calculated manually or by using the spreadsheet provided on the accompanying CD-ROM. When there is uncertainty about these values—fully described in Chapters 3 through 5—or where several of the performance variables are unknown (e.g., the technology or specific vehicle has not been selected), then the use of this procedure is not recommended. The planning graphs found in Chapter 6 provide *generic achievable capacity ranges* with less effort and potentially as much accuracy as the complete method where one or more input factors will have to be estimated.

Step 1: Determining the Maximum Load Point Station

Traditionally, the maximum load point station is the principal downtown station, or the downtown station where two or more rail transit lines meet. However, this is not always the case. With increasingly dispersed urban travel patterns, some rail transit lines do not serve the downtown. Los Angeles' Green Line and extensions to Vancouver's SkyTrain are examples.

Ridership models.

A regional transportation model will usually produce ridership data by station, both ons and offs and direction of travel. Such data are usually for a 2-hour peak-period or single peak hour and rarely for the preferable 15-minute period. Depending on the number of zones and nodes in the model, data accuracy at the station level can be poor—particularly if there is more than one station in a zone. Nevertheless, this is often the sole source of individual station volumes, and without it selection of the maximum load point station requires an educated guess.

Step 2: Determining the Control System's Minimum Train Separation

This step develops the methodology for determining the minimum train separation with three types of train control systems, each providing progressively increased throughput:

1. Three-aspect fixed-block signaling system,
2. Multiple-command cab signaling, and
3. Moving-block signaling system.

Although the equations that follow appear long, the arithmetic is simple and can be implemented using basic functions in a spreadsheet. However, before going to this effort, check the availability of the required input parameters in Exhibit 5-53. Parameters can be adjusted for system specific values or left at their default value. Train length is the most important variable. If most parameters are left at their default values, it would be simplest to refer to Exhibit 5-54, which shows the minimum train control separation against train length for the three types of train control system.

Exhibit 5-53
Minimum Train Control Separation Parameters(R15)

Default Value	Term	Description
calculated	t_{cs}	train control separation in seconds
650 ft, 200 m	L	longest train length
35 ft, 10 m	d_{eb}	distance from the front of stopped train to start of station exit block in feet or meters
calculated	v_a	station approach speed in ft/s or m/s
88 ft/s, 27.8 m/s	v_{max}	maximum line speed (88 ft/s = 60 mph , 27.8 m/s=100 km/h)
75%	f_{br}	braking safety factor—worst-case service braking is f_{br}% of specified normal rate—typically 75%
2.4–three-aspect, 1.2–cab, 1.0—moving block	b	separation safety factor—equivalent to number of braking distances (surrogate for blocks) that separate trains
3.0 s	t_{os}	time for overspeed governor to operate on automatic systems—to be replaced with driver sighting and reaction times on manual systems
0.5 s	t_{jl}	time lost to braking jerk limitation
1.5 s	t_{br}	brake system reaction time
4.3 ft/s^2, 1.3 m/s^2	a	initial service acceleration rate in ft/s^2 or m/s^2
4.3 ft/s^2, 1.3 m/s^2	d	service deceleration rate in ft/s^2 or m/s^2
32 ft/s^2, 10 m/s^2	a_g	acceleration due to gravity in ft/s^2 or m/s^2
0%	G_i	grade into station, downgrade = negative
0%	G_o	grade out of station, downgrade = negative
90%	l_v	line voltage as percentage of specification
20.5 ft, 6.25 m	P_e	positioning error—moving block only, in feet or meters
165 ft, 50 m	S_{mb}	moving-block safety distance—moving block only, in feet or meters

Exhibit 5-54
Minimum Train Separation versus Length[(R15)]

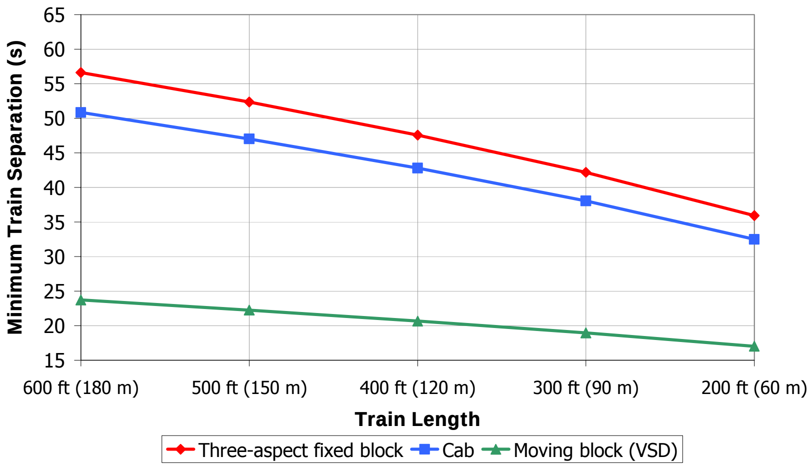
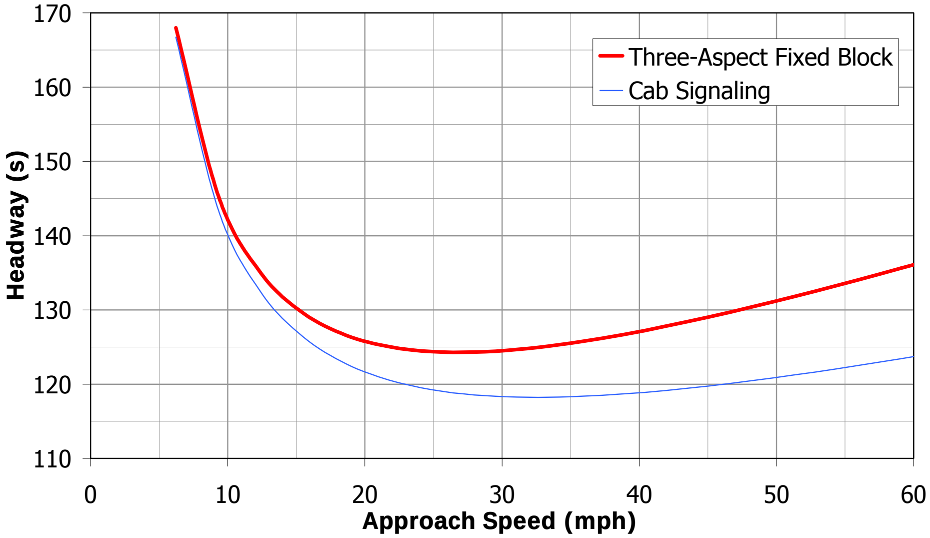


Exhibit 5-55 shows minimum station headways achieved using the typical values shown in Exhibit 5-53, derived from the equations presented later in this section, and including an assumed dwell time and operating margin. The optimum approach speeds shown in this exhibit should be compared with the maximum speeds imposed by switches and curves in the vicinity of the maximum load point station.

Exhibit 5-55
Station Headway for Lines at Capacity[(R15)]

An alternative figure using metric units appears in Appendix A.



NOTE: dwell = 45 s, operating margin = 20 s.

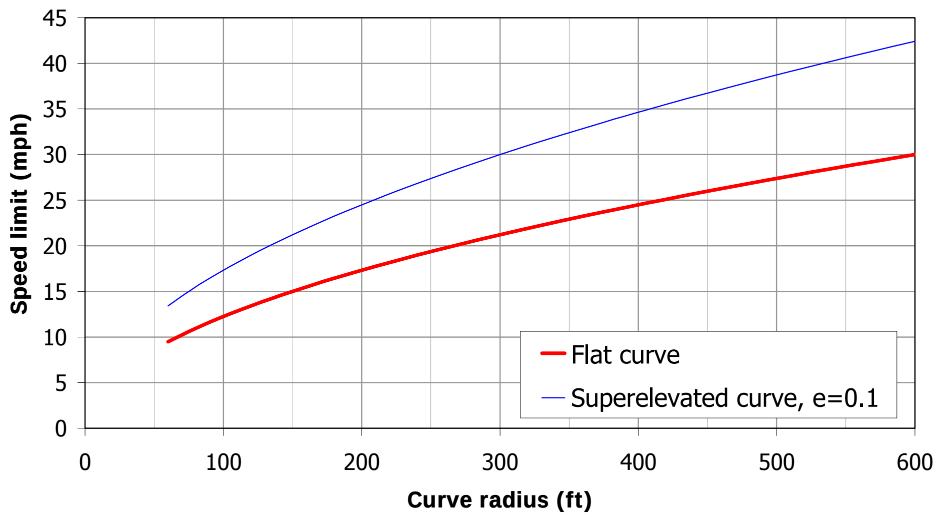
Optimum approach speeds.

Exhibit 5-55 shows that the optimum approach speed for three-aspect fixed-block signaling in this situation is 28 mph (45 km/h), while, for cab signaling, the optimum approach speed is 32 mph (52 km/h). If special work (interlockings) or curves restrict approach speeds below these values, then the lower values must be calculated and used. Typical speed limits for curves and turnouts (switches) are shown in Exhibit 5-56 and Exhibit 5-57, respectively. Determine any such station approach speed restrictions and their distance from the station stopping point. Next, compare this speed restriction with the normal approach speed at that distance from the station as shown in Exhibit 5-58. The most restrictive approach speed must then be used in the equations presented in this section.

Exhibit 5-56
Speed Limits on Curves(R15)

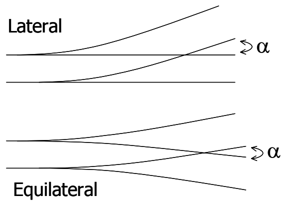
Curves and turnouts (switches) impose speed restrictions.

An alternative figure using metric units appears in Appendix A.



NOTE: Transition spirals are not taken into account.

Exhibit 5-57
Speed Limits on Turnouts



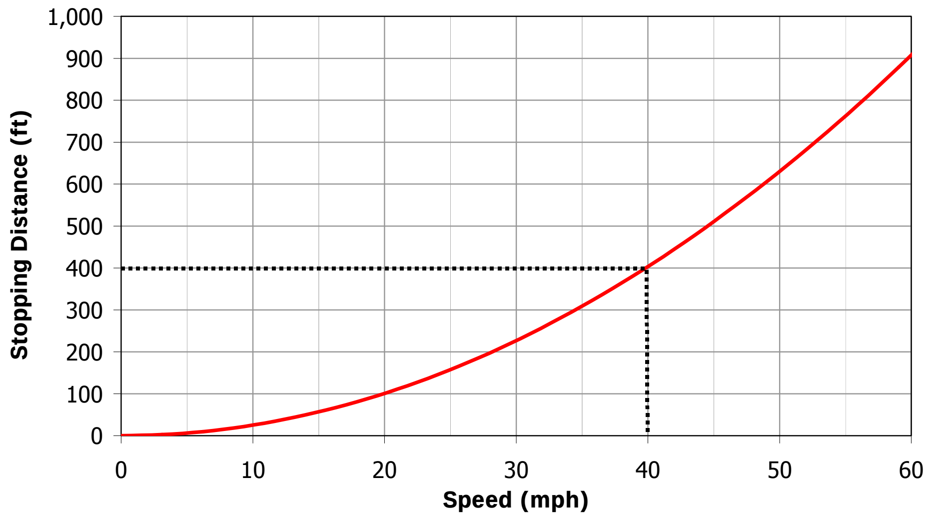
Turnout Number	Lateral Turnout		Equilateral Turnout	
	mph	km/h	mph	km/h
#6	15	24	21	34
#8	20	32	28	45
#10	25	40	35	57
#20	50	81	70	113

SOURCE: AREMA Manual for Railway Engineering (R6)
NOTES: Speeds shown are based on freight trains using level turnouts with curved switch points. Intercity passenger and rail transit cars are designed for greater roll through curves and can operate comfortably at somewhat higher speeds than shown. Many agencies have their own speed limits for turnouts that differ from those shown. For example, Denver RTD uses speeds for lateral turnouts that are 5 mph (8 km/h) *slower* than those shown.

Exhibit 5-58
Distance-Speed Chart(R15)

Use this chart to find how far from the station a computed optimal approach speed will occur, then determine if there is a lower speed limit at that location.

An alternative figure using metric units appears in Appendix A.



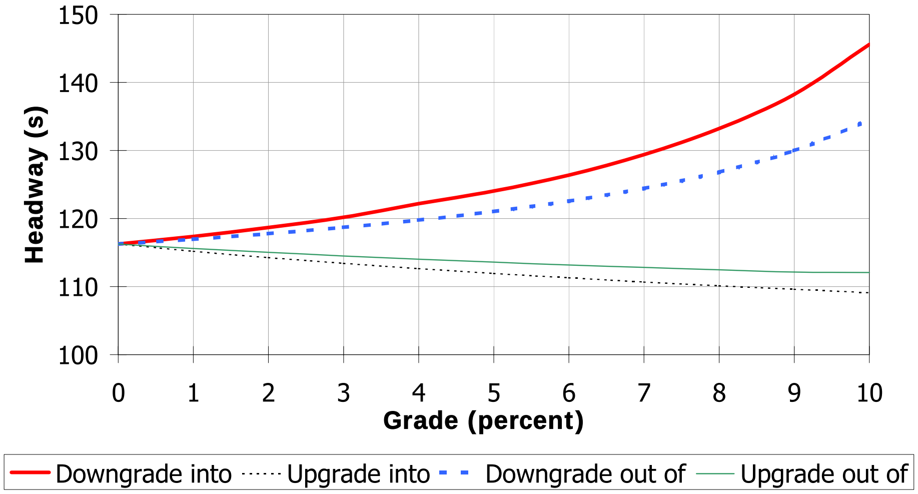
The dotted line example in Exhibit 5-58 shows that at 400 ft (120 m)[15] from a station, the approaching train will have a speed of 40 mph (64 km/h). If there is a speed limit at this point that is lower than 40 mph (64 km/h), then the minimum train separation, t_{cs}, must be calculated with the approach speed, v_a, set to that limit.

---

[15] Distance from the front of the approaching train to the stopping point.

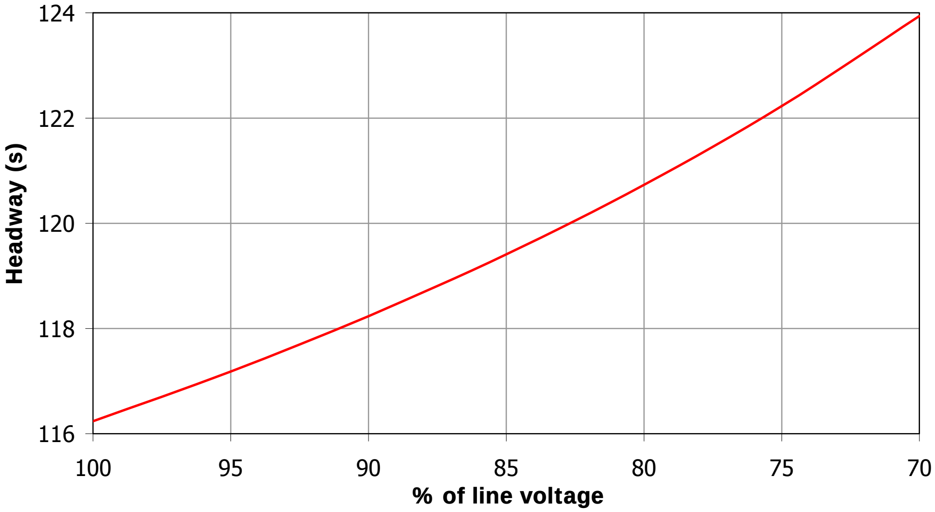
Two other factors affect minimum headways. Grades into or out of a station will change the acceleration and braking rates. Line voltage will drop below the nominal value on heavily used systems and reduce train performance. The results of grades and voltage drops are shown in Exhibit 5-59 and Exhibit 5-60, respectively. The calculations of these effects are complex and best left to a computer simulation. If a simulation model is not available, then the approximate headway changes can be read from Exhibit 5-59 and Exhibit 5-60, and the calculations adjusted by the appropriate number of seconds.

Exhibit 5-59
Effect of Grade on Station Headway[(R15)]



NOTE: cab signals, dwell = 45 s, operating margin = 20 s.

Exhibit 5-60
Headway Changes with Voltage[(R15)]



Fixed-Block and Cab Signaling Throughput

The minimum train control separation for fixed-block and cab signal systems is given by Equation 5-7, with variables as shown in Exhibit 5-53:

Equation 5-7

$$t_{cs}=\sqrt{\frac{2(L_t+d_{eb})}{a(1-0.1G_o)}}+\frac{L_t}{v_a}+\left(\frac{100}{f_{br}}+b\right)\left(\frac{v_a}{2d}\right)$$
$$+\frac{a(1-0.1G_i)l_v^2t_{os}^2}{20{,}000v_a}\left(1-\frac{v_a}{v_{max}}\right)+t_{os}+t_{jl}+t_{br}$$

Compare the approach speed producing the minimum train separation to any speed restrictions on the station approach.

This equation should be solved for the minimum value of t_{cs}. The approach speed, v_a, that produces this minimum value must then be checked against any speed restrictions approaching the station from Exhibit 5-58.

Moving-Block Throughput

Moving-block train separation safety distances can be fixed or variable.

Moving-block signaling systems replace separation by fixed blocks with a moving block based on the braking distance to a target point plus a safety separation distance. The safety separation distance can be fixed for a given system and type of rolling stock or can be continually adjusted with speed and grades.

Equation 5-8 determines the train control separation for a moving-block signaling system with fixed safety separation, with variables as given in Exhibit 5-53. Note that the time for the overspeed governor to operate is incorporated into the safety distance and so does not appear in the equation.

Equation 5-8

$$t_{cs}=\frac{L+S_{mb}}{v_a}+\frac{100}{f_{br}}\left(\frac{v_a}{2d}\right)+t_{jl}+t_{br}$$

Note that this equation is not affected by either line voltage or station grade. Lower voltages increase the time for a train to clear a station platform. In moving-block systems this time does not affect throughput. When a train starts to leave a station, the target point of the following train is immediately advanced accordingly. The worst-case approach grade is included in the determination of the safety distance. This can result in sub-optimal minimum train separation.

Higher throughput is usually obtained with a moving-block signaling system with a variable safety distance consisting of the braking distance at the particular speed plus a runaway propulsion allowance. The minimum train control headway of such a system is given by Equation 5-9, with variables and default values as given in Exhibit 5-53.

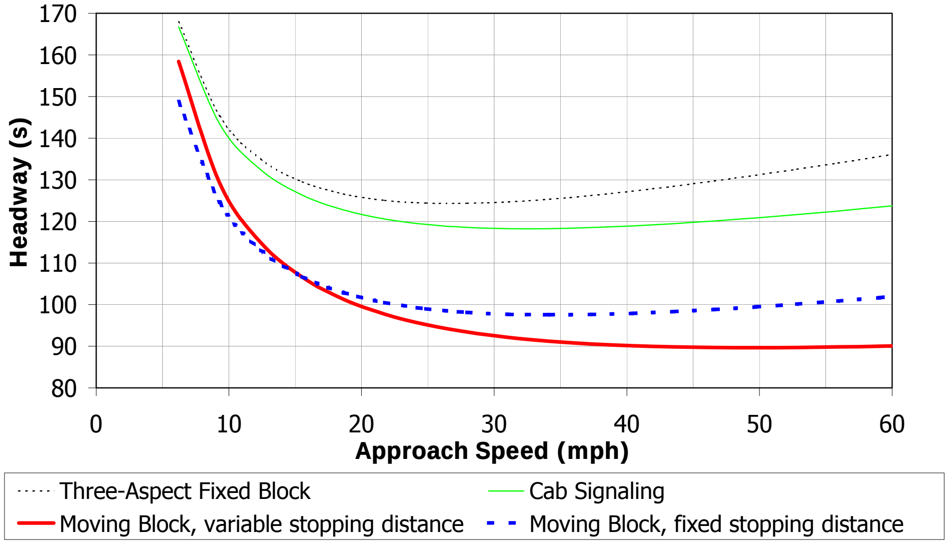
Equation 5-9

$$t_{cs}=\frac{L_t+P_e}{v_a}+\left(\frac{100}{f_{br}}+b\right)\left(\frac{v_a}{2d}\right)+\frac{a\left(1-\frac{a_g}{100}G_i\right)l_v^2t_{os}^2}{20{,}000v_a}\left(1-\frac{v_a}{v_{max}}\right)+t_{os}+t_{jl}+t_{br}$$

Equation 5-9 adjusts the safety separation entering a station due to any grade. A downgrade will increase the braking distance and so require a longer safety separation—and vice versa.

The results of Equation 5-8 and Equation 5-9 are shown in Exhibit 5-61. The resultant minimum station headway of 97 seconds occurs at an approach speed of 35 mph (56 km/h). The respective curves for a conventional three-aspect fixed-block signaling system and a cab signaling system are included for comparison. As would be expected, a moving-block system with a speed variable safety distance shows the lowest overall headway. The difference between the two methods of determining the safety distance represents an 8-second difference in the minimum headway. Voltage fluctuations have little effect on moving-block headways as the time to clear the platform is not a component in calculating the moving-block signaling system headway.

Exhibit 5-61
Moving-Block Station Headways Compared with Conventional Fixed-Block Systems(R15)



NOTE: dwell time = 45 s, operating margin = 20 s.

Clear capacity increases with a moving-block signaling system.

An alternative version of this exhibit appears in Appendix A.

Compare the approach speed producing the minimum train separation to any speed restrictions on the station approach.

The appropriate equation above should be solved for the minimum value of t_{cs}. The approach speed, v_a, that produces this minimum value must then be checked against any speed restrictions approaching the station from Exhibit 5-58.

Checking Results

Compare the results obtained from these equations with Exhibit 5-54. The calculated minimum train separation should be close to or moderately greater than the values charted. If lower, there is probably an error, as the charted values are the minimums using typical maximum rail transit performance criteria without applying any corrections for grades or speed restrictions into or out of the station.

Step 3: Determining the Dwell Time

This section deals with station dwell times. An operating margin and the minimum train signal system separation must be added to the station dwell time to produce the headway.

The train close-in time at the headway critical station is dependent on a train's physical performance and length, as well as other fixed system characteristics, and therefore can be calculated with some precision. Station dwell time cannot be determined with the same exactitude. Virtually all the literature references related to rail transit capacity assign a set time to dwell time. Many simulations do likewise, using typical figures of 15 to 20 seconds for lesser stations and 30 to 45 seconds for major stations. The one methodology to determine *controlling dwell*—dwell time plus operating margin—requires knowledge of station dwell times over the peak hour, which is information only available for existing systems or for new lines in areas where a station with similar passenger volumes can be analyzed.[16]

---

[16] See Alle (R2). No operating margin should be added when controlling dwell is calculated.

Chapter 3, *Station Dwells,* describes the main constituents of dwell time as follows:

- Passenger flow time at the busiest door,
- Remaining (unused) door open time, and
- Waiting to depart time (with doors closed).

Four methods of estimating dwell time or controlling dwell time are provided in this section. The first method is the one used in the Chapter 6 planning applications and by most of the literature references—simply assigning a reasonable figure to the headway critical station. The second method uses field data from TCRP Project A-8 allowing the selection of a controlling dwell time from the headway-critical station of rail transit lines with similarities to the one being analyzed. These two methods are suitable where information on passenger flows at the headway critical station is not available.

Four methods of estimating controlling dwell.

The third method is only suitable for new lines in cities with existing rail transit systems. Here the method outlined in Chapter 3 of using the mean dwell time plus two standard deviations based on a comparable station on the existing network is suggested. The fourth and final method uses a statistical approach of determining station dwell times based on peak hour passenger flows. This method is complex and still requires an estimate of the ratio of the busiest door to average door flow.

None of these methods are entirely satisfactory. This explains why practitioners over a period of three decades have resorted to simply assigning a reasonable value to station dwell time.

Method 1: Assigning a Value

Existing rail transit systems operating at or close to capacity have median station dwell times over the peak hour that range from 30 to 50 seconds with occasional exceptional situations—such as the heavy peak hour mixed flow at NYCT's Grand Central Station of more than 60 seconds. A tighter range of dwell time values—35 to 45 seconds—is used in the Chapter 6 planning procedures and can be used together with the more accurate calculation of the minimum train separation.

Method 2: Using Existing Dwell Time Data

Examples of existing dwell time data from the highest-use station on lines that are close to capacity are summarized in Exhibit 5-62. Selection of a dwell time from this table is less arbitrary than Method 1 and allows some selectivity of mode and the opportunity to pick systems and stations with similar characteristics to those of the one under examination.

The selected median station dwell times range from 27.5 seconds to 61.5 seconds. The highest data are mainly alighting and mixed-flow records from manually operated systems with two-person crews. Most station dwell times in Exhibit 5-62 fit into the 35 to 45 second range suggested in the previous method.

Exhibit 5-62
Peak-Period Station Dwell Times for Heavily Used Systems (1995)(R15)

System & City	Station	Total Pass.	Mean Dwell (s)	Mean Headway (s)
BART (San Francisco)	Embarcadero WB	2,298	48.0	155.0
CTS (Calgary)	1st St. WB (LRT)	298	33.0	143.0
CTS (Calgary)	3rd St. WB (LRT)	339	38.0	159.0
CTS (Calgary)	City Hall EB (LRT)	201	34.0	161.0
NYCT (New York)	Grand Central SB (4&5)	3,488	61.5	142.5
NYCT (New York)	Queens Plaza WB (E&F)	634	36.0	121.0
PATH (Newark)	Journal Square WB	478	37.0	204.0
Muni (San Francisco)	Montgomery WB (LRT)	2,748	32.0	129.0
SkyTrain (Vancouver)	Broadway EB	257	30.0	166.0
SkyTrain (Vancouver)	Metrotown EB (off-peak)	263	34.0	271.5
TTC (Toronto)	King SB	1,602	27.5	129.5
TTC (Toronto)	Bloor NB	4,907	44.0	135.0

NB: northbound, SB: southbound, EB: eastbound, WB: westbound

Method 3: Using Dwells from the Same System

This method is only applicable where a line of the same mode is being added to an existing system, in which case the controlling dwell time from an existing, similar, peak-point station can be used. Where passenger volumes at the headway critical station of the new line are different from the equivalent station on an existing line, the flow component of dwell time can be adjusted in proportion to hourly passenger movements in the station. Alternatively, the dwell time from an existing station with similar passenger volumes can be used.

Care should be taken if the train control system or operating procedures are different. If this is the case, consideration should be given to adjusting both the station dwell time and the operating margin.

Method 4: Calculating Dwells from Passenger Flows

TCRP Report 13, "Rail Transit Capacity,"(R15) develops regression equations to relate passenger flow times to the number of boarding, alighting, or mixed flow passengers, and, in turn, to convert this flow time to dwell time. These regression equations can be used to estimate the dwell time from hourly passenger flows into the maximum load point station. However, the best regression fit involves logarithmic functions and the estimation of a constant for the ratio between the highest doorway and the average doorway passenger flow rate. The mathematics are complex and it is uncertain if the results provide any additional accuracy that merits this complexity—particularly if the hourly station passenger volumes by direction are themselves somewhat uncertain.

This method is best suited to new lines in locations without rail transit and with a sufficiently refined and calibrated regional transportation model that can assign hourly passenger flow, by direction, to individual stations. This method is not detailed further in this manual.

Step 4: Selecting an Operating Margin

Chapter 5, *Operating Issues,* introduced the need to add an operating margin to the minimum train separation and dwell time to create the closest sustainable headway without interference.

Dilemma on at-capacity lines.

Ironically, the closer the trains operate, and the busier they are, the more chance there is of minor incidents delaying service due to an extended station dwell time, stuck door, or late train ahead. It is never possible to ensure that delays do not create interference between trains nor is there any stated test of reasonableness for a specific operating margin.[17] A very small number of rail transit lines in the United States and Canada are operating at capacity and so can accommodate little or no operating margin. On such lines, operations planners face the dilemma of scheduling too few trains to meet the demand, resulting in extended station dwell times and erratic service, or adding trains to the point that they interfere with one another. Striking a balance is difficult and the tendency in practice is to strive to meet demand—equipment availability and operating budget permitting. While the absolutely highest capacity is so obtained, it is poor planning to omit such an allowance for new systems.

The greater the operating margin that can be incorporated in the headway the better; systems running at maximum capacity have little leeway and the range of operating margins used in the simple procedure—20 to 25 seconds—remains the best guide. The recommended procedure is to aim for 25 seconds and back down to 20 or even to 15 seconds if necessary to provide sufficient service to meet the estimated demand. Where demand is unknown or uncertain in the long-term future—when a rail line in planning reaches maximum capacity—then 25 seconds should be used.

Step 5: Selecting a Passenger Loading Level

Chapter 4, *Passenger Loading Levels,* discusses the wide range of loading levels used in the United States and Canada. Selecting a loading level is a policy issue and the process for this procedure is the same as that of the planning-level procedure presented in Chapter 6. Use of the passenger occupancy per unit length of train is recommended. When selecting a loading level, take into account that this level is for the 15-minute peak period and that the average over the peak hour will be more relaxed.

Nominal linear loading levels.

If the line for which capacity is being determined is an addition to an existing system, then existing occupancy levels or, where available, existing loading policies can be used. Some cities have a wide variation of peak 15-minute loading levels from line to line. Where this variety exists, the loading level should be selected based on the closest matching line—for example, a heavy trunk serving downtown or a cross-town feeder line.

Exhibit 5-24 and Exhibit 5-25 provide a range of loading levels from 1.5 to 2.7 p/ft length (5 to 9 p/m length) for light rail, and 2.1 to 3.4 p/ft length (7 to 11 p/m length) for heavy rail. For new systems where attempts are being made to offer a higher quality of service, the recommended approach is to base the loading level on the commonly suggested medium comfort level for new rail transit systems of 5.4 ft^2 (0.5 m^2) per passenger, averaged over the peak hour—that is, no peak hour factor is required. This provides a recommended linear loading level of 1.8 p/ft length (6 p/m length) for heavy rail and 1.5 p/ft length (5 p/m length) for light rail.

Actual linear loading levels.

An alternative approach is to base the loading levels on either the nominal capacity of a vehicle or the actual peak hour utilization. The nominal capacity of vehicles, whether specified by the operating agency or manufacturer is arbitrary and for identical vehicles can differ by a factor of almost two. Exhibit 5-63 shows the actual peak 15-minute linear loading levels for major North American trunks, in descending order. Discounting the uniquely high values in New York, the remaining data offer realistic existing levels to apply in selecting a loading level for a comparable system—or a new line in the same system with similar characteristics.

---

[17] A goal for an operating margin, based on an average of one *disturbed* peak period per 10 weekdays (2 weeks) has been discussed with rail transit planners but has not been documented.

Exhibit 5-63
Passengers per Unit Train Length, Major North American Rail Trunks, 15-Minute Peak (1995)(R15)

An alternative figure using metric units appears in Appendix A.

System & City	Trunk Name	Mode	Car Length (ft)	Seats	Avg. Pass/Car	Pass/ft
NYCT (New York)	53rd Street Tunnel	HR	*see note*	50/70	197/227	3.2
NYCT (New York)	Lexington Ave. Local	HR	51.0	44	144	2.8
NYCT (New York)	Steinway Tunnel	HR	51.0	44	144	2.8
NYCT (New York)	Broadway Local	HR	51.0	44	135	2.7
TTC (Toronto)	Yonge Subway	HR	74.5	80	197	2.7
NYCT (New York)	Lexington Ave. Ex.	HR	51.0	44	123	2.4
NYCT (New York)	Joralemon St. Tun.	HR	51.0	44	122	2.4
NYCT (New York)	Broadway Express	HR	51.0	44	119	2.3
NYCT (New York)	Manhattan Bridge	HR	74.7	74	162	2.2
NYCT (New York)	Clark Street	HR	51.0	44	102	2.0
CTS (Calgary)	South Line	LR	79.6	64	153	1.9
GO Transit (Toronto)	Lakeshore East	CR	85.0	162	152	1.8
SkyTrain (Vancouver)	SkyTrain	HR	40.7	36	73	1.8
PATH (New York)	World Trade Center	HR	51.0	31	92	1.8
PATH (New York)	33rd St.	HR	51.0	31	88	1.7
CTA (Chicago)	Dearborn Subway	HR	48.0	46	82	1.7
NYCT (New York)	60th Street Tunnel	HR	74.7	74	126	1.7
NYCT (New York)	Rutgers St. Tunnel	HR	74.7	74	123	1.6
CTS (Calgary)	Northeast Line	LR	79.6	64	125	1.6
CTA (Chicago)	State Subway	HR	48.0	46	75	1.6
CalTrain (San Fran.)	CalTrain	CR	85.0	146	117	1.4
LIRR (New York)	Jamaica - Penn Sta.	CR	85.0	120	117	1.4
Metra (Chicago)	Metra Electric	CR	85.0	156	113	1.3
MARTA (Atlanta)	North/South	HR	75.0	68	82	1.1
MARTA (Atlanta)	East/West	HR	75.0	68	77	1.0

HR: heavy rail, LR: light rail, CR: commuter rail

NOTE: Service through NYCT's 53rd Street Tunnel in 1995 was provided by line E, operating 60-ft cars, and line F, operating 75-ft cars. Seats and car loadings are presented as "E/F." The number of passengers per foot given is for the combined lines; individually this value is 3.3 for the E and 3.0 for the F. The F was moved to the 63rd Street Connector in December 2001, and a new line V shared the 53rd Street Tunnel with line E.

Step 6: Determining an Appropriate Peak Hour Factor

The next step is to adjust the hourly capacity from the 15-minute rate within the peak hour to a peak hour rate using a peak hour factor from Chapter 4, *Passenger Loading Levels*. The peak hour factor is calculated according to Equation 5-1, with a summary of results for North American systems shown in Exhibit 5-64. The peak hour factor was also used in the optional Method 4 for calculating the station dwell time. If this method was used, then the same peak hour factor must be used to adjust the hourly capacity. Otherwise, the factor should be selected based on the rail mode and the type of system.

Unless there is sufficient similarity with an existing operation to use that specific figure, the recommended peak hour factors are

- 0.80 for heavy rail,
- 0.75 for light rail, and
- 0.60 for commuter rail operated by electric multiple-unit trains.

When passenger loading is designed for a higher quality of service, with the loading standard based on an average over the peak hour rather than over the peak 15 minutes, a peak hour factor of 1.00 can be used in place of the above values.

Exhibit 5-64
Diversity of Peak Hour and Peak 15-Minute Loading(R15)

System & City	Routes	Peak Hour Factor
Commuter Rail		
LIRR (New York)	13	0.56
Metra (Chicago)*	11	0.63
Metro-North (New York)	4	0.75
NJT (New Jersey)*	9	0.57
SEPTA (Philadelphia)	7	0.57
Light Rail		
CTS (Calgary)	2	0.62
RTD (Denver)	1	0.75
SEPTA (Philadelphia)	8	0.75
TriMet (Portland)	1	0.80
Rapid Transit		
BC Transit (Vancouver)	1	0.84
CTA (Chicago)	7	0.81
MARTA (Atlanta)	2	0.76
MDTA (Baltimore)	1	0.63
NYCT (New York)	23	0.81
PATH (New York)	4	0.79
STM (Montréal)	4	0.71
TTC (Toronto)	3	0.79

* Mainly diesel-hauled—not electric multiple unit.

Step 7: Putting It All Together

The final step in the method of determining a grade-separated rail transit line's maximum capacity is to determine the closest (minimum) headway, h_{gs}, as the sum of the calculated value of the minimum signaling system train separation, plus the calculated or estimated value of dwell time, plus the assigned operating margin.

$$h_{gs} = t_{cs} + t_d + t_{om}$$

Equation 5-10

The maximum number of trains per hour, T, (line capacity) then is:

$$T = \frac{3{,}600}{h_{gs}} = \frac{3{,}600}{t_{cs} + t_d + t_{om}}$$

Equation 5-11

PERSON CAPACITY

The maximum person capacity, P, is the number of trains multiplied by their length and the number of passengers per unit length, adjusted from peak-within-the peak to peak hour.

$$P = TLP_m(PHF) = \frac{3{,}600 LP_m(PHF)}{t_{cs} + t_d + t_{om}}$$

Equation 5-12

where:
P = person capacity (p/h);
T = line capacity (trains/h);
L = train length (ft, m);
P_m = linear passenger loading level (p/ft length, p/m length);
PHF = peak hour factor;
t_{cs} = minimum train control separation (s);
t_d = dwell time at critical station (s); and
t_{om} = operating margin (s).

Given the range of values that can be calculated, estimated, or assigned for the components of Equation 5-12, it is appropriate that the results be expressed as a range.

The results should be checked for reasonableness against typical capacities in Exhibit 5-44 and Exhibit 5-46, which are based on the planning-level loading levels of 1.5 p/ft length (5 p/m length) for light rail and 1.8 p/ft length (6 p/m length) for heavy rail—approximately 5.4 ft^2 (0.5 m^2) per passenger. Higher levels are possible only if less comfortable loading levels have been used. Lower levels would result from the assumption that all passengers are seated, inclusion of an excessive operating margin, or errors in the calculation.

These charts are not appropriate checks for electric multiple-unit commuter rail, whose signaling systems are usually designed for lower throughput with loading levels based on all passengers being seated. Commuter rail capacity based on train length is also affected by the common use of bi-level cars, although few such trains currently fit into the applicable category of electric multiple-unit operation.

CHAPTER 8. LIGHT RAIL CAPACITY

INTRODUCTION

The key is finding the weakest link in the capacity chain.

This chapter covers methods for determining the capacity of light rail transit lines. While the approach used in Chapter 7, *Grade Separated Rail Capacity*, will work in most situations, light rail transit lines often have characteristics such as street running, grade crossings, and single-track sections which are not covered in that chapter but which are of importance in capacity determination. The key to determining the capacity of a light rail transit line is to find the weakest link—the location or factor that limits the capacity of the entire line.

DETERMINING THE WEAKEST LINK

Range of light rail right-of-way types.

Determining the capacity of light rail transit lines is complicated by the variety of rights-of-way that can be employed. In the simplest case, a grade-separated right-of-way is used and the capacity calculation techniques given in Chapter 7 can be applied. However, most light rail transit lines use a combination of right-of-way types which can include on-street operation (often in reserved lanes) and private right-of-way with grade crossings. Other limitations can be imposed by single-track sections and the street block lengths. The line capacity is determined by the weakest link; this could be a traffic signal with a long phase length, but is more commonly the minimum headway possible on a block-signaled section. The first portion of this chapter discusses the capacity limitations imposed by right-of-way characteristics.

The right-of-way capacity constraints are discussed in the following sections in the order of their decreasing relative importance for most systems. This order is as follows:

- Single track with two-way operation,
- Signaled sections,
- On-street operation in exclusive lanes or mixed traffic, and
- Private right-of-way with grade crossings.

This order is not definitive for all systems, but it is appropriate for most. System-specific differences, such as short block lengths on signaled sections, will change the relative importance of each item.

Other Capacity Issues

Light rail loading levels.

Car loading levels for light rail transit, for use in the equations in this chapter, should be determined with reference to the passenger loading standards for light rail transit in Chapter 4, *Passenger Loading Levels*. Light rail loading levels are generally lighter than those for heavy rail transit, but not as generous as the one-seat-per-passenger policy common on commuter rail.

Light rail train lengths.

Light rail train lengths are more restricted than for heavy rail transit or commuter rail because of lower car and coupler strengths, and street block and station platform lengths. The latter issues were discussed in Chapter 1.

Access for passenger with mobility limitations.

One additional issue that is of particular importance to light rail operations and capacity is the method of access for passengers with mobility limitations. While the speed of each access method varies, all can have an effect where close headways and tight scheduling prevail. A discussion of the impact of the ADA related to wheelchair provisions can be found in Chapter 5.

SINGLE TRACK

Single track reduces capital costs but can add a serious capacity constraint.

This constraint only applies to two-way operation; not to one-way operation, such as on a downtown one-way street grid.

Single-track sections with two-way operation are the greatest capacity constraint on light rail lines where they are used extensively. Single-track sections are used primarily to reduce construction costs. Some lines have been built with single track as a cost-saving measure where the right-of-way would permit double track. In other areas single track has been built because widening the right-of-way and structures is impossible. Single-track sections can be very short in order to bypass a particular obstacle; for example, an overpass of a highway.

Determining the potential extent of single track.

While determining the potential extent of single-track construction is possible, the exact layout is highly system-specific. Estimates can be made of the number of track miles or kilometers required for a certain number of route miles or kilometers once the intended headway is known.[18] While this does not tell the user *where* the single-track sections can be used, it can provide assistance in determining the possible extent of single track for use in cost estimates.

Calculating Single-Track Headway Restrictions

Single-track occupancy time and distance.

Single track capacity constraints are site-specific.

Single-track sections greater than 0.25 to 0.30 miles (400 to 500 meters) are potentially the most restrictive capacity constraint for light rail. The headway limitation is simply twice the time taken to traverse the single-track section, plus an allowance for switch throw and lock—unnecessary for spring switches or gauntlet track[19]—plus an operating margin to minimize the potential wait of a train in the opposite direction.

The time to cover a single-track section is:

Equation 5-13

$$t_{st} = S_m\left(\frac{(N_{st}+1)}{2}\left(\frac{3v_{\max}}{d}+t_{jl}+t_{br}\right)+\frac{L_{st}+L_t}{v_{\max}}\right)+N_{st}t_d+t_s+t_{om}$$

where:

t_{st} = time to cover single-track section (s);

L_{st} = length of single-track section (ft, m);

L_t = train length (ft, m);

N_{st} = number of stations on single-track section;

t_d = station dwell time (s);

v_{max} = maximum speed reached (ft/s, m/s);

d = deceleration rate (ft/s^2, m/s^2);

t_{jl} = jerk limitation time (s);

t_{br} = operator and braking system reaction time (s);

S_m = speed margin;

t_s = switch throw and lock time (s); and

t_{om} = operating margin (s).

The speed margin is an allowance for out-of-specification equipment and train operators that do not drive at exactly the maximum permitted speed. It typically ranges from 1.08 to 1.20.

The minimum headway is:

Equation 5-14

$$h_{st} = 2t_{st}$$

where:

h_{st} = minimum single-track headway (s).

---

[18] See Allen (R3) for more information.

[19] Gauntlet track interlaces the four rails without needing switches, saving capital and maintenance costs, as well as potential operating problems due to frozen or clogged switch points. The disadvantage is that the single-track section cannot be used as an emergency turnback (reversing) location.

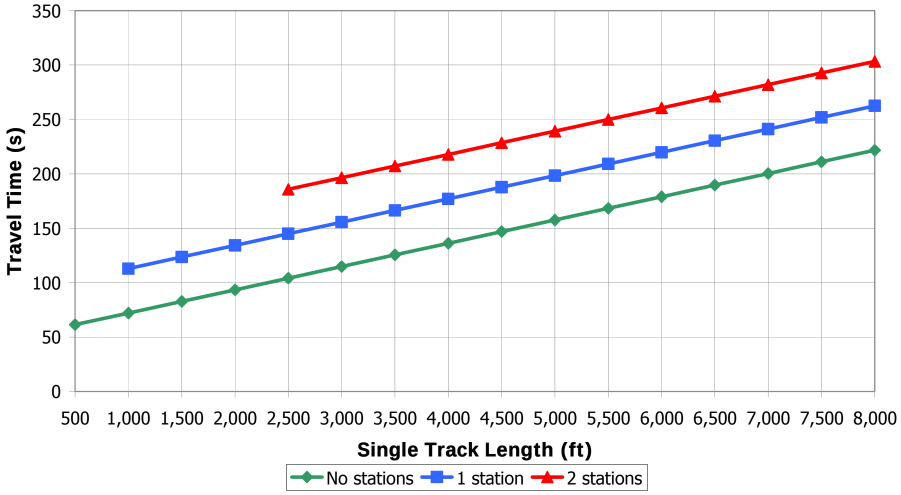
Default values for use with Equation 5-13 are given in Exhibit 5-65. The results of applying these default values are depicted in Exhibit 5-66. A spreadsheet that calculates the single-track capacity is included on the accompanying CD-ROM.

A spreadsheet for calculating single-track capacity is included on the accompanying CD-ROM.

Exhibit 5-65
Default Data Values for Single Track LRT Travel Time(R15)

Term	Value
Jerk limitation time	0.5 s
Brake system reaction time	1.5 s
Dwell time	15-25 s
Switch throw-and-lock time	6 s
Service braking rate	4.3 ft/s^2 (1.3 m/s^2)
Speed margin	1.1 to 1.2
Operating margin time	10-30 s

Exhibit 5-66
Light Rail Travel Time Over Single-Track Section(R15)



NOTE: Assumes speed limit of 35 mph, 180-foot train length, 20-s dwell time, 20-s operating margin, and other data as per Exhibit 5-65. *The recommended closest headway is twice this time.*

An alternative figure using metric units appears in Appendix A.

To estimate best headway multiply single-track time by two.

The value of the maximum single-track section speed should be the appropriate speed limit for that section. A speed of 35 mph (55 km/h) is a suitable value for most protected, grade-separated lines. If the single-track section is on-street then a speed below the traffic speed limit should be used. If there are signalized intersections, an allowance of half the signal cycle should be added to the travel time for each such intersection, adjusted for any improvements possible from traffic signal priority.

Scheduling for single track.

Trains should be scheduled from their termini such that passing locations are not close to the single-track sections. Where there is more than one single-track section, this can become difficult but not impossible.

Passing sections.

Lengthy single-track sections can severely limit headways and capacity and may require one or more double-track passing sections within the single-track section. These should, wherever possible, be of sufficient length to allow opposing trains to *pass on-the-fly* and allow some margin for off-schedule trains. Obviously, trains should be scheduled to meet at this location.

Exhibit 5-67
Single-Track Examples

(a) Seattle (b) Sacramento

The Seattle vintage trolley example shows the effect of a short passing section: one train must wait for the other.

SIGNALED SECTIONS

Economic signaling constraints.

Restrictions due to signaled sections are largely covered in Chapter 7. However, it should be realized that many light rail lines are not signaled with the minimum *possible* headway in mind, but more economically for the minimum *planned* headway. This can easily make signaled sections the capacity constraint. In this case, the signaling system design capacity should be used to determine the maximum throughput of trains. Typical design headways of 3 to 3½ minutes allow 20 and 17 trains per hour, respectively.

Exhibit 5-68
Signaled Section Examples

(a) Portland, Oregon (b) Denver

ON-STREET OPERATION

On-street capacity.

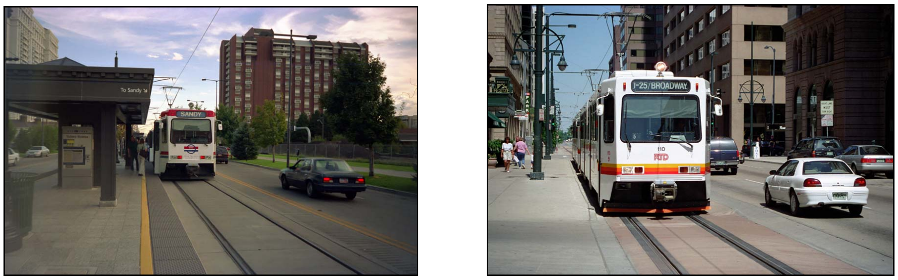
Historically, streetcar operation has achieved throughput in excess of 125 cars per hour on a single track in many North American locations. Even now the Toronto Transit Commission schedules single and articulated streetcars at a peak 15-minute rate of more than 60 cars per hour on Queen Street East in Toronto, where several car lines share a four-block stretch. The price of this capacity is low speed, congestion, irregular running, and potential passenger confusion at multiple-car stops.

Reserved lanes for light rail vehicles and streetcars.

Despite this record, on-street operation is often raised as a major capacity constraint for modern light rail systems, yet this is rarely the case on contemporary lines. This is particularly true on most newer lines where light rail trains have exclusive use of road lanes or a reserved center median where they are not delayed by other traffic making turns, queuing at signals, or otherwise blocking the path of the trains. Exclusive lanes for light rail are also being instituted on some of the older streetcar systems. Exhibit 5-69 shows examples of on-street light rail rights-of-way.

Exhibit 5-69
On-Street Light Rail Right-of-Way Types

(a) Mixed Traffic—Center Lane (Toronto) (b) Mixed Traffic—Curb Lane (Portland, Oregon)



(c) Exclusive Lane (Salt Lake City) (d) Exclusive Lane—Contraflow (Denver)

Even with these improvements in segregating transit from other traffic, light rail trains must still contend with traffic signals, pedestrian movements, and other factors beyond the control of the transit operator. The transit capacity in these situations can be calculated using the equations presented later in this chapter.

Calculating on-street train throughput.

Variability due to traffic congestion has been reduced as a factor as almost all recently built on-street light rail lines operate on reserved lanes. A number of older systems still have extensive operation in mixed traffic and so are subjected to the fluctuation in train throughput this causes by reducing *g*, the effective green time for trains. Traffic queuing, left turns, and parallel parking can all serve to reduce light rail transit capacity.

Signal priority.

Traffic signal priority allows the light rail train to extend an existing green phase or speed the arrival of the next one. Depending on the frequency of intersections and traffic congestion, this can have a substantial impact on the flow of general traffic in the area. As a result, signal priority in congested areas is often limited in its scope so as not to have too negative an effect on other traffic. The degree to which local politicians and traffic engineers will tolerate the effects of priority plays a large role in determining the effectiveness of signal priority schemes.

Signal progression.

Signal progression has supplanted pre-emption in many cases where light rail trains operate in congested downtown areas. This technique gives trains leaving stations a "green window" during which they can depart and travel to the next station on successive green lights. The benefits of progression increase with greater station spacing as less accumulated time is spent waiting for the progression to start at each station. The progression is frequently made part of the normal traffic signal phasing and so is fully integrated with signaling for automobiles on cross-streets. This reduces delays for transit and car drivers alike. Station stops are accommodated by the train missing one signal cycle and proceeding on the next. Ideally the signal cycle length will be slightly longer than a long average dwell time in order to allow the majority of trains to leave shortly after passenger boardings and alightings have ended.

It is useful if the train operator waiting at the first signal in a series of signals can determine when the "green window" will start, as this allows the operator to serve more passengers by maximizing the dwell time at the station. In this way, the train operator only closes the doors when he or she knows that the train will soon be able to proceed. In some cases this can be done by observing the operation of the other traffic signal phases. However, this may not be possible at some locations and in these cases a special signal display can be added that counts down the time to the start of the light rail phase. Such countdown timers are used at a number of locations on the downtown portion of the San Diego Trolley.

Vintage trolley operation.

Operating vintage trolleys in conjunction with light rail service can constrain capacity. With care, such services can interact harmoniously, but once established, it may be difficult to remove a heritage service with popular and tourist appeal—if and when that capacity is needed for the principal light rail service(s).

Determining On-Street Capacity

Streetcars operating in mixed traffic use capacity procedures similar to buses.

Single streetcars in classic mixed operation can be treated as similar to buses and capacity determined from the procedures of Part 4 of this manual, with suitable modifications reflecting longer vehicle lengths and differences in dwell time variability.

The minimum sustainable headway is double the longest traffic signal cycle.

Where, as is often the case, light rail train lengths approach the downtown block lengths, then the throughput is simply one train per traffic signal cycle, provided the track area is restricted from other traffic. When other traffic, such as queuing left-turning vehicles, prevents a train from occupying a full block, throughput drops as not every train can proceed upon receiving a green signal. A common rule of thumb is that the minimum sustainable headway is double the longest traffic signal cycle on the at-grade portions of the line. Equation 5-15 can be used to determine the minimum headway between trains operating on-street in exclusive lanes or mixed traffic.(R13,R15)

Equation 5-15

$$h_{os} = \max\left\{ \begin{array}{l} \dfrac{t_c + (g/C)t_d + Zc_v t_d}{(g/C)} \\ 2C_{\max} \end{array} \right\}$$

where:

h_{os} = minimum on-street section train headway (s);

g = effective green time (s), reflecting the reductive effects of on-street parking and pedestrian movements (mixed traffic operation only), as well as any impacts of traffic signal pre-emption;

Some transit agencies use the signal cycle time (*C*) as the minimum clearance time.

C = cycle length (s) at the stop with the highest dwell time;

C_{max} = longest cycle length (s) in the line's on-street section;

t_d = dwell time (s) at the critical stop;

t_c = clearance time between trains (s), defined as the sum of the minimum clear spacing between trains (typically 15-20 s or the signal cycle time) and the time for the cars of a train to clear a station (typically 5 s/car);

Z = standard normal variable corresponding to a desired failure rate, from Exhibit 4-6; and

c_v = coefficient of variation of dwell times (typically 40% for light rail, 60% for streetcars).

PRIVATE RIGHT-OF-WAY WITH GRADE CROSSINGS

Private right-of-way with grade crossings (Exhibit 5-70) is the predominant type of right-of-way for many light rail transit systems. This can take the form of a route which does not follow existing streets, or one which runs in the median of a road physically separated from other traffic except at crossings.

Exhibit 5-70
Light Rail Private Right-of-Way Examples

(a) Private right-of-way (Philadelphia)

(b) Street median (Los Angeles)

Capacity on lines with full signal pre-emption can be determined using the methods for grade-separated rail transit given in Chapter 7. However, allowances for any speed restrictions due to grade crossings must be made. Where full signal pre-emption is not available, Equation 5-15 should be used to determine line capacity since it incorporates the cycle length of traffic signals, pre-empted or not.

Signal Pre-emption

Pre-emption delays.

Light rail transit lines operating on private right-of-way are generally given full priority at grade crossings by railroad-type crossbucks, bells and gates, or by traffic signal pre-emption. Gated, railroad-style crossings are used where train and/or traffic speeds are high. Railway-type gated crossings consistently have the longest phase lengths of the three main crossing devices. Crossbucks and bells alone, or pre-empted traffic signals, are used where speeds are lower. Delays to other traffic are reduced when gates are not used since the time taken for gates to be lowered and raised (around 30 s) is removed as a factor.

The potential delay to cross traffic at crossings with traditional railroad protection is almost three times longer than with 100% pre-empted signalized intersections. At higher train frequencies, these occupancy times will become unacceptable and signalized intersections will be required—potentially reducing light rail speeds, but not the light rail capacity—as the crossing occupancy time is well within a normal green phase.

Grade Crossings and Station Dwell Times

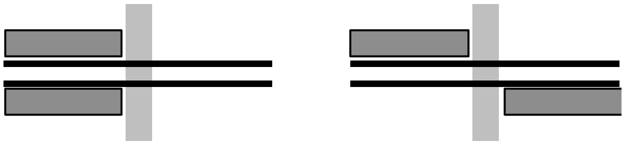
Grade crossings adjacent to stations.

Grade crossing activation and occupancy times can be affected by the presence of a station adjacent to the crossing. If the train must use the crossing after stopping at a station, the activation of the crossing signals is often premature and the crossing is unavailable to other traffic for more than the optimum time. In this case the train is also starting from a stop and so must accelerate through the crossing, adding to the total delay. Where the station platform is on the far-side of the crossing, the arrival time at the crossing can be predicted consistently and premature activation of the crossing is not a factor. The train is also either coasting or braking through the crossing from cruising speed and so will occupy it for less time.

Stations can be designed to place both platforms on one side of the crossing or to locate one platform on each side of the crossing such that trains use the crossing before stopping at the station. Both arrangements are shown in Exhibit 5-71. Using far-side platforms is advantageous for the operational reasons given above, reduced right-of-way requirements, and, for median operation, allowing left turn bays to be readily incorporated into the street.

Exhibit 5-71
Light Rail Platform Options at a Crossing(R15)

Far-side platforms can be advantageous.



(a) Facing (b) Far-side

Avoiding premature activation of crossing gates and signals.

Additional dwell time may need to be allowed when grade crossings adjacent to station exits are manually activated.

Delays caused by premature activation of crossing gates and signals at near-side stations can be reduced using wayside communication equipment. This can be done with the operator being equipped with a control to manually start the crossing cycle before leaving the station (as in Portland) or by an automatic method. An extra 10 seconds dwell time is an appropriate allowance when station exits are adjacent to grade crossings, and train operators manually initiate the crossing cycle after passenger movements at the station have finished.

An example of the automatic approach can be found on the San Diego Trolley. The trolley shares some of its track with freight trains and uses a communication device that identifies light rail trains to crossing circuits located on the far side of stations. If the crossing controller identifies a train as a light rail train, a delay to allow for station dwell time is added before the crossing is activated. This ensures that the crossing remains open for cross traffic for most of the time that the light rail train is stopped in the station. If the controller cannot identify the train as a light rail train, it assumes the train is a freight and activates the crossing gates without delay.

Train to wayside communication.

Other systems use an inductive link between the light rail train and wayside to activate signal pre-emption, switches and, in the future, ADA-mandated information requirements. The most common methods are the Philips (Vetag) and SEL systems. The lowest-cost detection approach is the classic overhead contactor. Trolleybus technology using radio signals from the power collection pick-up to coils suspended on the overhead wires is also applicable to light rail but is not used in the United States or Canada.

TRAIN THROUGHPUT

Determining the weakest link for light rail capacity.

Calculating the capacity of light rail transit lines is a complex process because of the varieties of rights-of-way that can be employed for the mode. The basic approach is to find the limiting factor or *weakest link* on the line and base the capacity on this point. The limiting factor for each line could be street-running with long traffic signal phases, a section of single track, or the length of signal blocks where block signaling is used.

The key factors to be considered are:

1. *Single track*—use Equation 5-13 or Exhibit 5-66.
2. *Signaled sections*—if designed for the minimum *planned* headway, use this headway; otherwise, use the procedures of Chapter 7 to find the minimum *possible* headway.
3. *On-street operation*—use Equation 5-15. Capacity effects are strongly related to the degree of priority given to light rail vehicles relative to other traffic.
4. *Private right-of-way without signal pre-emption*—use Equation 5-15. Where station exits are located adjacent to grade crossings, additional dwell time may need to be added if the crossing is activated manually by the train operator after passenger movements have ceased.
5. *Private right-of-way with grade crossings and signal pre-emption*—use the procedures of Chapter 7.

The first step in the process is to check the headway capabilities of any single-track section over 1,600 ft (500 m) in length, following the procedure given earlier in this chapter. Next, compare this headway with the design headway of the signaling system and with twice the longest traffic signal cycle of any on-street section. Select the most restrictive headway in seconds and convert this into trains per hour (line capacity) by dividing into 3,600. The following equations describe this mathematically:

Equation 5-16

$$h_{lr} = \max \begin{cases} h_{st} \\ h_{gs} \\ h_{os} \end{cases}$$

where:

h_{lr} = minimum light rail headway (s);

h_{st} = minimum single-track headway (s), from Equation 5-13;

h_{gs} = minimum grade-separated headway (s), from Equation 5-10; and

h_{os} = minimum on-street headway (s), from Equation 5-15.

The line capacity, T, in trains per hour is:

Equation 5-17

$$T = \frac{3{,}600}{h_{lr}}$$

PERSON CAPACITY

The maximum person capacity, *P*, is the number of trains multiplied by their length and the number of passengers per unit length, adjusted from peak-within-the peak to peak hour.

Equation 5-18

$$P = TLP_m(PHF) = \frac{3{,}600LP_m(PHF)}{h_{lr}}$$

where:

P = person capacity (p/h);
T = line capacity (trains/h);
L = train length (ft, m);
P_m = linear passenger loading level (p/ft length, p/m length);
PHF = peak hour factor;
3,600 = number of seconds in an hour; and
h_{lr} = minimum light rail headway (s).

Where there are no single-track or on-street constraints, and the signaling system is designed for maximum throughput, the person capacity can be determined through the procedures of Chapter 6, summarized for shorter light rail trains in Exhibit 5-44 and Exhibit 5-46. At the upper end of these levels, the system has become a segregated heavy rail transit system using light rail technology.

No allowance is contained in either of these exhibits for extended dwells due to low-level (step) loading, wheelchairs, or on-board fare collection. With minimum headways provided by cab signals of better than 120 seconds, it is reasonable to expect level loading—whether high or low—and off-vehicle fare collection.

Nor is any allowance made for headway constraints due to junctions or speed restrictions in the maximum load point station approach. Where any of these situations may apply, the procedures of Chapter 7 should be followed.

Predominantly segregated light rail lines with block signaling can reach the achievable capacity of some heavy rail systems. At this upper end of the light rail spectrum, achievable capacity calculations should follow those of heavy rail transit.

Maximum light rail transit capacities.

Note that no light rail lines in the United States and Canada approach volumes of 10,000 passengers per peak hour direction per track, except San Francisco's Muni Metro subway, which is shared by six routes, and Boston's Green Line subway. Achievable capacities to and above 20,000 passengers per peak hour direction are reported in Europe; however, at these levels, the lines, often called light metro, pre-metro, or U-bahn, have many or all of the characteristics of heavy rail transit operated by light rail equipment.

This page is intentionally blank.

CHAPTER 9. COMMUTER RAIL CAPACITY

INTRODUCTION

Commuter rail ridership in North America is dominated by the systems in the New York area where the busiest routes use electric multiple-unit trains on dedicated tracks with little or no freight service. The capacity of such systems can best be determined from the procedures of Chapter 7. Care must be taken to take into account the sometimes lower vehicle performance and lower throughput of signaling systems where these are based on railroad rather than rapid transit practices.

Use the grade-separated rail procedures for commuter rail operated using electric multiple-unit trains on dedicated tracks.

Elsewhere, with the exception of SEPTA's Philadelphia lines, Chicago's Metra Electric and South Shore lines, and the Mont-Royal tunnel line of the AMT in Montréal, commuter rail uses diesel locomotive-hauled coaches and follows railroad practices. Electric locomotive-hauled coaches are also used by SEPTA and New Jersey Transit on routes that also run electric multiple-unit cars. Dual-powered (electric and diesel) locomotives are used by the Long Island Rail Road (LIRR) and Metro-North Railroad in the New York area. All new starts are likely to use diesel locomotive-hauled coaches.

For the remaining lines, there is no easy answer for calculating capacity. Unlike rapid and light rail transit, whose vehicles have similar performance characteristics within their respective modes, the performance of diesel locomotives used by various U.S. commuter operations varies considerably. This performance, measured by the *power-to-weight (P/W) ratio,* ranges from 2 to 10 for commuter rail operations, which makes it difficult to develop a "standard" commuter rail performance for use in capacity calculations. For comparison, a typical diesel Amtrak intercity train has a P/W ratio of 4 to 6, while electric high-speed corridor trains (such as the Metroliner used in the Washington-New York-Boston corridor) have P/W ratios of 10 and higher.(R10) Exhibit 5-72 shows the effect of different P/W ratios on the time and distance needed to accelerate from a stop, and the delay incurred as a result.

Commuter rail capacity determination is inexact.

Exhibit 5-72
Effect of P/W Ratio on Train Acceleration to 80 mph (128 km/h)(R10)

	Power-to-Weight (P/W) Ratio				
	2	4	6	8	10
Distance to accelerate (mi)	23.0	7.3	3.6	2.5	1.9
Distance to accelerate (km)	37.0	11.8	5.8	4.0	3.1
Acceleration time (min)	23.7	7.7	4.3	3.0	2.3
Time lost (min)	3.7	2.3	1.6	1.2	1.0

There are other issues affecting commuter rail capacity that make it difficult to provide a simple analytical technique. First, many smaller commuter rail lines do not own the tracks they use, and therefore the number of trains they can operate will depend on negotiations with the owning railroad. Second, the mix of users of the tracks—and their impacts on capacity—will vary greatly from location to location. Generally, simulation is the only tool available for calculating the capacity of these commuter rail lines. Finally, the number of platforms available at terminal stations may constrain capacity. Consequently, this chapter does not present any equations for calculating commuter rail capacity. Instead, it focuses on the factors that impact capacity and potential means of improving capacity.

Simulation is often the only tool available for calculating commuter rail capacity. For comparison, Appendix B identifies the number of trains operated by, and passengers served by, various commuter rail systems.

TRACK OWNERSHIP AND USAGE

For commuter rail lines that use tracks owned by another railroad, the number of trains that can be operated in the peak hour is dependent on negotiations with the owning railroad. As the number of trains using a track increases—particularly when only a single track is available—the average speed of all trains decreases. Train meets have a compounding impact on capacity: each meet produces delay to the train that must wait, and each delay produces an increased probability of additional future meets. The impact of meets is even more severe when different classes of trains with different characteristics (e.g., passenger and freight trains) share the same tracks.(R21)

One concern that a freight railroad will have when passenger trains are proposed to be added to its tracks will be the impacts on train running times. Train crews have a maximum permitted number of hours they can work at a time, and an increase in train travel time may put them at risk of exceeding that limit if any unexpected delay occurs. Freight railroads may also need to reserve capacity (paths) for freight trains to service local customers during hours that passenger service is being contemplated, or to get trains to a certain location by a certain time.(R18)

There are a number of consumers of track capacity, some recurring but most not. The most common consumers of capacity are(R21)

- Trains (not all use the same amount),
- Track patrols,
- Track maintenance,
- Track deterioration requiring temporary speed restrictions,
- Passenger station stops,
- Industrial switching,
- Freight yard interactions,
- Train or train control system failures,
- Incidents (e.g., crossing accidents, deer, and trespassers), and
- Weather.

Trains will be assigned different levels of priority, and there may be different levels of priority within a particular class of trains. For example, passenger train types can include high-speed intercity, conventional intercity, commuter zone express, commuter local, and deadhead (non-revenue) passenger trains. Freight train types include intermodal, manifest, bulk commodity, and local freight. An individual train's priority may also be raised or lowered depending on special circumstances. For example, early trains will have lower priority, trains whose crews are nearing their legal work hour limit will have higher priority, and heavy trains may be given higher priority, particularly on grades, because of the time required to regain their speed after a stop. The relative priority of each train will determine which one is delayed when two trains meet or one overtakes another.(R18)

Although railroads are becoming more receptive to accommodating commuter rail services—and the revenue and capital upgrading they produce—they have the upper hand and obtaining paths for commuter trains at a reasonable cost can require difficult and protracted negotiations.

Transit agency ownership of track used for commuter rail.

There are an increasing number of exceptions where the operating agency has purchased trackage and/or operating rights and so has more, or total, say in the operation and the priority of passengers over freight. The two New York commuter railroads own the great majority of track they operate on; however, in the case of MTA-Metro North Railroad, priorities must be determined between Metro North's commuter operations and Amtrak's Northeast Corridor services. New Jersey Transit, SEPTA in Philadelphia, MBTA in Boston, Metra in Chicago, and Metrolink in Los Angeles, among others, also own substantial portions of the trackage they use. Some agencies, such as SEPTA, have leverage with the freight railroads, as they own track used by the freight carriers. However, even when an agency owns track or trackage rights, there may still be strict limits on the number of trains that can be operated because of interlockings and grade crossings with other railroads.

TRAIN THROUGHPUT

Determining train throughput requires consulting the railroad agreement or the railroad or agency signaling engineers to determine the maximum permitted number of commuter trains per hour. Generally these numbers will be based on a train of maximum length, so the length-headway variations of Chapter 2 will not enter into the picture.

A definitive answer may not always be obtained, particularly with single-track sections that are shared with freight. Freight traffic can be seasonal and available commuter rail trips can vary. Usually the agreement will ensure a minimum number of commuter rail trips per hour. These may be uni-directional—that is, all trains must platoon in one direction in each peak period. This is generally not a capacity problem but rather an efficiency issue with respect to equipment and staff utilization. Uni-directional operation is an issue on lines where reverse commuting to suburban work sites is important. For example, Chicago's Metra has services aimed specifically at the growing reverse commuter market.

Signal blocks for freight trains are considerably longer than for rail transit operations, due to the length of the trains, and the amount of time and distance required to bring a long, heavy freight train to a stop. Trains are the only means of land transport that cannot stop within their range of vision.(R19) Because of these long stopping distances and the resulting longer block lengths, and the lower speed of freight trains compared with rail transit, both commuter and freight trains take longer to traverse a signal block than their rail transit counterparts. This longer block transit time translates into significantly longer headways between trains and, therefore, lower capacity.

Line Capacity Range

The number of commuter rail trips available per hour may range from one to the double digits. Ten or more trains per hour is at the upper range of traditional railroad signaling and will exceed it if long, slow freights must be accommodated. At the upper end of this range, commuter rail is effectively in sole occupancy of the line for the peak period and is approaching levels where the capacity calculations of Chapter 7 can be considered.

Train throughput where commuter rail has exclusive occupancy of the track.

Only in this case can the grade-separated train separation equation (Equation 5-7) be used as a rough approximation of railroad signaling throughput. The input values should be adjusted using suitably lower braking and acceleration rates and longer train lengths, and by adjusting the separation safety factor *b* from the suggested value of 2.4 for a rapid transit three-aspect signaling system to 3 or 4. This equation and the associated equation for junction throughput do not apply in locations and times where freight and commuter rail trains share trackage or where the signaling system is designed solely for freight with long signal blocks.

Operating practices and patterns.

Additional complications are raised by the variety of commuter services operated and the number of tracks available. The busier commuter rail lines tend to offer a substantial number of stopping patterns in order to minimize passenger travel times and maximize equipment utilization. A common practice is to divide the line into zones with trains serving the stations in a zone and then running express to the station(s) in the CBD. Through local trains provide connections between the zones. A number of lines in the Chicago and New York areas are operated this way—Metra's Burlington Northern line to Aurora operates with five zones in the morning peak, Metro-North's New Haven line (including the New Canaan Branch) operates with seven zones. Such operating practices are made possible with three or more tracks over much of the route and the generous provision of interlockings to allow switching between tracks. Grade-separated junctions are also common where busy lines cross or converge. The capacity of this type of operation is hard to generalize and should be considered on a case-by-case basis. Such heavy operations are similar to grade-separated rapid transit in many ways, but have some notable exceptions, such as the wide range of services operated.

Station Constraints

Train storage at downtown terminals.

Another principal difference between commuter rail and the other rail transit modes is that commuter rail trains are often stored at the downtown terminals during the day. This reduces the need for track capacity in the off-peak direction and allows a higher level of peak-direction service to be operated. Metro-North in New York, with 46 platform tracks[20] at Grand Central Terminal, is thus able to use three of its four Park Avenue tunnel tracks in the peak direction. Even when one of the tunnel tracks was closed for reconstruction, 23 trains per hour were handled on the remaining two peak-direction tracks.

The situation at New York's Penn Station is less relaxed. The LIRR has exclusive use of five tracks and shares four more with Amtrak and New Jersey Transit. Currently the LIRR operates the East River tunnels with two tracks inbound and two tracks outbound with a peak headway of 3 minutes per track. With limited station capacity, two-thirds of LIRR trains continue beyond Penn Station to the West Side Yard. However, not all tracks used by the LIRR at Penn Station continue to the yard and some trains must be turned in the station. This can be done in as little as 3.5 minutes in a rush, but 5 minutes is the minimum scheduled time.

Station Dwells

Dwells are less critical for commuter rail than for heavy rail transit.

Station dwell times on commuter rail lines are generally not as critical as they are on rapid transit and light rail lines, as frequencies are lower and major stations have multiple platforms, such as those shown in Exhibit 5-73. In most cases, the longest dwells are at the multiple-platform downtown terminals where the train is not blocking others while passenger activity takes place.

Exhibit 5-73
Multiple-Platform Commuter Rail Terminal Examples


(a) Toronto (b) Philadelphia

Passenger flows are generally uni-directional and so are not slowed by passengers attempting to board while others alight and vice-versa. Exceptions are locations where major transferring activity takes place between trains but these are limited. Jamaica station on the LIRR is one of the few examples of a station with major transfers as it serves as a funnel where eight lines converge from the east and two major lines diverge to the west. Most transfers are made cross-platform and are scheduled for 2 or 3 minutes. SEPTA's four-track regional rail tunnel through Center City Philadelphia is one of the few North American locations where commuter trains

---

[20] There is some variation between sources regarding the size of Grand Central Terminal, Metro-North reports 46 platform tracks. A number of other sources give the station a total of 67 tracks, including storage and maintenance tracks.

run through from one line to another without terminating downtown. SEPTA schedules provide a very generous time of 10 minutes for trains to make two station stops over this 1.4-mi (2.3-km) line segment.[21]

Platform level and commuter rail car door layout.

Commuter rail station dwell times are dependent on the platform level and car door layout. The busiest lines are equipped with high platforms and remotely controlled sliding doors, as on rapid transit cars. Single-level cars often use conventional traps for high- and low-platform stations but these are time consuming to operate and require a large operating crew. Cars used on lines with both high and low platforms can be fitted with conventional trap doors at the car ends and sliding doors for high-platform use at the center of the car, as on New Jersey Transit, the South Shore in Chicago, and the Mont-Royal line in Montréal. Most bi-level and gallery cars are designed for low platforms and have the lowest step close to the platform for easy and rapid boarding and alighting. Bi-level cars of the type popularized by GO Transit feature two automatic sliding double stream doors per side allowing cars to be emptied in 1 to 2 minutes. Gallery cars usually feature one exceptionally wide door (6.5 ft or 2 m) at the center of each side to allow rapid boarding and alighting with multiple passenger streams.

MEANS OF INCREASING LINE CAPACITY

If the line capacity is determined to be insufficient for the desired level of commuter rail operations, there are three main ways that capacity can be increased: (1) add another track, (2) reduce running times between sidings, and (3) reduce the delay resulting from train meets and overtakes.(R1)

Methods that do one or more of these things are described below, along with a qualitative discussion of each method's potential benefits and potential constraints. Simulation will be required to quantify the effects of a particular method for increasing capacity.

Double Tracking

Double tracking allows some trains to meet without having to stop. Double-track sections can be formed by joining or extending existing sidings, but need to be at least three signal blocks (4.5 to 7.5 mi or 7 to 12 km) long in order to be effective. Longer double-track sections should provide crossovers to allow both meets and overtakes to occur within the double-track section.(R1)

Avoid ending sidings and double-track sections
- On or near grades,
- On curves, and
- Near grade crossings.

The ends of sidings or double-track sections should not be located on or near heavy grades (1% or more), because of the difficulty of starting and stopping heavy trains. Curves should also be avoided at the ends of double-track sections, because of the difficulty of installing and maintaining switches located on curves. Finally, grade crossings should not be located near the ends of double-track sections, because they would be blocked by a train stopped for a meet or overtake.(R1)

Double-tracking an entire line, while very beneficial from a capacity standpoint, is also very costly.

At the extreme, the entire line can be double-tracked. Adding double track to all of Tri-Rail's line in South Florida will allow it to increase service from one passenger train per direction per hour to three. However, the cost of double-tracking a long rail line can be very high, particularly when bridges or tunnels are required, or when additional right-of-way must be acquired.

---

[21] While there are three stations on this segment, timetables only provide departure times and so do not include the dwell time at the first Center City station. Another North American example of a downtown commuter rail station where commuter trains run through is Toronto's Union Station.

Adding and Lengthening Sidings

Sidings are short sections of double track not long enough for trains to pass without one having to stop.

Shorter sections of double track are known as sidings. When trains meet at a siding, one will need to stop and wait for the opposing train to pass (sections of the line that are considered "double track" are long enough for some trains to meet without having to stop). Trains experience two types of delay at sidings, *fixed* and *variable.* Fixed delay includes delay associated with decelerating, stopping, and accelerating, as well as any difference in operating speed between the siding and the main line. Variable delay consists of time that a train must wait for the opposing train once it is in the siding.(R23)

Increasing the number of sidings reduces variable delay, as trains can be directed to a siding closer to the time a meet will occur, but does not change the fixed delay associated with stopping. The capacity benefit diminishes as each new siding is added, because the variable delay is reduced by smaller and smaller increments, but the fixed delay remains.(R1)

Lengthening sidings reduces variable delay, because the distance between the ends of sidings is reduced. However, it adds to fixed delay, because the amount of time required to transit a siding increases as the siding's length increases.(R1)

Providing Higher-Speed Siding Entries and Exits

Increasing the siding entry speed may also require improvements to the siding itself.

Fixed delay is reduced when trains can enter and exit the main line at higher speeds. A siding's entry and exit speed is controlled by the angle of departure of the siding from the main line, which is measured by the switch number (see Exhibit 5-11). The higher the switch number, the faster the entry and exit speed. Additionally, the siding must permit speeds at least as high as the entry and exit speeds, it must be signaled, and it must be long enough to allow a train to stop from the higher entry speed.(R1)

Train Control System Improvements

Signals can be moved closer together, which shortens block lengths and permits trains to run closer together, within the limits created by the safe braking distance needed for the worst-case train. Changing the signal spacing mainly reduces delay when one train overtakes another, as the overtaken train can depart sooner once the other train has passed. Shortening the lengths of blocks can also create a minor improvement in meet delay, as dispatchers have better information about train positions to help them make decisions about which siding to have a train make a meet at.(R1)

Infrastructure Improvements

Improving track conditions to improve train speeds may not improve capacity, if blocks have to be lengthened to accommodate faster trains.

Track conditions on a railroad being considered for commuter rail service may restrict trains' maximum speed. The Federal Railroad Administration defines various track classes, based on such factors as curvature, superelevation, track condition, number of crossties per unit length, and so forth, and sets maximum allowed passenger and freight train speeds based on those classes. Infrastructure improvements to upgrade the track class will improve train operating speeds; however, capacity may not change, as signal blocks may need to be lengthened to safely accommodate the higher speeds, resulting in little or no net change in time to transit a block. Exhibit 5-74 shows the maximum speeds allowed for different track classes.

Exhibit 5-74
U.S. Railroad Track Classes

	Passenger		Freight	
Track Class	mph	km/h	mph	km/h
Excepted	Not allowed	Not allowed	10	16
1	15	24	10	16
2	30	48	25	40
3	60	96	40	64
4	80	128	60	96
5	90	144	80	128

NOTE: Track classes 6 and higher, not shown, are used for high-speed intercity passenger rail.
SOURCE: Code of Federal Regulations, Title 49, Part 213.

Other infrastructure issues can create capacity constraints:(R1)

- *Junctions* are often under the control of different dispatchers, requiring a train to be held at a junction, blocking the exit. Providing a siding at the junction can mitigate this problem.
- Trains operate more slowly when entering and exiting *freight yards.* Providing the ability to bunch trains, either through closer signal spacing or additional tracks can mitigate impacts on capacity. Older freight yards may have been designed for shorter trains; the yard entry track needs to be sufficiently long to hold an entire train without blocking the mainline, while yard switches are lined manually.
- Cars may be temporarily stored on the mainline during *switching operations* on industrial tracks. A service track to store these cars can be constructed to mitigate this problem.

COMMUTER RAIL OPERATING SPEEDS

Exhibit 5-75 gives average commuter rail operating speeds, including station stops, for different combinations of P/W ratios, station spacings, and dwell times. The exhibit assumes conventional block signaling, track conditions providing a passenger train speed limit of 80 mph (128 km/h), no grades, and no delays due to other trains. Note that in most cases, except for the higher P/W ratios and longer station spacings, a train will not be able to accelerate to the assumed speed limit before it has to slow for the next station. When the characteristics of the line (e.g., grades and station locations) and equipment to be used are known, a train simulator should be used to estimate operating speeds. A dwell time of 30 seconds would be difficult to achieve on a higher-volume line, but might be appropriate for lower-volume lines and off-peak periods.(R10)

Exhibit 5-75
Average Commuter Rail Operating Speeds(R10)

	Average Operating Speed (mph)		
Station Spacing (mi)	P/W = 3.0	P/W = 5.8	P/W = 9.1
Average Dwell Time = 30 s			
1.0	16.8	20.3	22.3
2.0	25.8	30.9	35.0
4.0	36.4	44.1	48.6
5.0	40.3	48.7	52.7
Average Dwell Time = 60 s			
1.0	14.8	17.4	18.8
2.0	23.3	27.4	30.6
4.0	33.8	40.4	44.1
5.0	37.8	45.0	48.5

NOTE: P/W = power-to-weight ratio
Assumes 80-mph speed limit, no grades, and no delays due to other trains.

An alternative figure using metric units appears in Appendix A.

PERSON CAPACITY

Except for a few situations where standing passengers are accepted for short distances into the city center, commuter rail train capacity is based solely on the number of seats provided on each train. A peak hour factor of 0.90 or 0.95 is used to allow for variations in passenger boarding demand.

Constant train length.

Where the equipment design is known, the best procedure is to add the number of seats in a train. Unless there is an agency policy of peak hour occupancy at 95% of total seats, the 0.90 factor should be used. Where trains are the same length, the commuter rail capacity is simply:

Equation 5-19

$$(\text{trains per hour}) \times (\text{seats per train}) \times 0.90$$

Variable train length.

In many cases, train length is adjusted according to demand. The longest train will be the one arriving just before the main business starting time in the morning—and vice-versa in the afternoon. Shorter trains may be used at the extremities of the peak period. In this case the total number of seats provided over the peak hour must be determined and the peak hour factor applied.

Seats per unit of train length and short trains.

Where the rolling stock design is unknown, the number of seats per unit length of train can be used, based on the shortest platform where the service will stop. A number of systems, particularly the older ones, operate trains that exceed the platform length at a number of stations. This situation is particularly common where platforms are constrained by physical and built-up features. Passengers must take care to be in the correct car(s) if alighting at a station with short platforms.[22] Train length on electric lines can also be limited by the amount of current the overhead or third-rail is able to supply.

Characteristics of existing commuter rail cars.

Exhibit 5-76 shows the number of seats and seats per meter length of selected North American commuter rail cars. All cars have substantially the same outside dimensions—the AAR passenger car maximums of 82.7 ft (25.2 m) long and 10.5 ft (3.2 m) wide.

Passenger loads range from more than 2 to less than 0.6 p/ft length (7 to 2 p/m length). A 2+3 seating configuration is needed to reach 2.1 p/ft length (7 p/m length). Such seating is not popular with passengers and the middle seats are not always occupied with some passengers preferring to stand for shorter trips.

A capacity of 2.1 p/ft length (7 p/m length) can be used as a maximum. A range of 1.5 p/ft length (5 p/m length) is the upper end for single-level cars, with 1.2 p/ft length (4 p/m length) preferred. These preferred and recommended levels allow some space for toilets, wheeled mobility aids, strollers, luggage, and bicycles. If these provisions are extensive, then the car capacity should be reduced accordingly. Obviously, the train length should exclude the length of the locomotive(s) and any service cars, and should be adjusted for any low-density club, bar, or food service cars.

An allowance for standing passengers is not recommended. However, if the nature of the service has significant short trips, it may be appropriate to add 10% to the number of seats on the train. Heavy rail standing densities are not appropriate for commuter rail.

---

[22] Another common station limitation, lack of park-and-ride capacity, is considered in Chapter 5.

Exhibit 5-76
Commuter Rail Car Capacity(R15)

System and City	Car Designation	Date Built	Seats	Seats/ft (m)
Bi-level cars				
LIRR (New York)	C-1	1990	190	2.4 (7.3)
MBTA (Boston)	BTC	1991	185	2.3 (7.1)
MBTA (Boston)	CTC	1991	180	2.3 (6.9)
GO Transit (Toronto)	Bi-Level Trailer	1977-91	162	2.1 (6.3)
Metra (Chicago)	TA2D, E, F	1974-80	157	2.0 (6.1)
Tri-Rail (Miami)	Bi-Level III	1988	159	2.0 (6.1)
CalTrain (San Francisco)	Gallery Coach	1985-87	148	1.9 (5.7)
SCRRA (Los Angeles)	Bi-Level V Mod.	1992-93	148	1.9 (5.7)
Metra (Chicago)	Gallery	1995	148	1.9 (5.7)
Single-level cars				
NICTD (Chicago)	TMU-1	1992	130	1.6 (5.0)
NJT (New Jersey)	Comet IIB	1987-88	126	1.6 (4.9)
Metro-North (New York)	M-6 D	1993	126	1.6 (4.9)
MBTA (Boston)	CTC-1A	1989-90	122	1.55 (4.7)
NJT (New Jersey)	Comet III	1990-91	118	1.5 (4.6)
LIRR (New York)	M-3	1985	120	1.5 (4.6)
SEPTA (Philadelphia)	JW2-C	1987	118	1.5 (4.6)
MARC (Baltimore)	Coach	1992-3	120	1.5 (4.6)
MARC (Baltimore)	Coach	1985-87	114	1.45 (4.4)
NJT (New Jersey)	Comet II/IIA	1982-83	113	1.45 (4.4)
LIRR (New York)	M-3	1985	114	1.45 (4.4)
MARC (Baltimore)	E/H Cab	1991	114	1.45 (4.4)
VRE (Washington, D.C.)	Cab	1992	112	1.4 (4.3)
Metro-North (New York)	SPV 2000	1981	109	1.4 (4.2)
NICTD (Chicago)	EMU-2	1992	110	1.4 (4.2)
Metro-North (New York)	M-6 B	1993	106	1.35 (4.1)
MARC (Baltimore)	E/H Cab	1985-87	104	1.3 (4.0)
NJT (New Jersey)	Comet III	1990-91	103	1.3 (4.0)
MBTA (Boston)	BTC-3	1987-88	96	1.2 (3.7)
AMT (Montréal)	MR90 (emu)	1994	95	1.2 (3.7)
NICTD (Chicago)	EMU-1	1982	93	1.2 (3.6)
Conn DOT (New York)	SPV 2000	1979	84	1.05 (3.2)

NOTE: Identical car models listed more than once reflect different seating configurations.

This page is intentionally blank.

CHAPTER 10. AUTOMATED GUIDEWAY TRANSIT CAPACITY

INTRODUCTION

AGT fits into the category of *Grade-Separated Rail,* whose capacity determination was specified in Chapter 7. However, there are some nuances specific to AGT that must be considered.

AGT has a relatively low share of transit ridership.

AGT is an almost negligible part of urban, public, fixed guideway transit—being used for less than 0.1% of passenger trips in the United States—increasing only when institutional systems are considered, most of which are intra-airport shuttles. Technology ranges widely from standard-gauge advanced light rapid transit, to downtown people-movers in Detroit and Miami, to small-scale monorails in amusement parks. All AGT systems are proprietary designs. As such, their performance, acceleration, and braking rate vary greatly, as does their balance between speed, vehicle size, and capacity.

TRAIN CONTROL SEPARATION

Train control systems on AGT range from sophisticated moving-block signaling systems to basic manual systems in which only one train may be on a section of line—or the entire line—at a time. Manual or radio dispatching may ensure that a train does not leave a station until the leading train has left the station ahead. One variation uses sectioned power supply. Power is disconnected for a given distance behind an operating train.

These operating variations are not fully accommodated in the methodology of Chapters 2 and 7. If the basic AGT performance criteria are known, then the procedures of Chapter 7 will provide an approximation of the minimum train separation time for a range of AGT train controls—from a moving-block signaling system to a simple fixed-block system. A surrogate of this can be roughly simulated by setting the train detection uncertainty factor (*B*) at four times the minimum braking distance. The results are shown in Exhibit 5-77 for trains of typical AGT lengths, using the specific AGT values in Exhibit 5-78, with terms adjusted from typical rail transit values shaded.

Exhibit 5-77
AGT Minimum Train Separation Times(R15)

	Minimum Train Separation (s)	
Train Length	Fixed Block	Moving Block
160 ft (50 m)	48.7	16.7
80 ft (25 m)	37.6	13.4
40 ft (12.5 m)	20.5	11.2

Exhibit 5-78
Suggested AGT Separation Calculation Default Values(R15)

An alternative figure using metric units appears in Appendix A.

Default Value			
Heavy Rail	AGT	Term	Description
20 ft	20 ft	P_e	positioning error
650 ft	165 ft	L	length of the longest train
35 ft	0 ft	d_{eb}	distance from front of train to exit block
75%	75%	f_{br}	braking safety factor—% of maximum braking rate
2.4	4	b	train detection uncertainty constant— fixed block
1	1	b	train detection uncertainty constant— moving block
3 s	1 s	t_{os}	time for overspeed governor to operate
0.5 s	0.5 s	t_{jl}	time lost to braking jerk limitation
4.3 ft/s^2	2.0 ft/s^2	a	service acceleration rate
4.3 ft/s^2	3.3 ft/s^2	d	service deceleration rate
1.5 s	0.5 s	t_{br}	brake system reaction time
60 mph	50 mph	v_{max}	maximum line velocity
165 ft	80 ft	S_{mb}	moving-block safety distance

NOTE: shaded lines indicate AGT default values that differ from heavy rail default values.

The results show that separation times with a simulated single aspect block system are two to three times longer than with the more complex—and expensive—moving-block signaling system. The moving-block results agree with those of Auer,(R7) the only reference specializing in AGT train control. Here, typical short train AGT separation with moving-block control was cited at 15 seconds.

The separation range is wide and highly dependent on the train control system of the proprietary AGT system. The best method of determining the minimum train separation is from the system manufacturer or designer. Using the methodology of Chapter 7 should be a last resort when specific train separation information is not available.

PASSENGER FLOW RATES AND DWELLS

AGT systems that are part of a normal transit system can assume flow rates and station dwell times as determined in Chapter 3. However, most AGT systems are classed as institutional and the majority of passengers are unlikely to be regular, experienced transit users. Doorways are rarely of typical transit width or configuration. The most common arrangement is the quadruple-flow door with associated platform screen doors—shown in Exhibit 5-79.

Exhibit 5-79
Orlando Airport People-Mover Doorways

Doorway flow rates on AGT

Doorway flow rates and the associated station dwell times were monitored on the three C-100 systems at the Seattle-Tacoma Airport in May 1995. The range of users varied greatly and included many people with baggage and a few with baggage carts. After the arrival of a full flight with a preponderance of business passengers, passenger flow rates reached and exceeded standard transit doorway flow rates. At other times, doorway flow rates were often well below the transit rates documented in Chapter 3. Under these circumstances calculating flow times—and from them dwell times—is unwise. The results are unlikely to be accurate or may reflect only a very specific sub-set of users.

AGT headways.

The selection of a minimum headway for AGT systems should reflect the train control separation, dwell time, and any operating margin that conforms with existing operations or is suggested by the system manufacturer. The typical headway of airport systems is 120 seconds with a few operating down to 90 seconds. Claims have been made for closer headways with some proprietary systems. Headways shorter than 90 seconds are possible but may limit dwell times and constrain the operating margin. They should be considered with caution unless off-line stations are adopted. Off-line stations make closer headways possible and practical—at a price.

LOADING LEVELS

AGT loading levels tend to be atypical of transit overall.

Loading levels of AGT cars tend to be atypical of normal transit operations. Those systems that are integral parts of public transit networks—such as the Detroit and Miami downtown people-movers—can use loading levels derived from Chapter 4.

Other systems range widely. At one extreme are the airport shuttles with wide cars and no or few seats where loading can reach 3 p/ft length (10 p/m length) under pressure from arriving business-type flights. Loading diversity on airport systems fluctuates related to flight arrival times, rather than 15-minute peak periods within a peak hour. After an arriving flight three trains at 120-second headways can exceed maximum loading levels—to be followed by a number of under-utilized trains.

At the other extreme are the narrow, all-seated configuration amusement park monorails with loading as low as 0.6 to 0.9 p/ft length (2 to 3 p/m length). The peak hour factor on the latter type systems attains unity when arrangements—and continual passenger queues—ensure that every seat on every train is occupied—in some cases, through all hours of operation.

The hourly achievable capacity of non-public transit AGT systems requires consultation with the system supplier. The methodologies and calculations of this manual should only be used as a last resort—and then treated as a guideline.

OFF-LINE STATIONS

Off-line stations increase capacity.

Off-line stations maximize system capacity. They are used on several rail transit lines in Japan to achieve some of the highest throughput for two-track rapid transit lines in the world. In North America, they are the exclusive preserve of the AGT line in Morgantown, West Virginia.[23]

Off-line stations permit a train throughput that is partly independent of station dwell time. Throughput is that of the train control system plus an allowance for switch operation and a reduced operating margin.[24] Morgantown and certain other AGT systems use on-vehicle switching techniques where even this allowance—typically 6 seconds—can be dispensed with. In theory, trains or single vehicles can operate at or close to the minimum train control separation—which can be as low as every 15 seconds—refer to Exhibit 5-78.

Major stations with high passenger volumes may require multiple platform berths, otherwise partial dwell times must be added to the train separation times to obtain the minimum headway. The achievable capacity of such specialized systems should be determined through consultation with the system manufacturer or design consultant.

---

[23] Systems with multiple platform terminal stations could be regarded as a sub-set of off-line stations. The Mexico City Metro and PATH (New York) are examples of such arrangements. Not coincidentally, these two systems achieve, respectively, the highest passenger throughput and the closest regular headway on the continent — for two-track rail transit systems.

[24] Operating margins are intended to accommodate irregularities in train control separation and dwell times. Off-line stations remove the need to allow for dwell time variations.

This page is intentionally blank.

CHAPTER 11. ROPEWAY CAPACITY

INTRODUCTION

Ropeways in North America are more commonly used by private owners than by public transit agencies.

This chapter covers the capacity of transit modes that are hauled by cable (wire rope). Although these modes are not widely used in North America for public transit, they are sometimes considered as modal alternatives in transit feasibility studies, and have been constructed as part of a number of private developments, particularly ski areas. In Europe, funicular railways can be found in a number of hilly urban settings, and both funiculars and aerial tramways are used for access to some remote villages inaccessible by road.

Surface modes include some of the oldest mechanized purely urban transportation systems, discounting extensions of intercity rail networks into city centers. Vehicles are either permanently attached to the rope or can attach and detach from the rope by means of a grip mechanism. In either case, the motor driving the rope is located in a remote location, not on the vehicle itself, and the vehicle operates on a guideway. As described in Part 2, surface ropeway modes include *cable cars,*[25] *inclined planes* (funicular railways), and *cable-hauled automated people-movers*.

Aerial ropeways suspend the carrier (comprising the cabin, hanger, and grip) from a rope. The cable may serve to suspend and haul the carrier (*monocable*); two ropes may be used, a fixed track rope for suspension and a moving haul rope for propulsion (*bicable*); or multiple ropes may be used to provide greater wind stability. Carriers can operate in a back-and-forth, shuttle operation, or can be part of a continuously circulating system. The motor driving the haul rope(s) is located at a remote location (one end or the other of the line). The common aerial ropeway modes are *aerial tramways* and *aerial lifts* (gondolas, ski lifts, and funitels).

For the purposes of this chapter, two capacity categories are used: (1) reversible systems and (2) continuously circulating systems. These categories include both surface and aerial ropeway modes as members.

REVERSIBLE SYSTEM CAPACITY

A reversible system typically provides two vehicles that are always attached to a rope and that move back and forth along the line at the same time. When one vehicle is at one terminal, the other vehicle will be at the opposite terminal. Vehicles are accelerated to line speed by increasing the speed of the haul rope and decelerated by slowing the haul rope. Passenger loading and unloading occurs while the vehicle is stopped. Modes that fall into this category are inclined planes and aerial tramways.

The line capacity of a reversible system is dependent on the length of the line, the line speed, and dwell times at stations. Reversible systems are usually designed with only two stations. A third station, if used, desirably should be located exactly halfway along the line so that both vehicles can be in the station at the same time. If the station is not located exactly halfway, then each vehicle will make two intermediate stops: one while at the station and one while the other vehicle is at the station.

Manufacturers claim line speeds of up to 33 to 46 ft/s (10 to 14 m/s) for modern funiculars and up to 39 ft/s (12 m/s) for aerial tramways. The average line speed will be somewhat less, due to acceleration and deceleration needs, and (for aerial tramways) any slowing of the line required as the carrier passes over towers.

---

[25] Some aerial tramways are also called "cable cars." As used here, the term refers to the surface mode that now is only found in San Francisco.

Equation 5-20 provides the directional line capacity of a reversible system.

Equation 5-20

$$T = \frac{1{,}800 N_v}{(N_s t_d) + \dfrac{L_l}{v_l}}$$

where:

T = line capacity (trains/h, carriers/h);
1,800 = number of seconds in an hour, divided by two;
N_v = number of vehicles (1 or 2);
N_s = number of stops per direction:
1—two-station system,
2—three-station system, with middle station exactly halfway, and
3—three-station system, with offset middle station;
t_d = average dwell time (s);
L_l = line length (ft, m); and
v_l = average line speed (ft/s, m/s).

CONTINUOUSLY CIRCULATING SYSTEM CAPACITY

A continuously circulating system provides multiple carriers, cars, or trains that move around a route that forms a loop. Vehicles can be attached to the rope at all times (*fixed-grip)* or can be attached and detached as needed (*detachable grip*).

The concept of moving at high speed along the line and detaching from the line at stops and stations is shared by all detachable-grip modes, including detachable-grip aerial lifts, funitels, cable-hauled automated people movers (APMs), and cable cars. At stops or stations, passenger loading takes place while the vehicle is stopped (cable cars and some APMs), or while moving at creep speed (0.8 ft/s or 0.25 m/s). Manufacturers claimed line speeds range up to 20 ft/s (6 m/s) for detachable-grip gondolas, to 23 ft/s (7 m/s) for funitels, and 26 ft/s (8 m/s) for cable-hauled APMs.

Fixed-grip modes do not detach from their haul rope. Fixed-grip ski lifts load and unload passengers at line speed, but for other applications, the rope must be brought to either a full stop or creep speed at stations. To minimize the number of stops that passengers must make between stations, many fixed-grip gondola systems are designed as *pulse* systems, with three or four carriers attached in a series. At the station, all of the carriers in the series can be loaded and unloaded at the same time, thus minimizing the number of intermediate stops and improving overall travel speeds. Fixed-grip gondolas have a maximum claimed line speed of 23 ft/s (7 m/s).

The line capacity of a continuously circulating system is dependent on the average line speed and the spacing between carriers. For APMs, which can have multiple stations, dwell time is used to develop the minimum safe spacing between trains, following the procedure described in Chapter 7 for grade-separated systems. Platform doors are often used both for safety (keeping passengers from falling onto the tracks or between cars of a train), and to control dwells, by keeping late-arriving passengers on the platform from holding the train doors open. For fixed-grip aerial lifts, dwell time is incorporated in the average line speed. Dwell time is not a factor for detachable-grip aerial lifts and funitels, as the carriers circulate through the station at a constant, low speed, without stopping. Equation 5-21 provides the directional line capacity of a continuously circulating system.

$$T = 3{,}600 \frac{v_l}{d_c}$$

Equation 5-21

where:

T = line capacity (trains/h, cars/h, carriers/h);
v_l = average line speed (ft/s, m/s); and
d_c = average carrier/train/car spacing on the line (ft/carrier, m/carrier).

PERSON CAPACITY

Manufacturers' stated capacities typically do not account for loading diversity.

Manufacturers of ropeway systems tend to state *theoretical* person capacities, based on the maximum number of people that can be carried over the course of an hour, assuming all passenger space within each vehicle is occupied. For some applications that may experience constant queues, such as ski areas, this may be a reasonable assumption. However, for public transit use, as well as any other application where minimizing passenger wait time is desired, a peak hour factor should be applied. The PHF accounts for the system's inability to fill every seat in every vehicle, as some capacity is reserved to handle surges in passenger demand.

The person capacity of an aerial ropeway cannot be easily increased, except for gondola systems designed with future expansion in mind.

Changing the person capacity of aerial ropeway systems is difficult, because the infrastructure (e.g., towers, rope size, vertical clearances) is designed around a particular number and size of carriers. Changing the carrier size typically requires major changes to the infrastructure. However, it is possible to design a gondola system for a larger number of carriers than will be used initially. This reduces initial capital costs and allows the provided capacity to be matched to demand, as additional carriers can be added later as needed, up to the maximum number for which the system was designed.

Because the number of carriers used on detachable-grip systems can be varied by the operator, the person capacity of these systems can be adjusted over time by adding additional carriers. In this case, consideration should be given to differentiating between capacities that can currently be achieved with a given number of carriers, and the maximum capacity that could be achieved.

The size of the cabins used by the various modes addressed in this chapter vary greatly. Once a particular cabin size is selected, it is difficult—if not impossible—to add person capacity by using larger carriers, without rebuilding much of the system. Other infrastructure elements (e.g., towers, platforms, clearances) are designed around a particular carrier and may not be able to accommodate a larger carrier. Exhibit 5-80 provides typical ranges of cabin sizes for each mode.

Exhibit 5-80
Typical Cabin Sizes of Ropeway Modes

Mode	Capacity (p/car)	Comments
	Surface Modes	
Inclined plane/funicular	20-175	Two-car trains possible
Automated people mover	30-140	Multiple-car trains possible
	Aerial Modes	
Aerial tramway	20-180	Double-decked at upper limit
Gondola	4-15	
Funitel	24-30	

SOURCE: Manufacturer data.

The person capacity of a ropeway system is the line capacity (in carriers per hour) multiplied by the cabin size and a peak hour factor, as shown in Equation 5-22.

$$P = TC_c(PHF)$$

Equation 5-22

where:

P = person capacity (p/h);
T = line capacity (carriers/h);
C_c = carrier capacity (p/carrier); and
PHF = peak hour factor.

This page is intentionally blank.

CHAPTER 12. REFERENCES

1. Agnew, Gary, "Single Track Capacity Issues, Part 2," *TRB Workshop on Railroad Capacity and Corridor Planning,* 81st Annual Meeting of the Transportation Research Board, Washington, DC (January 2002).
2. Alle, P., "Improving Rail Transit Line Capacity Using Computer Graphics," *Logistics and Transportation Review,* Vol. 17, No. 4, University of British Columbia, Faculty of Commerce, Vancouver, BC (December 1981).
3. Allen, Duncan W. Practical Limits of Single-Track Light Rail Transit Operation. In *Transportation Research Record 1361,* TRB, National Research Council, Washington, DC (1992).
4. American Public Transportation Association, *Average New Rail Vehicle Costs, 2000-2001,* http://www.apta.com/research/stats/rail/railcost.cfm, accessed January 28, 2002.
5. American Public Transportation Association, *APTA Ridership Report, Third Quarter 2002,* http://www.apta.com/research/stats/ridershp/riderep/documents/02q3rep.pdf, accessed February 1, 2003.
6. American Railway Engineering and Maintenance-of-Way Association, *AREMA Manual for Railway Engineering,* Landover, MD (2000).
7. Auer, J.H., "Rail-Transit People-Mover Headway Comparison," *IEEE Transactions on Vehicular Technology,* Institute of Electrical and Electronics Engineers (1974).
8. Batelle Institute, *Recommendations en vie de l'amènagement d'une installation de transport compte tenu de donnèes anthropomètriques et des limites physiologiques de l'homme,* Geneva, Switzerland (1973).
9. Demery, Leroy W., "Supply-Side Analysis and Verification of Ridership Forecasts for Mass Transit Capital Projects," *APA Journal* (Summer 1994).
10. Galloway, Drew, "Train Performance Characteristics," *TRB Workshop on Railroad Capacity and Corridor Planning,* 81st Annual Meeting of the Transportation Research Board, Washington, DC (January 2002).
11. Horowitz, Bruce, "Commuter Operations Capacity Issues," *TRB Workshop on Railroad Capacity and Corridor Planning,* 81st Annual Meeting of the Transportation Research Board, Washington, DC (January 2002).
12. Jacobs, Michael, Robert E. Skinner, and Andrew C. Lemer, *Transit Project Planning Guidance – Estimate of Transit Supply Parameters,* Transportation Systems Center, U.S. Department of Transportation, Washington, DC (1984).
13. Levinson, H.S., "Capacity Concepts for Street-Running Light Rail Transit," Rahmi Akçelik, Editor, in *Proceedings of the Second International Symposium on Highway Capacity,* Australian Road Research Board Ltd. and Transportation Research Board, Sydney, Australia (August 1994).
14. National Fire Protection Association, *NFPA 130 Standard for Fixed Guideway Transit and Passenger Rail Systems,* 2000 Edition, Washington, DC (2000).
15. Parkinson, Tom and Ian Fisher, *TCRP Report 13: Rail Transit Capacity,* TRB, National Academy Press, Washington, DC (1996). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_13-a.pdf

16. Port Authority (Pittsburgh, PA), *Elements of Stage II Light Rail Reconstruction Program,* http://www.ridegold.com/grow/capital/stageii/components.asp, accessed January 28, 2002.
17. Pushkarev, Boris S., Jeffrey M. Zupan, and Robert S. Cumella, *Urban Rail in America: An Exploration of Criteria for Fixed-Guideway Transit,* Indiana University Press, Bloomington, IN (1982).
18. Reistrup, Paul, "Prioritizing Train Movements," *TRB Workshop on Railroad Capacity and Corridor Planning,* 81st Annual Meeting of the Transportation Research Board, Washington, DC (January 2002).
19. Reistrup, Paul, "Summary," *TRB Workshop on Railroad Capacity and Corridor Planning,* 81st Annual Meeting of the Transportation Research Board, Washington, DC (January 2002).
20. San Diego Trolley, Inc., *Technical Fact Sheet,* San Diego, CA (August 4, 2000).
21. Schaefer, Bill, "Introduction," *TRB Workshop on Railroad Capacity and Corridor Planning,* 81st Annual Meeting of the Transportation Research Board, Washington, DC (January 2002).
22. Tereschuck, Peter D., "San Diego Light Rail Transit Goes to the Superbowl," presented at the TRB 79th Annual Meeting, Washington, DC (January 2000).
23. Wilson, Rick, "Single Track Capacity Issues, Part 1," *TRB Workshop on Railroad Capacity and Corridor Planning,* 81st Annual Meeting of the Transportation Research Board, Washington, DC (January 2002).

CHAPTER 13. EXAMPLE PROBLEMS

Example Problem 1

The Situation

A transit agency is planning to build a heavy rail transit line and wants to determine the minimum train separation possible with a cab signaling system and with a variable safety distance moving-block signaling system.

The Question

1. What is the minimum train separation (ignoring station dwell time and operating margin effects) with each type of signaling system?
2. What is the minimum headway with typical dwells and operating margins?
3. What is the resultant maximum capacity for a new system with higher quality loading standards?

The Facts

The agency is planning to use trains consisting of a maximum of eight 25-m cars. Trains will operate at a maximum of 100 km/h (27.8 m/s) and will be traveling at 52 km/h (14.4 m/s) when entering stations if the cab signaling system is chosen, and at 55 km/h (15.3 m/s) if a moving-block system is selected.[26] The distance from the front of a stopped train to the station exit block is 10 m. Assume that there are no grades into or out of stations and that no civil speed restrictions limit approach speeds to sub-optimal levels.

Solution required for two signaling systems.

Outline of Solution

To answer this question, two equations must be used, one for each signaling system type. Equations 5-7 and 5-9 are found in Chapter 7. Note that these equations provide allowances for grades and line voltage effects that have been removed as they are not required to answer this question. The values for all variables are summarized as follows:

Value	Term	Description
calculated	t_{cs}	train control separation
200 m	L_t	length of the longest train
10 m	d_{eb}	distance from front of stopped train to start of station exit block in meters
14.4 m/s (cab) 15.3 m/s (moving block)	v_a	station approach speed
27.8 m/s	v_{max}	maximum line speed (27.8 m/s = 100 km/h)
75%	f_{br}	braking safety factor—worst-case service braking is f_{br}% of specified normal rate—typically 75%
1.2 (cab) 1 (moving block)	b	separation safety factor—equivalent to number of braking distances (surrogate for blocks) that separate trains
3.0 s	t_{os}	time for overspeed governor to operate on automatic systems—driver sighting and reaction times on manual systems
0.5 s	t_{jl}	time lost to braking jerk limitation
1.5 s	t_{br}	brake system reaction time
1.3 m/s^2	a	initial service acceleration rate
1.3 m/s^2	d	service deceleration rate
6.25 m	P_e	positioning error—moving block only

---

[26] Note that these station approach speeds are the optimal speeds to achieve minimum train separation. Solving for the optimal approach speed directly is not a simple task and is best done using a computer spreadsheet's solver or goal seek function to automate the iterative process that is required.

Steps

1. Determine train control separation

(a) with cab signaling

The relevant equation is Equation 5-7, modified to remove dwell, operating margin, voltage, and grade:

$$t_{cs} = \sqrt{\frac{2(L_t + d_{eb})}{a}} + \frac{L_t}{v_a} + \left(\frac{100}{f_{br}} + b\right)\left(\frac{v_a}{2d}\right) + \frac{at_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

$$t_{cs} = 18.0 + 13.9 + (2.53)(5.54) + (0.406)(0.507) + 3.0 + 0.5 + 1.5$$

$$t_{cs} = 51.1\,\text{s}$$

Compare the approach speed producing the minimum train separation with any speed restrictions on the station approach.

(b) with moving-block signaling

The relevant equation is Equation 5-9, modified to remove dwell, operating margin, voltage, and grade:

$$t_{cs} = \frac{L_t + P_e}{v_a} + \left(\frac{100}{f_{br}} + b\right)\left(\frac{v_a}{2d}\right) + \frac{at_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

$$t_{cs} = 13.5 + (2.33)(5.88) + (0.382)(0.550) + 3.0 + 0.5 + 1.5$$

$$t_{cs} = 32.4\,\text{s}$$

The net result is that the minimum train separation at stations (negating the effects of station dwells and an operating margin) would be 51.1 seconds with a cab signaling system or 32.4 seconds with a variable safety distance moving-block system and automatic train operation.

2. Determine controlling dwell

In Chapter 7, *Grade-Separated Systems,* four methods were shown for determining the controlling dwells. Method 2, *Using Existing Dwell Data*, is not applicable to a new system. The simplest option is to use Method 1, which recommends a range of dwell values from 35 to 45 seconds. If there are no indications of any single very high volume stations (where the more complicated dwell calculations should be used) then a median value of 40 seconds can be selected.

Determine dwell using simple method.

3. Determine the operating margin

In Chapter 5, *Operating Issues,* it was suggested that the more operating margin that can be incorporated in the headway the better, with 20 to 25 seconds as the best guide. Here, 25 seconds is selected to provide better reliability. The total of the controlling dwell at the busiest station and the operating margin is then 65 seconds. Adding this to the minimum train separation times, calculated above, results in minimum headways of 116.1 and 97.4 seconds, respectively. These should be rounded up to an integral number of trains per hour, that is, 120 seconds—30 trains per hour, and 100 seconds—36 trains per hour.

4. Determine passenger loading and capacity

Chapter 4 indicates that a recommended comfortable heavy-rail car loading for a new system is 6 passengers per linear meter of train length, inclusive of diversity allowances. At this loading level, the specified train of eight 25-meter-long cars can carry 8 x 6 x 25 = 1,200 passengers.

The Results

Multiplying the number of passengers per train by the number of trains per hour provides passengers per peak hour direction per track of 36,000 p/h/dir and 43,200 p/h/dir, respectively. Reflecting the approximations used in this determination, the results should be rounded down to the nearest 1,000—36,000 and 43,000.

Comments

The planning-level graphs in Chapter 6 also could have been used to answer the third question about person capacity. The results obtained above correspond to the lower bounds of the capacity ranges in Exhibits 5-44 and 5-46. The lower bounds in the graphs correspond to a combined dwell time and operating margin of 70 seconds, whereas this example used a combined time of 65 seconds. The reason the calculated results are not higher than the graphs' lower bounds was the decision made in Step 3 to use clock headways, which resulted in 1 fewer train per hour and, thus, 1 fewer train's worth of person capacity (approximately 1,200 people). Exhibit 5-28 shows that many North American rail systems operating at or close to capacity do not use clock headways.

Example Problem 2

The Situation

The transit agency from Example Problem 1 has decided to use a variable safety distance moving-block signaling system. The agency would now like to know if it can economize on construction by building a flat junction at a point where two of its lines diverge. The agency's long-term plan is to run a 2-minute headway through the junction.

The Question

Can a flat junction on this proposed system support a 2-minute headway or must a flying junction be constructed?

The Facts

Many of the variables are the same as those used in the previous example. In addition, the agency plans to build its tracks 5 meters apart and use #10 turnouts (switches) with a throw-and-lock time of 6 seconds at mainline junctions. To make operations through a flat junction reliable, the agency plans to increase the operating margin to 45 seconds, hence the headway increases from 100 to 120 seconds.

Outline of Solution

Solving this problem requires the use of Equation 5-5.

Steps

Equation 5-5 is:

$$h_j = h_l + \sqrt{\frac{2(L_t + 2 f_{sa} d_{ts})}{a}} + \frac{v_l}{a+d} + t_s + t_{om}$$

The variables used in the equation are summarized in the following table:

Value	Term	Description
Calculated	h_j	limiting headway at junction
32.4 s	h_l	line headway, from Example Problem 1, Step 1b
200 m	L_t	train length
9.62	f_{sa}	switch angle factor (9.62 for a #10 switch, from Equation 5-5)
5 m	d_{ts}	track separation
1.3 m/s^2	a	initial service acceleration rate
1.3 m/s^2	d	service deceleration rate
27.8 m/s	v_l	line speed (27.8 m/s = 100 km/h)
6.0 s	t_s	switch throw and lock time
45 s	t_{om}	operating margin

Substituting the known variables into the equation produces:

$$h_j = 32.4 + 21.3 + 10.7 + 6.0 + 45$$

$$h_j = 115.4 \text{ s}$$

The Results

While the resulting value of *H(j)* would appear to support 2-minute headways, it is only about four seconds less than the planned headway. Based on this narrow margin, it would be prudent to opt for a flying junction rather than risk service disruptions with a flat junction—even with the operating margin increased to 45 seconds. This is consistent with that recommendation in Chapter 2 that junctions should be grade-separated at headways below 3 minutes.

Calculations concur with the rule of thumb that junctions should be grade-separated at headways below 3 minutes.

Example Problem 3

The Situation

A busy heavy rail line operates through a major transfer station with long station dwell times.

The Question

What is the maximum person capacity through this station?

The Facts

- A generous loading standard means more passengers seated.
- The transit agency's loading standard is 6 passengers per meter of car length during the peak 15 minutes.
- Service is provided by 10-car trains with each car being 22.8 m long.
- The dwell time at the controlling dwell station averages 30 seconds with a standard deviation of 21 seconds.
- There is a 1.5% downgrade into the station.
- The line is automated and uses moving-block signaling.
- Train operators are responsible for closing the doors and initiating acceleration; this delay is incorporated into the dwell time.
- Trains are evenly loaded over their length.

Outline of Solution

The solution consists of three key steps: (1) determining each train's passenger capacity, (2) determining the minimum train separation based on the signaling system and train length, and (3) incorporating the station dwell time and an operating margin. To determine the minimum headway, allowances for dwell time and an operating margin must be added to the minimum train separation time. The results of these steps can then be combined to produce the maximum capacity based on the parameters given.

Steps

1. Determine the train capacity

When a PHF is and is not needed.

This step is very straightforward and is based on the number of cars in each train, the length of each car, and the number of passenger spaces per unit of car length. Because the agency's loading standard is based on peak-within-the-peak conditions, a peak hour factor must be used. In the absence of other information, a PHF of 0.80 is appropriate for heavy rail. This factor accounts for lower passenger demand during the other 45 minutes of the peak hour, which would result in unused capacity. If the agency policy had been to maintain an average loading of 6 p/m length during the peak hour, resulting in more crowded peak-within-the-peak conditions, no PHF would have been needed.

$$(10 \text{ cars/train})(22.8 \text{ m/car})(6 \text{ p/m})(0.80) = 1{,}094 \text{ p/train}$$

2. Determine the minimum train separation

This step requires use of Equation 5-9. Since consideration of station dwell times and the operating margin are deferred to the next step, they are not included in the equation below:

$$t_{cs} = \frac{L_t + P_e}{v_a} + \left(\frac{100}{f_{br}} + b\right)\left(\frac{v_a}{2d}\right) + \frac{a(1-0.1G_i)l_v^2 t_{os}^2}{20{,}000v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

The values for all variables are summarized as follows:

Value	Term	Description
calculated	t_{cs}	train control separation
200 m	L_t	length of the longest train
10 m	d_{eb}	distance from front of stopped train to start of station exit block in meters
15.3 m/s	v_a	station approach speed
22.2 m/s	v_{max}	maximum line speed (22.2 m/s = 80 km/h)
75%	f_{br}	braking safety factor—worst-case service braking is f_{br}% of specified normal rate—typically 75%
1	b	separation safety factor—equivalent to number of braking distances (surrogate for blocks) that separate trains
3.0 s	t_{os}	time for overspeed governor to operate on automatic systems—driver sighting and reaction times on manual systems
0.5 s	t_{jl}	time lost to braking jerk limitation
1.5 s	t_{br}	brake system reaction time
1.3 m/s^2	a	initial service acceleration rate
1.3 m/s^2	d	service deceleration rate
-1.5%	G	grade into the station
6.25 m	P_e	positioning error—moving block only

Substituting the variables in the equation produces:

$$t_{cs} = 15.7 + (2.33)(6.92) + (0.440)(0.388) + 3.0 + 0.5 + 1.5$$

$$t_{cs} = 37.0 \text{ s}$$

3. Incorporate station dwells and an operating margin

Controlling dwell is average dwell time plus twice the dwell time standard deviation. To determine the headway that can be operated under the conditions given, station dwell times and an operating margin must be incorporated. The line headway is controlled by a controlling dwell. Chapter 7 gives a number of methods of estimating the controlling dwell time from dwell time data. The approach used here estimates the controlling dwell by taking the average dwell time at the controlling dwell station and adding twice the dwell time standard deviation. This method produces a result that also incorporates an operating margin to allow for minor irregularities of operation. The average dwell time is 30 seconds. Adding twice the dwell time standard deviation of 21 seconds produces a controlling dwell, incorporating operating margin, of 72 seconds.

No additional operating margin is needed when the dwell plus two standard deviations method is used.

The Results

Combining the controlling dwell with the minimum train separation produces a station headway of 109 seconds, which can be rounded up to 112.5 seconds to provide an integral number of 32 trains per hour. With a passenger load of 1,094 p/train, the line can carry approximately 35,000 passengers during the peak hour in the peak direction through this station.

Example Problem 4

The Situation

A light rail line operates with a single-track section.

The Question

What is the maximum possible service frequency?

The Facts

- Service is provided by 3-car trains, with each car 90 ft long.
- The single track section is 4,000 ft long with one intermediate station, with a dwell time of 20 s.
- The section is on a road with a speed limit of 30 mph.

Assumptions

- It is assumed that there are no other longer single-track sections on the line, nor more restrictive limitations imposed by any signaled sections of the line or by any signalized intersections.

Outline of Solution

The maximum possible service frequency is twice the travel time through the single-track section, plus an allowance for operational irregularities.

Steps

A self-guiding spreadsheet with this equation and instructions is provided on the accompanying CD-ROM.

Calculate the travel time over the single-track section from Equation 5-13:

$$t_{st} = S_m\left(\frac{(N_{st}+1)}{2}\left(\frac{3v_{\max}}{d}+t_{jl}+t_{br}\right)+\frac{L_{st}+L_t}{v_{\max}}\right)+N_{st}t_d+t_s+t_{om}$$

The values for all variables are summarized as follows:

Value	Term	Description
calculated	t_{st}	time to cover single-track section
1.1	s_m	speed margin
1	N_{st}	number of stations on the single-track section
44.0 ft/s	v_{max}	maximum line speed (44.0 ft/s = 30 mph)
0.5 s	t_{jl}	time lost to braking jerk limitation
4.3 ft/s^2	d	deceleration rate
1.5 s	t_{br}	brake system reaction time
4,000 ft	L_{st}	length of single-track section
270 ft	L_t	train length
20 s	t_d	dwell time
6.0 s	t_s	switch throw-and-lock time
20 s	t_{om}	operating margin (middle of range from Exhibit 5-65)

Substituting these results into the equation produces:

$$t_{st} = 1.1\ [\ (1)(30.7 + 0.5 + 1.5) + 97.0\ ] + 20 + 6 + 20$$

$$t_{st} = 189 \text{ s}$$

The Results

The resultant time to cover the single-track section is 189 seconds. The minimum headway on a single-track section is twice this time, or 378 seconds, which should be rounded up to the nearest even hourly headway of 480 seconds (7½ minutes). If the light rail line has significant on-street operating segments it is unlikely that service can be maintained with sufficient regularity that trains will not be held up at the entrance to the single-track section, waiting for the opposing train to clear. In this case, it is prudent to increase the minimum headway to the next even interval, or trains every 10 minutes.

A 7½-minute headway is often expressed in transit timetables as service every 7 to 8 minutes.

Comments

In the event of track maintenance or an emergency such as a traffic accident, failed light rail train or derailment, crossovers are usually provided to permit single track working around the obstruction. For long-term obstructions—such as a track renewal program—temporary crossovers, called *shoo flys*, can be used. Where a signaling system is used, this operation is only possible if either (1) the signaling system is equipped for two-way operation on either track, or (2) operations are reverted to a slower manual, line-of-sight operation. Such emergency operation is then limited to a frequency as calculated by Equation 5-13 and line capacity is reduced.

Single track working in emergencies.

As an example, if normal service is a train every 5 minutes, and a 4,000-ft section of single track is used to pass an obstruction, service will be limited to 7½ minutes. Nominal capacity will be reduced from 12 to 8 trains per hour (i.e., by one-third). This reduction is sufficiently small that it may be accommodated temporarily by accepting higher levels of crowding. Passengers are generally willing to accept this in emergency conditions.

Longer single-track sections will reduce capacity further. This loss may be made up where operational policies and signaling systems permit platooning trains over the single-track section. Two or three trains can follow each other closely under line-of-sight operating practice at lower speeds. Full capacity may be restored, but additional trains and drivers will be required to compensate for the slower speeds and waiting time while trains accumulate to form a platoon.

Capacity reduction with single track working.

Wrong-side or wrong-way working over line sections with grade crossings on on-street track can be confusing to motorists and pedestrians and can be hazardous. As a result many light rail operators prohibit such operations except where there are no alternatives, such as in tunnels or subways. Instead, their emergency planning calls for a bus bridge around any blockage that is expected to take a significant time to clear. All North America light rail operators also have or are affiliated with major bus operations and can expect to obtain buses and drivers for such emergency use on short notice—usually by scavenging buses from nearby high-frequency routes.

Exhibit 5-47 presents the line capacity for varying single-track lengths for 2-car trains and a 35-mph maximum speed. Line capacity is relatively insensitive to train length, more sensitive to maximum operating speed, and significantly sensitive to the number of stations or stops—each additional stop will add 1½ to 2 minutes, as a result of dwell times for trains traveling in each direction and the associated acceleration and deceleration delays.

Example Problem 5

The Situation

An existing commuter rail agency would like to expand its operations to a new route that is owned by a freight railroad.

The Question

Based on the constraints given below, can the commuter rail agency provide service on the new line with its current single-level car fleet, or must it order new double-level cars for the line?

The Facts

- The freight railroad will only allow six commuter rail trains per hour to use its line.
- Physical constraints mean that station platforms on the new line can be no more than eight cars in length.
- The commuter rail agency currently uses single-level cars that have 120 seats but is considering the purchase of two-level cars with 180 seats, although it would prefer to purchase more single-level cars to maintain a standard fleet.
- The agency has a policy of planning service based on cars being at 90% of seated capacity.
- The agency would like to be able to accommodate a flow of 6,000 passengers per hour in the peak hour.
- Train scheduling can be adjusted to meet the peak 15-minute demand, provided no more than six trains are operated per hour.
- Trains are limited by railroad contract but can be spaced through the peak hour to best match demand.

Outline of Solution

To determine which car type, if either, can satisfy the agency's capacity needs, the hourly capacity of the line using each car type must be determined. This procedure is simplified in this example by the agency's ability to schedule trains to meet the peak 15-minute demand, avoiding the need to consider the temporal distribution of travel. The capacity that can be provided with each car type should be considered independently.

Steps

The hourly capacity, P, is determined as follows:

$$P = (\text{passengers per car}) \times (\text{cars per train}) \times (\text{trains per hour}) \times (\text{PHF})$$

Single-level cars

The effective capacity per car is 90% of 120 or 108 passengers. An eight-car train of single-level cars could thus carry 864 passengers. With six trains per hour, the capacity is 5,184 passengers per hour.

Two-level cars

The effective capacity per car is 90% of 180 or 162 passengers. An eight-car train of two-level cars could thus carry 1,296 passengers. With six trains per hour, the capacity is 7,776 passengers per hour.

The Results

Since eight-car trains of single-level cars are unable to handle the predicted demand, it appears that the agency should plan on ordering two-level cars for use on this route. The calculation above shows that the two-level cars can accommodate the projected demand with some room for ridership growth.

Longer trains that overhang platforms are a poor compromise.

The only alternative to purchasing the two-level cars would be to operate longer trains and assign passengers to cars according to their destination station, since not all cars would be adjacent to a platform at all stations. This would only work if the platforms at major terminal stations could accommodate all the cars of each train. As this complicates train operations and would likely create passenger confusion, the option of purchasing two-level cars is preferable.

Example Problem 6

The Situation

An automated feeder line is planned from a new suburban office development to an existing heavy rail station.

The Question

Based on the use of advanced train control systems, what is the maximum capacity of this line?

The Facts

The developer wants to incorporate the AGT stations in an elevator lobby on the second floor of each building, which limits station length to 85 feet. Although the line is short, the developer wants to offer a high-quality service in which 50% of the passengers are seated. Most AGT systems are proprietary and the manufacturer would provide capacity capabilities. In this case, the developer does not wish to approach a manufacturer at this stage.

Outline of Solution

In practice trains cannot run as close as suggested by theory.

Exhibit 5-77 shows that an AGT moving-block train control system can provide a minimum train separation of 13.4 seconds with 80-foot trains. Adding the recommended typical dwell time of 40 seconds and the recommended operating margin of 25 seconds would result in a minimum headway of 78.4 seconds. This should be rounded up to 80 seconds. Chapter 10 states that "headways shorter than 90 seconds are possible but may limit dwell times and constrain the operating margin. They should be considered with caution unless off-line stations are adopted." As the developer has indicated a relatively relaxed loading level, it is realistic to expect dwells to be lower than normal and hence the 80-second headway can be accepted as practical. This equates to 3,600/80 or 45 trains per hour.

The 85-foot platform can hold two 40-foot cars, a common AGT size and comparable to a city bus. As no specific car design can be assumed, it is reasonable to assume that wide double doors will take up 12 feet of each car side, leaving 28 feet for seating. At a pitch of 3.5 feet, this allows 8 rows of seats. The seats will be 2+2 with five abreast at each end (there are no driving cabs on an automated AGT). Such a car can thus accommodate (6 x 4) + (2 x 5) for a total of 34 seats. The desired maximum of 50% of the passengers standing brings the total car passenger capacity to 68. Note that an AGT car of this size, on a short-distance line, would normally be rated for 100 passengers, most of whom would stand.

The Results

The resultant maximum capacity at the preferred loading level is the number of trains per hour (45), multiplied by the number of passengers per train (68), or 3,060 passengers per peak hour direction. As always with such calculations where there are approximations, the number should be rounded down, in this case to 3,000 p/h/dir. Note that this is a *maximum* capacity; the result would need to be multiplied by a peak hour factor to determine the number of people that could be accommodated without exceeding the preferred loading level during the hour.

Example Problem 7

The Situation

The developer from Example Problem 6 is expanding the suburban office development to include a major shopping complex and recreation facility with an ice hockey arena.

The Question

How can the AGT line be expanded to handle this load?

The Facts

- Ridership estimates are that the system will handle 25% of the arena's maximum capacity of 24,000 people, plus an estimated demand of 1,200 passengers per hour from the shopping complex.
- Two adjacent stations serve the sports arena, while the shopping center has three stations.
- The developer has contracted with the office building tenants to run trains at least every 6 minutes until midnight each day, including weekends and holidays.

Outline of Solution and Results

To handle 24,000/4 + 1,200 = 7,200 passengers per hour, one solution would be to operate longer trains with higher occupancy and to omit stops in the office buildings with their short stations. The 45-train-per-hour capacity is no longer practical as heavy loads at the two sports arena stations will extend dwells and longer trains will increase the minimum train separation. The capacity is decreased to 40 trains per hour, or 90-second headways. Ten of these trains, one every 6 minutes, will remain short to serve the office complex. These ten trains have an estimated capacity of 150 passengers each (two cars per train multiplied by 75 p/car, assuming that a higher proportion of sports fans will stand, compared with office tenants). The remaining 30 trains must carry 5,700 passengers per hour (7,200 – (10 x 150)). This results in 5,700/30 or 190 passengers per train. Three-car trains holding 75 p/car would be required to meet the demand.

Longer trains could skip stations with too short platforms.

A peak hour factor is not applied to special event person capacity calculations, as the offered capacity is generally fully utilized and passengers do not expect to be able to board the first train that arrives.

In Chapter 10, it was stated that off-line stations permit headways that are partly independent of station dwell time with throughput that of the control system minimum train separation, plus an allowance for switch operation, lock and clearance, and a reduced operating margin. Exhibit 5-77 shows that a moving-block signaling system with 80-foot trains has a minimum train separation of 13.4 seconds. Allowing an operating allowance for merging trains of 45 seconds and rounding up results in permitted headways as low as 60 seconds, or 60 trains per hour. In this case, the demand of 7,200 passengers per hour with 150 passengers per train can be met by 48 trains, well within the 60-train maximum.

Off-line stations would permit trains to operate directly from each arena station to the heavy rail station. However, economics enter the picture. It is unlikely that the developer would be willing to build more expensive off-line stations and purchase addition rolling stock for a sports arena demand that only occurs a few days a year. It is more likely that the system would be designed for maximum office and shopping complex demands. When a sports event takes place, the AGT line would be filled to capacity and the overload would be handled by transit authority buses—of which there is a surplus at the off-peak hours typical of sport event starts and finishes.

It is not always economical to meet occasional peak demands with rail transit.

Example Problem 8

The Situation

A university hospital is located on a bluff above a river. The university has run out of room to expand on the bluff and is seeking to move some of its operations to a new campus along the riverfront. For the two campuses to function efficiently as a single entity, good transportation links will need to be provided between them. The university is exploring various means to provide these links, including shuttle buses and roadway and parking improvements. Another option under consideration is a direct link between the two campuses using an aerial ropeway, either an aerial tramway or a detachable-grip aerial lift (gondola) system.

The Questions

1. For the aerial tramway, how large will the carriers need to be to handle the projected passenger demand?
2. For the gondola, how many carriers will be needed?

The Facts

Based on the university functions to be located on the riverfront and an estimate of total faculty, staff, and student sizes at build-out, the university estimates that a total of 750 persons will need to be carried in the peak direction during the peak hour. The line would be approximately 800 m long, with no intermediate stations. A decision on a specific manufacturer has not been made; however, as a starting point, assume that the aerial tramway cabin door would be wide enough that three people can walk through at a time and that the gondola carriers would seat eight people each.

Aerial tramway dwell time includes the time to unload and load passengers from the cabin, plus an assumed allowance of 60 seconds to (1) clear exiting passengers from the platform and (2) perform communications checks prior to the carrier departing. Maximum acceleration and deceleration is 0.2 m/s^2.

Gondola carriers take 60 seconds to traverse each station after detaching from the line. The carriers move at creep speed (0.25 m/s) through the station to allow passenger loading and unloading.

Outline of Solution

Aerial Tramway

Aerial tramway capacity is based on the number of carriers used (one or two, two is typical), the number of stops per direction (one, in this case), station dwell time (not yet known), line length (given), line speed (a user decision), and the size of the carriers (a user decision). Passenger service time will be based on the time to clear a full cabin, and then load a full cabin. Several combinations of line speeds and cabin sizes may need to be tried in developing a solution.

Gondola

Gondola capacity is based on the spacing between carriers (not yet known) and the average line speed (a user decision). To solve this problem, the minimum number of carriers needed to serve the demand will be calculated by working backward from the required capacity.

Solution

Aerial Tramway

As a starting point, a 60-passenger cabin and the fastest possible line speed (12 m/s) will be selected. At a maximum acceleration rate of 0.2 m/s^2, it takes 60 seconds (12 divided by 0.2) to reach line speed. The average speed during acceleration is half the line speed, or 6 m/s. As a result, the carrier would travel 360 m (60 s multiplied by 6 m/s) during acceleration. The carrier would travel another 360 m during deceleration, meaning that it would only travel 80 m at line speed (800 m line length, minus two times 360 m). The total trip time would be about 127 seconds.

Spending only 10% of the trip length at line speed would be inefficient, so a lower line speed should be tried. At a line speed of 10 m/s, acceleration and deceleration would take 50 seconds each and would cover a total distance of 500 m. As a result, the carrier could travel at line speed for 300 m (more than 40% of the distance) and could cover that distance in 30 seconds. The total trip time would be about 130 seconds. The corresponding average line speed would be 800 meters divided by 130 seconds, or 6.15 m/s.

In the absence of other data, Exhibit 5-15 can be consulted to determine average passenger boarding and alighting times. From a review of the data provided in the exhibit, 1.85 seconds per alighting passenger per door channel and 2.1 seconds per boarding passenger per door channel can be chosen as median values. With three door channels, it takes 37 seconds on average for passengers to exit a full 60-passenger cabin (60 p times 1.85 s/p, divided by 3 door channels), and 42 seconds to board. The total dwell time, including the 60-second allowance discussed in the facts of the problem, is 139 seconds.

All the information needed to calculate line capacity is now known. Entering this information into Equation 5-20 gives:

$$T = \frac{1{,}800 N_v}{(N_s t_d) + \dfrac{L_l}{v_l}} = \frac{(1{,}800\ \text{s/h})(2\ \text{veh})}{(1)(139\ \text{s}) + \dfrac{(800\ \text{m})}{(6.15\ \text{m/s})}} = \frac{3{,}600\ \text{veh - s/h}}{269\ \text{s}} = 13\ \text{veh/h}$$

Multiplying 13 carriers per hour by 60 passengers per carrier gives a theoretical directional capacity of 780 passengers per hour, which is more than the required 750 passengers per hour. However, because passengers are not likely to arrive evenly throughout the hour, a peak hour factor should be applied. Using a PHF of 0.90, the directional person capacity of the system is about 700 passengers per hour, which is insufficient to avoid pass-ups.

Repeating the above process with an 80-passenger cabin results in a 165-second dwell time, with all other input values remaining the same. The resulting line capacity is 12 carriers per hour, which provides a directional person capacity of about 865 passengers per hour when a peak hour factor of 0.90 is applied.

Gondola

Since the only thing known about the gondola system is an assumed carrier size (8 passengers), the number of carriers required will be determined by working backward from the required capacity. Using a PHF of 0.90, a theoretical directional capacity of 833 passengers per hour is needed (demand of 750 passengers per hour, divided by 0.90). Dividing this capacity by 8 passengers per carrier results in 105 eight-passenger carrier arrivals per hour required at a station. However, because each carrier will make more than one trip each hour, the number of actual carriers required will be smaller.

A carrier traveling at a line speed of 6 m/s (the maximum for a detachable-grip lift) requires 134 seconds to travel the length of the line. Therefore, a round trip on the line takes 268 seconds. In addition, the carriers take 1 minute to travel through each station at creep speed, adding another 120 seconds to the round-trip journey. Consequently, a carrier makes one round trip every 388 seconds, or 9.28 round trips per hour. The number of carriers that will provide the required number of hourly station arrivals is 105 arrivals per hour divided by 9.28 arrivals per carrier per hour, or 12 carriers (rounded up).

The Results

Although the aerial tramway carrier travels twice as fast as a gondola at their respective maximum line speeds, it takes much longer to accelerate and decelerate the aerial tramway carrier. As it turned out, the travel times of the two modes were nearly the same over the length of the relatively short route. The headway between aerial tramway carriers is approximately 5 minutes, while the headway between gondolas is about 32 seconds.

APPENDIX A: EXHIBITS IN METRIC UNITS

Exhibit 5-24m
Linear Passenger Loading—Articulated LRVs[(R15)]

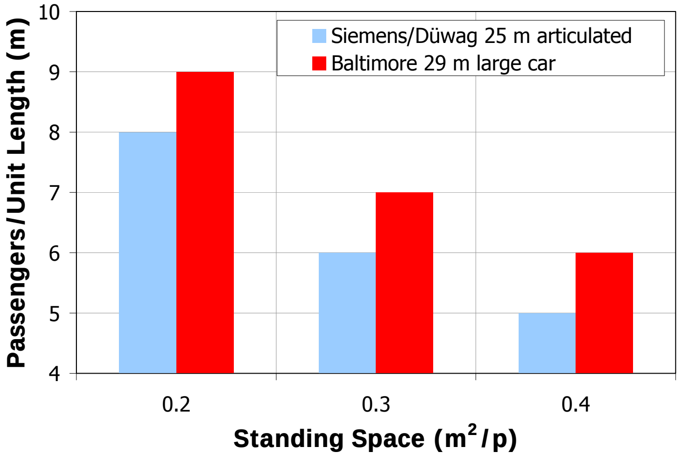


Exhibit 5-25m
Linear Passenger Loading—Heavy Rail Cars[(R15)]

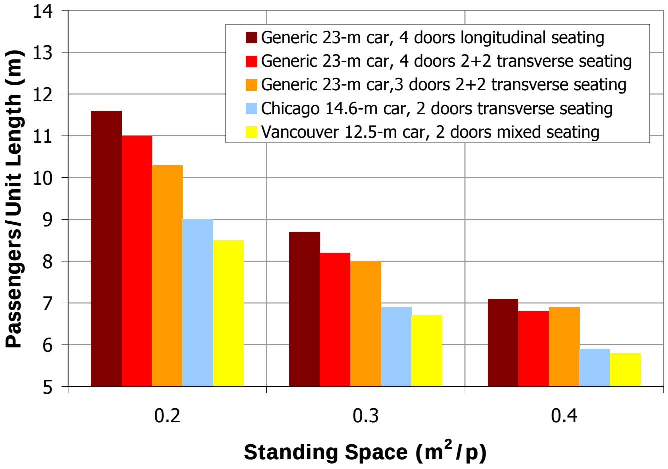
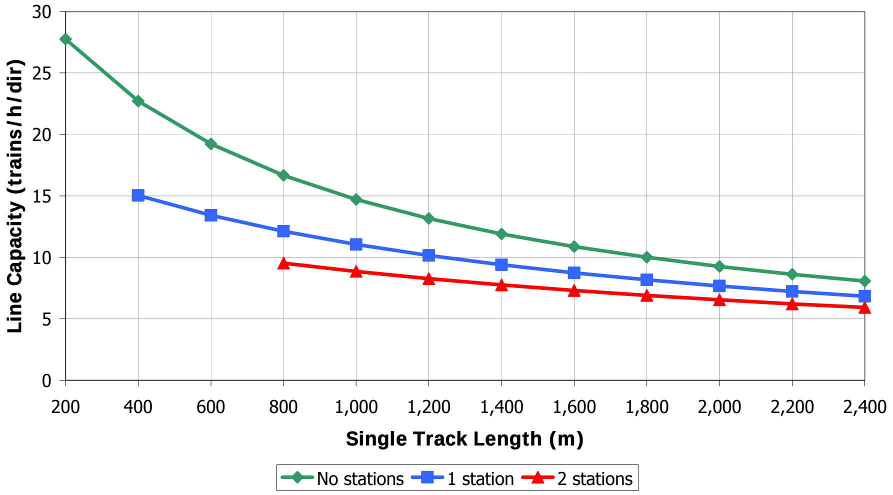


Exhibit 5-26m
Summary of Linear Passenger Loading (p/m) (1995)[(R15)]

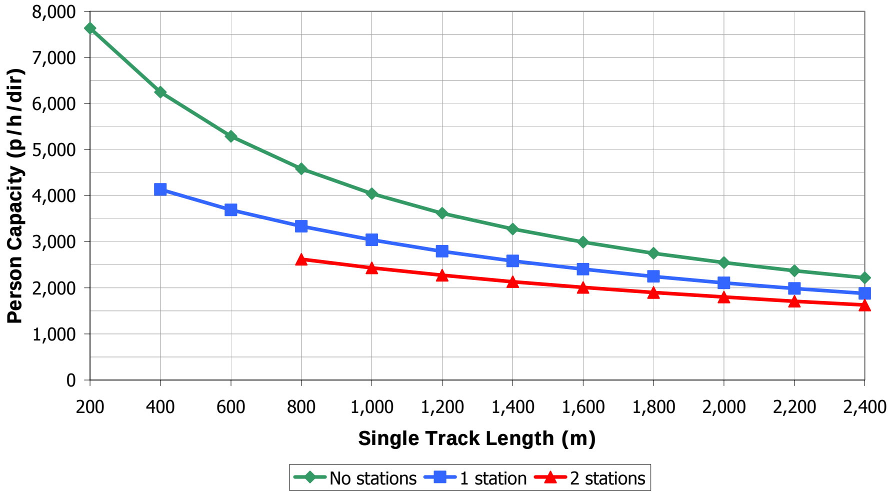
	Average	Median	Standard Deviation
All Systems	6.4	5.9	2.0
Commuter Rail	4.8	4.5	0.7
Heavy Rail	6.8	6.3	2.0
Heavy Rail less New York	5.5	5.6	1.5
MTA-NYCT alone	7.9	7.8	1.8

Exhibit 5-47m
Single-Track Line Capacity—Two-Car Light Rail Trains



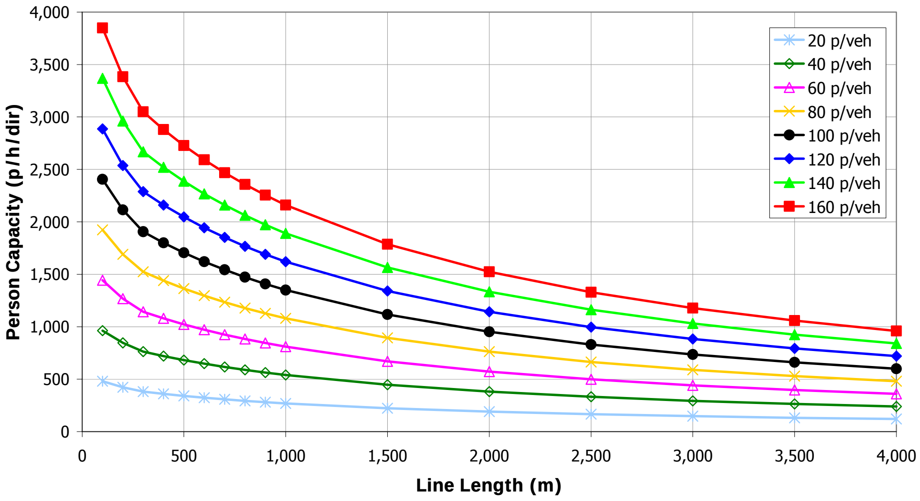
NOTE: Assumes 55-km/h speed limit, 55-m train length, 20-s dwell time, and 20-s operating margin.

Exhibit 5-48m
Single-Track Person Capacity—Two-Car Light Rail Trains



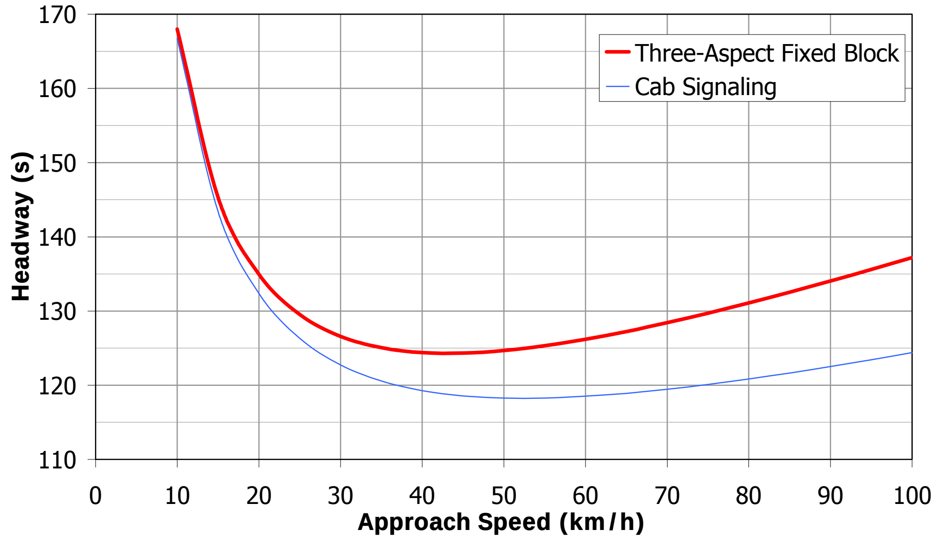
NOTE: Assumes 55-km/h speed limit, 55-m train length, 20-s dwell time, and 20-s operating margin.

Exhibit 5-51m
Reversible Ropeway Person Capacity



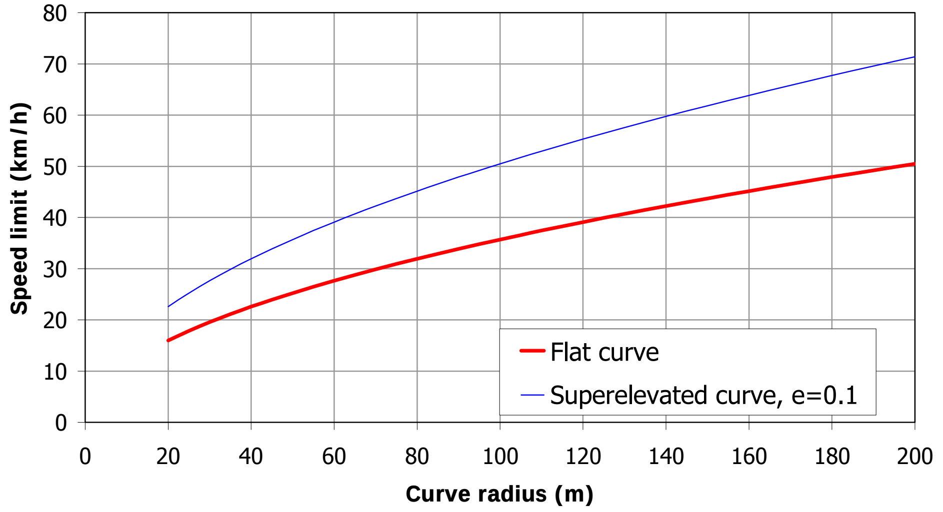
NOTE: Assumes 10 m/s line speed, 0.2 m/s^2 acceleration, two-vehicle operation, 90-s dwell time, and 0.90 PHF.

Exhibit 5-55m
Station Headway for Lines at Capacity(R15)



NOTE: dwell = 45 s, operating margin = 20 s.

Exhibit 5-56m
Speed Limits on Curves(R15)



NOTE: Transition spirals are not taken into account.

Exhibit 5-58m
Distance-Speed Chart(R15)

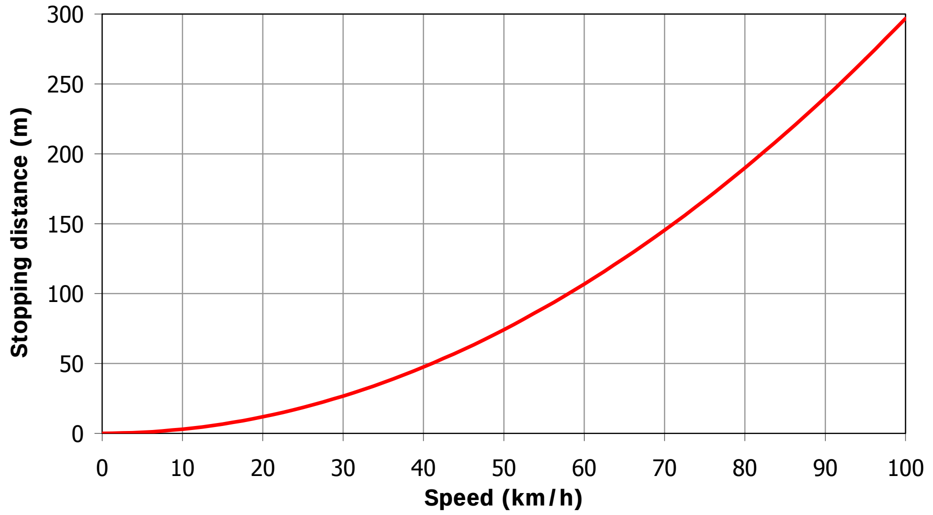


Exhibit 5-61m
Moving-Block Station Headways Compared with Conventional Fixed-Block Systems(R15)

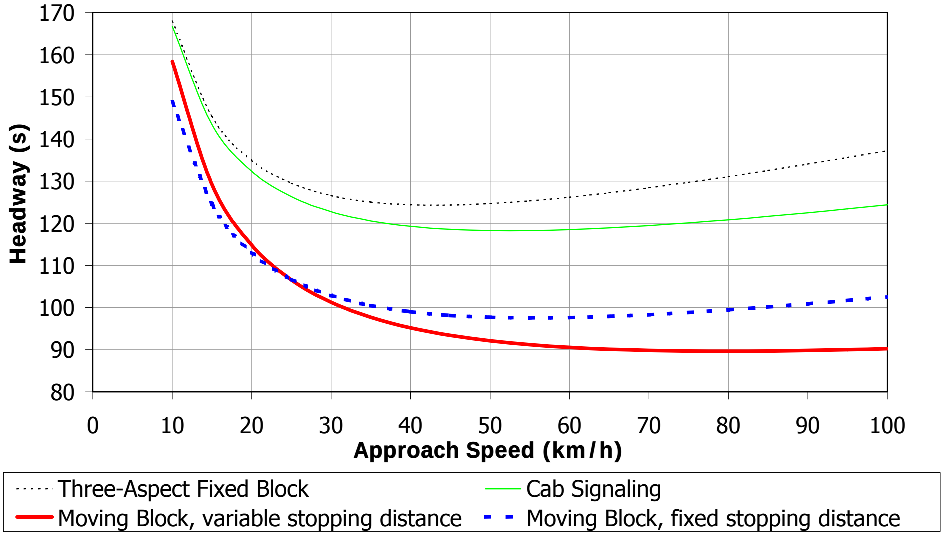


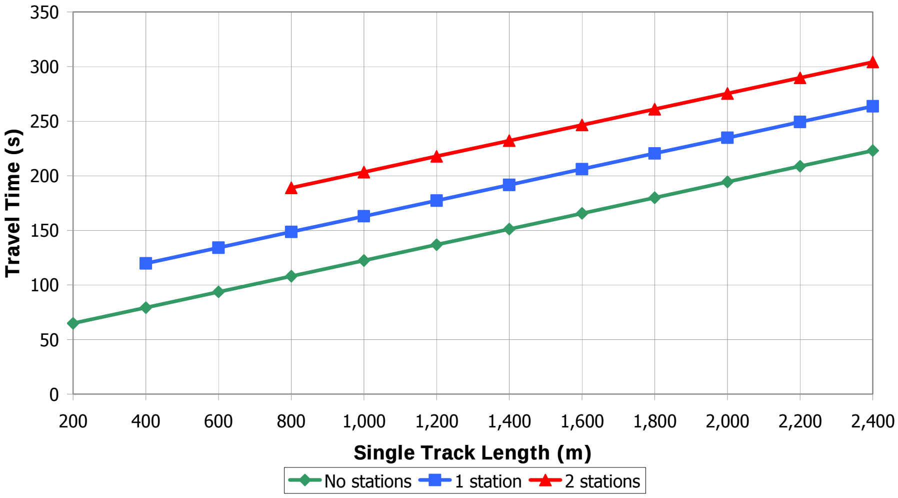
Exhibit 5-63m
Passengers per Unit Train Length, Major North American Rail Trunks, 15-Minute Peak (1995)(R15)

System & City	Trunk Name	Mode	Car Length (m)	Seats	Avg. Pass/Car	Pass/m
NYCT (New York)	53rd Street Tunnel	HR	*see note*	50/70	197/227	10.4
NYCT (New York)	Lexington Ave. Local	HR	15.6	44	144	9.3
NYCT (New York)	Steinway Tunnel	HR	15.6	44	144	9.3
NYCT (New York)	Broadway Local	HR	15.6	44	135	8.7
TTC (Toronto)	Yonge Subway	HR	22.7	80	197	8.7
NYCT (New York)	Lexington Ave. Ex.	HR	15.6	44	123	7.9
NYCT (New York)	Joralemon St. Tun.	HR	15.6	44	122	7.8
NYCT (New York)	Broadway Express	HR	15.6	44	119	7.6
NYCT (New York)	Manhattan Bridge	HR	22.8	74	162	7.1
NYCT (New York)	Clark Street	HR	15.6	44	102	6.6
CTS (Calgary)	South Line	LR	24.3	64	153	6.3
GO Transit (Toronto)	Lakeshore East	CR	25.9	162	152	5.9
SkyTrain (Vancouver)	SkyTrain	HR	12.4	36	73	5.9
PATH (New York)	World Trade Center	HR	15.6	31	92	5.9
PATH (New York)	33rd St.	HR	15.6	31	88	5.7
CTA (Chicago)	Dearborn Subway	HR	14.6	46	82	5.6
NYCT (New York)	60th Street Tunnel	HR	22.8	74	126	5.5
NYCT (New York)	Rutgers St. Tunnel	HR	22.8	74	123	5.4
CTS (Calgary)	Northeast Line	LR	24.3	64	125	5.1
CTA (Chicago)	State Subway	HR	14.6	46	75	5.1
CalTrain (San Fran.)	CalTrain	CR	25.9	146	117	4.5
LIRR (New York)	Jamaica - Penn Sta.	CR	25.9	120	117	4.5
Metra (Chicago)	Metra Electric	CR	25.9	156	113	4.4
MARTA (Atlanta)	North/South	HR	22.9	68	82	3.6
MARTA (Atlanta)	East/West	HR	22.9	68	77	3.4

HR: heavy rail, LR: light rail, CR: commuter rail

NOTE: Service through NYCT's 53rd Street Tunnel in 1995 was provided by line E, operating 18.35-m cars, and line F, operating 22.8-m cars. Seats and car loadings are presented as "E/F." The number of passengers per meter given is for the combined lines; individually this value is 10.8 for the E and 9.8 for the F. The F was moved to the 63rd Street Connector in December 2001, and a new line V shared the 53rd Street Tunnel with line E.

Exhibit 5-66m
Light Rail Travel Time Over Single-Track Section(R15)



NOTE: Assumes speed limit of 55 km/h, train length of 55 m, 20-s dwell time, 20-s operating margin, and other data as per Exhibit 5-65. *The recommended closest headway is twice this time.*

Exhibit 5-75m
Average Commuter Rail Operating Speeds(R10)

Station Spacing (km)	Average Operating Speed (km/h) P/W = 3.0	P/W = 5.8	P/W = 9.1
Average Dwell Time = 30 s			
1.6	27.0	32.7	35.9
3.2	41.5	49.7	56.4
6.4	58.6	71.0	78.2
8.0	64.9	78.4	84.8
Average Dwell Time = 60 s			
1.6	23.8	28.0	30.3
3.2	37.5	44.1	49.3
6.4	54.4	65.0	71.0
8.0	60.9	72.5	78.1

NOTE: P/W = power-to-weight ratio
Assumes 128-km/h speed limit, no grades, and no delays due to other trains.

Exhibit 5-78m
Suggested AGT Separation Calculation Default Values(R15)

Default Value Heavy Rail	AGT	Term	Description
6.25 m	6.25 m	P_e	positioning error
200 m	50 m	L	length of the longest train
10 m	0 m	d_{eb}	distance from front of train to exit block
75%	75%	f_{br}	% service braking rate
2.4	4	b	train detection uncertainty constant— fixed block
1	1	b	train detection uncertainty constant— moving block
3 s	1 s	t_{os}	time for overspeed governor to operate
0.5 s	0.5 s	t_{jl}	time lost to braking jerk limitation
1.3 m/s^2	0.6 m/s^2	a	service acceleration rate
1.3 m/s^2	1.0 m/s^2	d	service deceleration rate
1.5 s	0.5 s	t_{br}	brake system reaction time
100 km/h	80 km/h	v_{max}	maximum line velocity
50 m	25 m	S_{mb}	moving-block safety distance

NOTE: shaded lines indicate AGT default values that differ from heavy rail default values.

This page is intentionally blank.

APPENDIX B: RAIL ROUTE CHARACTERISTICS

Exhibit 5-81
Light Rail Route Characteristics and Ridership (2002)

Region	Route	Length		Stations	Weekday	Peak Hour		
		mi	km		Ridership	Pass.	Trains	Cars
Baltimore (MTA)	Hunt Valley-Cromwell	57.6	92.7	32	24,700		17	33
Baltimore (MTA)	Penn Station-BWI							
Boston (MBTA)	B-Boston College	6.4	10.3	19	30,700			
Boston (MBTA)	C-Cleveland Circle	5.1	8.2	14	14,500			
Boston (MBTA)	D-Riverside	13.5	21.7	24	21,800			
Boston (MBTA)	E-Heath	5.6	9.0	14	14,600			
Boston (MBTA)	Red (Mattapan)	2.6	4.2	8	7,800			
Buffalo (NFTA)	Metro Rail	6.4	10.3	8	25,000		10	22
Calgary (CTS)	201-Fish Creek*	1.2	2.0	11				
Calgary (CTS)	202-Whitehorn	8.9	14.3	9	60,200	5,900	16	48
Cleveland (GCRTA)	67X-Blue	30.8	49.6	35	11,800			
Cleveland (GCRTA)	67AX-Green							
Dallas (DART)	Red	44	72	34	51,200			
Dallas (DART)	Blue							
Dallas (DART)	M-Line Streetcar	3.8	6.1		1,000			
Denver (RTD)	C-Orange	13	21	12				
Denver (RTD)	D-Green	14.0	22.4	20	31,400	3,400	12	26
Edmonton (ETS)	LRT	7.6	12.3	10	38,000	3,800		30-31
Galveston (Island Tr.)	Trolley	2.6	4.2	15			4	4
Guadalajara (STEU)	1-North/South	9.4	15.5	19			12	24
Guadalajara (STEU)	2-East/West	5.3	8.5	10			8	16
Houston (Metro)	METRORail	7.5	12.1	16	scheduled 2004 opening			
Jersey City (NJT)	Bayonne	9.5	15.3	16				
Jersey City (NJT)	West Side Avenue							
Kenosha (Kenosha Tr.)	Electric Streetcar	1.0	1.6		150		1	1
Little Rock (CATA)	River Rail Streetcar	2.1	3.4	8	scheduled 2004 opening			
Los Angeles (LACMTA)	Blue	21.3	34.3	22	72,300		19	39
Los Angeles (LACMTA)	Gold	13.6	21.9	13	opened 2003			
Los Angeles (LACMTA)	Green	19.9	32.0	14	33,400		12	12
Memphis (MATA)	Main Street Trolley*	2.9	4.7					
Mexico City (STEDF)	Tren Ligero	16	26	18				11
Minneapolis (Metro Tr.)	Hiawatha Line	11.6	18.7	17	scheduled 2003-04 opening			
Monterrey (Metrorrey)	1-East/West	11.5	18.5	19			19	
Monterrey (Metrorrey)	2-North/South	2.8	4.5	6				
New Orleans (RTA-NO)	Canal	5.6	9.3		scheduled 2003-04 opening			
New Orleans (RTA-NO)	Riverfront	1.6	2.6	10	1,400			4
New Orleans (RTA-NO)	St. Charles	6.6	10.6	57	11,600			15
Newark (NJT)	City Subway	6.0	9.7	12	16,900	1,800		
Ottawa (OCT)	O-Train	5.0	8.0	5	5,800		1	2
Philadelphia (SEPTA)	10-Overbrook	5.9	9.5	44	7,600			
Philadelphia (SEPTA)	11-Darby	6.7	10.8	48	8,200			
Philadelphia (SEPTA)	13-Yeadon/Darby	7.0	11.2	49	8,600			
Philadelphia (SEPTA)	15-Girard	8.2	13.2		scheduled 2004 opening			
Philadelphia (SEPTA)	34-Angora	5.0	8.0	31	7,300			
Philadelphia (SEPTA)	36-Eastwick	7.1	11.4	49	8,700			
Philadelphia (SEPTA)	100-Norristown	13.5	21.7	22	7,800			16
Philadelphia (SEPTA)	101-Media	8.5	13.7	35	7,300			19
Philadelphia (SEPTA)	102-Sharon Hill	5.3	8.5	27				
Pittsburgh (PAT)	42L-Library	8.1	13.0	46	5,100			
Pittsburgh (PAT)	42S-South Hills†	10.5	16.9	36	19,300			
Pittsburgh (PAT)	52-Allentown	2.5	4.0		700			
Pittsburgh (PAT)	Overbrook	5.5	8.9	8	scheduled 2003 opening			
Portland (TriMet)	Blue-East/West	32.4	52.1	46	70,300		9	18
Portland (TriMet)	Red-Airport	12.8	20.6	19	10,500	500	4	4
Portland (TriMet)	Yellow-Interstate	7.2	11.6	17	scheduled 2004 opening			
Portland (City)	Portland Streetcar	2.4	3.9	18	4,200		4	4
Sacramento (SRTD)	Light Rail*	20.6	33.1	30	29,000	1,500	8	32
St. Louis (Bi-State)	MetroLink*	45.7	73.5	26	42,400		22	44
Salt Lake City (UTA)	701-North/South	12.3	19.8	15	29,500		7	21
Salt Lake City (UTA)	702-University*	2.5	4.0	5				
San Diego (SDT)	Blue*	25.2	40.5	31	50,000		18	54
San Diego (SDT)	Orange	21.6	34.8	24	24,500		9	29
San Francisco (SF Muni)	F-Market & Wharves	6.0	9.7	30	19,200			
San Francisco (SF Muni)	J-Church*	15.7	25.3		15,200			
San Francisco (SF Muni)	K-Ingleside	13.2	21.2		25,300			
San Francisco (SF Muni)	L-Taraval	5.4	8.7		29,900			
San Francisco (SF Muni)	M-Ocean View	6.8	10.9		33,300			
San Francisco (SF Muni)	N-Judah	13.2	21.2		45,600			

Table continues on the next page.

Exhibit 5-81 (cont'd.)
Light Rail Route Characteristics and Ridership (2002)

		Length			Weekday	Peak Hour		
Region	**Route**	**mi**	**km**	**Stations**	**Ridership**	**Pass.**	**Trains**	**Cars**
San Jose (VTA)	Baypointe-Sta. Theresa†	18.0	29.0	31	24,600			
San Jose (VTA)	Mountain View-Milpitas	11.5	18.5	19	5,600			
Seattle (KC Metro)	Waterfront Streetcar	1.9	3.0	9	600			
Tacoma (Sound T)	Tacoma Link	1.6	2.6	5	opened 2003		2	2
Tampa (Hartline)	TECO Line Streetcar	2.3	3.7	10	1,200		4	4
Toronto (TTC)	501-Queen	15.2	24.5	210	45,100	1,100		12
Toronto (TTC)	502-Downtowner	6.5	10.5	90	4,300	340		6
Toronto (TTC)	503-Kingston Road	5.7	9.2	83	2,000	350		6
Toronto (TTC)	504-King	7.9	12.7	125	50,700	1,500		28
Toronto (TTC)	505-Dundas	6.7	10.8	105	36,600	700		11
Toronto (TTC)	506-Carlton	9.2	14.8	154	40,300	900		15
Toronto (TTC)	508-Lake Shore	5.9	9.5	140	1,100	210		3
Toronto (TTC)	509-Harbourfront	2.8	4.5	29	2,400	300		6
Toronto (TTC)	510-Spadina	3.5	5.6	42	40,200	2,000		32
Toronto (TTC)	511-Bathurst	2.9	4.7	42	14,800	800		14
Toronto (TTC)	512-St. Clair	4.4	7.1	56	32,200	1,500		22
Trenton (NJT)	Southern New Jersey	34	55	20	scheduled 2003 opening			

*Extension of existing line underway in 2002.
†Data include all branches of the route.

SOURCES: Operator survey, APTA (R5)

NOTES: Routes that entirely duplicate other routes (e.g., the S-Castro/Embarcadero shuttle in San Francisco and the 703-Sandy/University route in Salt Lake City) not included. Only vintage trolleys operated by public transit agencies are included. The Tandy Subway in Fort Worth was a privately operated light rail line open to the public; it closed in 2002.

Because of overlapping routes, the sum of individual route lengths and stations may be greater than the actual system totals. Some systems included overlaps in length totals; others did not. Lengths are for a single direction of a route.

Most Toronto streetcar lines serve subway stations at their outer ends and run through downtown, giving them effectively four peak points per line. They also serve many short trips and have high off-peak use. This accounts for the exceptionally low ratio of peak hour to daily ridership.

Exhibit 5-82
Heavy Rail Route Characteristics and Ridership (2002)

		Length			Weekday	Peak Hour		
Region	**Route**	**mi**	**km**	**Stations**	**Ridership**	**Pass.**	**Trains**	**Cars**
Atlanta (MARTA)	East/West†	16.0	25.8	16	71,400	3,000	8	60
Atlanta (MARTA)	North/South†	22.2	35.7	18	117,900	5,100	8	58
Baltimore (MTA)	Metro	29.4	47.3	14	48,500		9	54
Boston (MBTA)	Blue	5.9	9.5	12	57,000			
Boston (MBTA)	Orange	11.2	18.0	19	157,000			
Boston (MBTA)	Red†	20.5	33.0	22	227,000			
Chicago (CTA)	Blue†	34.2	55.1	44	125,600	8,400	15	120
Chicago (CTA)	Brown	11.3	18.2	28	79,300	9,500	18	108
Chicago (CTA)	Green†	21.1	33.9	29	38,600	3,200	8	48
Chicago (CTA)	Orange	12.4	19.9	17	39,400	5,800	11	88
Chicago (CTA)	Purple	16.2	26.1	25	24,500	3,400	7	42
Chicago (CTA)	Red	21.7	34.9	34	200,200	11,900	19	152
Chicago (CTA)	Yellow	5.0	8.1	2	3,400	800	9	18
Cleveland (GCRTA)	66X-Red	19.1	30.8	17	24,100		14	28
Los Angeles (LACMTA)	Red†	16.0	25.7	16	105,600	30,600	14	70
Mexico City (STC)	1	11.7	18.8	20	852,000¤			
Mexico City (STC)	2	14.5	23.4	24	853,000¤			
Mexico City (STC)	3	14.7	23.6	21	767,000¤			
Mexico City (STC)	4	6.6	10.7	10	88,000¤			
Mexico City (STC)	5	9.8	15.7	13	238,000¤			
Mexico City (STC)	6	8.6	13.9	11	127,000¤			
Mexico City (STC)	7	11.7	18.9	14	247,000¤			
Mexico City (STC)	8	12.5	20.1	19	355,000¤			
Mexico City (STC)	9	9.5	15.3	12	334,000¤			
Mexico City (STC)	A	10.6	17.0	10	263,000¤			
Mexico City (STC)	B	14.7	23.7	21	282.000¤			
Miami (MDT)	Metrorail*	21.1	34.0	21	46,300		15	86
Montréal (STM)	1-Green	13.7	22.1	27	369,800	21,900		
Montréal (STM)	2-Orange	15.4	24.8	28	407,700	24,400		
Montréal (STM)	4-Yellow	2.7	4.3	3	56,900	10,900		
Montréal (STM)	5-Blue	6.0	9.7	12	85,600	6,400		

Table continues on the next page.

Exhibit 5-82 (cont'd.)
Heavy Rail Route Characteristics and Ridership (2002)

		Length			Weekday	Peak Hour		
Region	**Route**	**mi**	**km**	**Stations**	**Ridership**	**Pass.**	**Trains**	**Cars**
New York (NYCT)	1-Clark St NB	36	58	57		6,400	9	90
New York (NYCT)	1-66th St SB					10,400	11	110
New York (NYCT)	2-Clark St NB	48	77	49		7,100	10	100
New York (NYCT)	2-66th St SB					7,100	9	90
New York (NYCT)	3-72nd St SB	12	19	18		12,100	11	110
New York (NYCT)	4-Borough Hall NB	38	61	54		13,600	15	150
New York (NYCT)	4-86th St SB					16,600	12	120
New York (NYCT)	5-Borough Hall NB	47	76	45		9,200	10	100
New York (NYCT)	5-86th St SB					13,600	10	100
New York (NYCT)	6-68th St SB	24	39	38		25,900	21	210
New York (NYCT)	7-Vernon Jackson SB	15	24	21		22,500	24	264
New York (NYCT)	A-High St NB†	49	79	70		19,000	17	150
New York (NYCT)	A-125th St SB					12,100	10	86
New York (NYCT)	B-72nd St SB	18	29	26		4,600	6	48
New York (NYCT)	C-High St NB	36	58	48		6,300	8	64
New York (NYCT)	C-72nd St SB					5,700	6	48
New York (NYCT)	D-125th St SB	19	31	18		9,300	9	72
New York (NYCT)	E-23rd St-Ely Ave SB	25	40	32		17,000	11	110
New York (NYCT)	F-York St NB	43	69	55		12,600	14	112
New York (NYCT)	F-23rd St-Ely Ave SB					21,300	17	136
New York (NYCT)	G	10	16	17				
New York (NYCT)	J,Z-Marcy Ave SB	21	34	30		8,600	11	88
New York (NYCT)	L-Bedford Ave NB	16	26	24		19,300	16	128
New York (NYCT)	M-Court St NB	27	43	37		3,700	7	56
New York (NYCT)	M-Marcy Ave SB					5,100	6	48
New York (NYCT)	N-Court St NB	33	53	45		3,300	6	56
New York (NYCT)	N-Queensboro Plz SB					10,000	7	66
New York (NYCT)	Q-DeKalb Ave NB	24	39	25		18,900	16	144
New York (NYCT)	R-Court St NB	35	56	45		3,600	6	48
New York (NYCT)	R-Queens Plaza SB					11,400	8	66
New York (NYCT)	S-Franklin Ave	2	3	4				
New York (NYCT)	S-42nd St	1	2	2				
New York (NYCT)	S-Grand St	2	3	3				
New York (NYCT)	S-Rockaway	5	8	5				
New York (NYCT)	V			24				
New York (NYCT)	W-Pacific St NB	32	51	28		9,500	9	72
New York (NYCT)	W-Queensboro Pl. SB					8,100	6	48
New York (SIR)	Staten Island Railway	23.0	37.0	22	14,400			
Newark (PATH)	Hoboken-33rd Street	3.5	5.6	6	47,800	6,700	14	98
Newark (PATH)	Journal Sq.-Hoboken	3.3	5.3	4	9,200	1,300	8	56
Newark (PATH)	Newark-33rd Street	11.4	18.3	9	126,800	17,800	12	84
Philadelphia (SEPTA)	Market-Frankford	12.2	19.6	28	172,200			
Philadelphia (SEPTA)	Broad-Ridge†	11.4	18.3	24	111,400			
Philadelphia (PATCO)	PATCO Speedline	14.2	22.9	13	36,000	6,800	23	138
San Francisco (BART)	Dublin-Pl./Daly City*	39.0	62.9	17	54,700	2,300	4	36
San Francisco (BART)	Fremont/Daly City	38.7	62.4	19	48,400	3,600	4	38
San Francisco (BART)	Pittsburg/Colma	44.8	72.3	22	124,300	6,200	11	103
San Francisco (BART)	Richmond/Daly City	27.6	44.5	19	50,500	4,400	4	37
San Francisco (BART)	Richmond/Fremont	36.1	58.2	18	59,800		4	26
San Juan	Tren Urbano	21.4	34.4	18	scheduled 2003 opening			
Toronto (TTC)	Bloor-Danforth	16.3	26.2	31	465,900	20,200	25	150
Toronto (TTC)	Yonge-Univ.-Spadina	18.8	30.2	32	614,000	26,200	25	150
Toronto (TTC)	Scarborough RT	4.0	6.4	6	42,300	4,100	17	68
Vancouver (TransLink)	Expo††	17.9	28.8	20	144,600	15,000	35	140
Vancouver (TransLink)	Millennium*	25.7	41.4	27**	opened mid-2002		25	††
Washington (WMATA)	Red	31.6	50.8	26**		12,700	20	120
Washington (WMATA)	Blue*	26.9	43.2	25		5,000	10	54
Washington (WMATA)	Orange	26.2	42.1	26		10,600	20	104
Washington (WMATA)	Yellow	10.6	17.1	12		4,700	10	56
Washington (WMATA)	Green	22.8	36.6	21		7,400	10	60

*Extension of existing line underway in 2002.

SOURCE: Operator survey

**Additional infill station under construction in 2002.

†Data include all branches of the route.

††Expo line figures are prior to the opening of the Millennium line. The total number of cars operated on the Expo and Millennium lines combined ranges from 180 to 198, depending on the proportions of Mark I and Mark II trains used.

¤Estimates based on 2001 annual route, 2001 annual system, and 2001 weekday system ridership.

NOTES: Routes that entirely duplicate other routes (e.g., S-63 Street/6 Avenue shuttle in New York) not included.

Because of overlapping routes, the sum of individual route lengths and stations may be greater than the actual system totals. Some systems included overlaps in length totals; others did not. Lengths are for a single direction of a route.

Exhibit 5-83
Commuter Rail Route Characteristics and Ridership (2002)

		Length			Weekday	Peak Hour		
Region	**Route**	**mi**	**km**	**Stations**	**Ridership**	**Pass.**	**Trains**	**Cars**
Baltimore	Brunswick†	73.4	118.1	19				
Baltimore	Camden	36.8	59.2	11				
Baltimore	Penn	76.5	123.1	14				
Boston	Attleboro/Providence	43.6	70.2	8	10,300			
Boston	Fairmount	9.5	15.3	4	1,300			
Boston	Fitchburg	49.5	79.6	18	4,100			
Boston	Franklin	30.3	48.8	13	9,100			
Boston	Greenbush	18	29	7	scheduled 2006 opening			
Boston	Haverhill/Reading	32.9	52.9	13	5,000			
Boston	Kingston/Plymouth†	35.7	57.4	6	3,800			
Boston	Lowell	25.5	41.0	8	5,000			
Boston	Mid'borough/Lakeville	35.3	56.8	6	3,600			
Boston	Needham	13.7	22.0	11	4,800			
Boston	New Bedford/Fall Riv.†	47.6	76.6	8	scheduled 2005 opening			
Boston	New'port/Rockport†	35.3	56.8	18	8,300			
Boston	Rockport/Ipswich†	18.8	30.2	3	1,700			
Boston	Worcester/Fr'ham	44.3	71.3	15	8,200			
Burlington	Champlain Flyer	12.5	20.1	5	200		1	2
Chicago	BNSF	37.5	60.3	27	57,900	13,800	14	112
Chicago	Electric Div. Main Line	31.5	50.7	34	33,300	8,300	14	80
Chicago	Electric Div. Blue Is.	4.4	7.1	7	2,900	950	4	10
Chicago	Electric Div. S. Chicago	4.7	7.6	8	8,100	2,000	4	18
Chicago	Heritage Corridor	37.2	60.0	6	2,200	1,000	2	9
Chicago	Milwaukee North Line	49.5	79.6	21	22,500	5,000	6	39
Chicago	Milwaukee West Line	39.8	64.0	23	22,100	5,300	7	51
Chicago	North Central Service	52.8	85.0	14	4,400	1,400	2	11
Chicago	Rock Island	46.8	75.3	25	36,200	9,400	9	68
Chicago	South Shore	89.7	144.4	21	13,400	3,200	4	32
Chicago	SouthWest Service	28.9	46.5	10	6,900	2,700	3	24
Chicago	UP North Line	51.6	83.0	26	28,500	5,800	7	42
Chicago	UP Northwest Line†	70.5	113.4	22	38,100	9,200	10	79
Chicago	UP West Line	35.5	57.1	17	28,600	6,900	7	55
Dallas-Ft. W.	Trinity Railway Express	34.0	55.8	9	7,800		5	
Los Angeles	91 Line	61.5	99.0	10	900	320	2	6
Los Angeles	Antelope Valley	76.6	123.3	10	6,000	1,300	3	11
Los Angeles	Inland Empire-Or. Cty.	100.1	161.1	13	5,800	1,200	3	12
Los Angeles	Orange County	87.3	140.5	13	5,800	1,700	3	12
Los Angeles	Riverside	58.7	94.5	7	4,300	1,100	2	10
Los Angeles	San Bernardino	56.5	90.9	13	10,100	2,200	3	17
Los Angeles	Ventura County	66.3	106.7	11**	3,900	750	2	7
Miami	Tri-Rail	72.0	115.8	18	9,500	3,200	4	14
Montréal	Blainville	29.2	47.0	9	7,300			
Montréal	Delson	14.9	24.0	7	700			
Montréal	Deux Montagnes	16.9	27.2	12	27,000	2,500		
Montréal	Dorion-Rigaud	40.0	64.4	18	12,900	3,500		
Montréal	Saint-Hilaire	17.4	28.0	4	800			
New Haven	Shore Line East	32.8	52.8	7	1,100			
New Jersey	Atlantic City	67.9	109.3	8	1,500	220	2	
New Jersey	Boonton	47.9	77.1	20	5,700	1,900	5	
New Jersey	Main/Bergen County	95.2	153.1	31	17,100	4,700	10	
New Jersey	Montclair	12.8	20.6	6	1,200	340	2	
New Jersey	Morris & Essex†	60.2	96.9	33	25,700	4,800	13	
New Jersey	North Jersey Coast	66.7	107.4	25	37,300	6,900	7	
New Jersey	Northeast Corridor†	60.8	97.9	14	54,100	6,700	8	
New Jersey	Pascack Valley	30.6	49.3	17	6,100	1,900	4	
New Jersey	Raritan Valley	43.4	69.9	19	12,800	3,000	6	
NY-Long Isl.	Babylon†	36.9	59.4	15	68,300	13,000	14	132
NY-Long Isl.	Far Rockaway	21.5	34.6	17	12,900	2,800	5	36
NY-Long Isl.	Flatbush Terminal	9.3	15.0	4		6,500	12	86
NY-Long Isl.	Hempstead	20.1	32.4	15	14,100	3,200	5	36
NY-Long Isl.	Hunterspoint Terminal							
NY-Long Isl.	Long Island City Term.	9.0	14.5	7		120	2	11
NY-Long Isl.	Long Beach	23.4	37.7	11	20,100	5,000	6	56
NY-Long Isl.	Montauk	106.9	172.0	22	7,300	1,300	4	20
NY-Long Isl.	Oyster Bay	23.9	38.5	13	5,000	1,000	2	11
NY-Long Isl.	Penn Terminal	9.3	15.0	6		41,500	38	380
NY-Long Isl.	Port Jefferson	57.9	93.1	22	51,400	11,000	12	109
NY-Long Isl.	Port Washington	18.4	29.6	13	41,400	9,100	8	76
NY-Long Isl.	Ronkonkoma	94.3	151.8	22	39,100	8,700	6	68
NY-Long Isl.	West Hempstead	13.1	21.1	11	3,600	1,300	3	20

Table continues on the next page.

Exhibit 5-83 (cont'd.)
Commuter Rail Route Characteristics and Ridership (2002)

		Length			Weekday	Peak Hour		
Region	**Route**	**mi**	**km**	**Stations**	**Ridership**	**Pass.**	**Trains**	**Cars**
NY-Metro N.	Harlem	77.4	124.5	36	85,500	12,300	17	134
NY-Metro N.	Hudson	75.8	122.0	29	48,000	8,300	13	94
NY-Metro N.	New Haven	60.7	97.7	26	104,400	15,700	20	157
NY-Metro N.	New Canaan Branch	7.9	12.7	4	5,000			
NY-Metro N.	Danbury Branch	24.2	38.9	7	2,600		1	2
NY-Metro N.	Waterbury Branch	27.1	43.6	6	600			
Philadelphia	R1	29.6	47.7	16	5,000	1,100	13	29
Philadelphia	R2	57.1	75.7	35	13,700	9,000	26	93
Philadelphia	R3	48.0	77.3	36	18,300	13,400	37	143
Philadelphia	R5	70	127.0	49	36,100	20,100	53	214
Philadelphia	R6	24.7	39.8	19	7,700	4,400	22	62
Philadelphia	R7	45.1	73.7	26	15,200	9,100	29	101
Philadelphia	R8	23.7	38.5	20	10,600	6,800	27	78
Philadelphia	PennDOT	72.2	116.2	12	700			
San Diego	Coaster	41.1	66.1	8	5,000		4	
San Francisco	CalTrain	76.8	123.6	33	29,000			
San Jose	Altamont Comm. Exp.	86.0	138.4	10	2,800		2	12
Seattle	Sounder*	39.3	63.2	8	2,900	1,500	3	
Syracuse	City Express	3.5	5.6	4	100			
Toronto	Bradford	41.5	66.8	6	1,600	800	1	7
Toronto	Georgetown	29.4	47.3	8	8,700	3,300	3	24
Toronto	Lakeshore East	31.6	50.9	10	30,000	7,500	5	51
Toronto	Lakeshore West	39.3	63.3	12	37,200	10,100	6	62
Toronto	Milton	31.2	50.2	8	13,200	4,000	3	27
Toronto	Richmond Hill	21.0	33.8	5	4,800	1,800	3	18
Toronto	Stouffville	29.0	46.7	8	2,000	1,200	2	12
Vancouver	West Coast Express	43	65	8	7,600	2,500	3	22
Washington	Fredericksburg	53.8	86.5	11	6,300	1,300	2	11
Washington	Manassas	35.8	57.6	10	5,300	1,200	2	10

*Extension of existing line underway in 2002.

**Additional infill station under construction in 2002.

†Data include all branches of the route.

SOURCE: Operator survey, APTA (R5)

NOTES: Because of overlapping routes, the sum of individual route lengths and stations may be greater than the actual system totals. Some systems included overlaps in length totals; others did not. Lengths are for a single direction of a route.

Burlington's Champlain Flyer ceased operations in March 2003. Syracuse's OnTrack City Express operates 11:15 a.m. to 6:30 p.m. Wednesday through Sunday.

This page is intentionally blank.

PART 6
FERRY CAPACITY

CONTENTS

LIST OF EXHIBITS

This page is intentionally blank.

CHAPTER 1. FERRY CAPACITY

INTRODUCTION

Ferry service plays a major role in urban transportation systems in many North American cities such as New York, San Francisco, Seattle, and Vancouver. Ferry transit provides an alternative to cross water barriers that would otherwise necessitate expensive infrastructure that may not be feasible to construct. Ferry transit corridors can also offer direct access to residential and business areas and can potentially reduce the transit travel time that would otherwise be experienced in mixed traffic.

Ferry system capacity is a relatively undeveloped topic.

There is currently little information regarding waterway system- or vessel-related capacity. Ferry operators are stimulating discussion in this area, but it remains a facet of waterway capacity that is relatively undeveloped.(R3) The objective of Part 6 is to build an initial framework for determining the capacity of ferry transit services in North America.

This chapter is arranged in three primary sections: an overview of ferry facilities and service that affect capacity, a methodology to calculate vessel capacity, and a methodology to calculate passenger capacity.

FERRY FACILITIES AND SERVICE

Ferry Service

The type of ferry service provided by different operators can vary significantly. Some operators may provide passenger service with short trip lengths, relatively high frequencies, and a number of stops. Other ferry services may accommodate passengers, and possibly their autos, on trips with only one origin and destination. Ferry capacity evaluations must consider these different service configurations.

A breakdown of typical ferry types is provided below:

- *Water Taxis:* small watercraft that typically serve short cross-waterways or waterway circulation routes;
- *Passenger Ferries:* larger vessels that have higher passenger capacity and speeds than water taxis and typically serve short- to moderate-length routes; and
- *Auto Ferries:* also known as roll-on, roll-off ferries, these ferries transport vehicles as well as passengers. They are typically used on longer routes across major bodies of water and on low-volume rural roads crossing rivers.

By definition, a water taxi provides on-demand service to a variety of destinations. However, the term is commonly applied to small watercraft serving multiple-stop routes.

Exhibit 6-1 illustrates the different service types. A breakdown of some of the characteristics of U.S. and international ferry service is provided in Exhibit 6-2. A more comprehensive list of ferry service providers can be found in Part 2.

Intermodal transfers are usually required at one or both ends of ferry trips.

Because ferries can only take passengers to the water’s edge, intermodal transfers are usually required at one and often both ends of the ferry trip. Options for providing this transfer include park-and-ride lots, feeder bus service, roll-on, roll-off bus service (for auto ferries), and terminals located close to rail service (as in New York and San Francisco).

Exhibit 6-1
Ferry Service Type Examples

(a) Water Taxi (Baltimore) (b) Auto Ferry (British Columbia)

(c) Passenger Ferry (San Francisco) (d) Passenger Ferry (Boston)

Exhibit 6-2
Examples of U.S. and International Ferry Service Characteristics

Location	Service	# of Vessels	# of Terminals	# of Routes	Peak Frequency (min)	Annual Riders (000)
Ft. Lauderdale	Water taxi	4	36	1	On-demand	300
Sydney	Passenger	27	29	10	15-30	13,000
Hong Kong	Passenger	86	19	19	10	30,000
San Francisco	Passenger	12	9	6	30, 45+	3,500
Seattle	Auto, Passenger	26	20	10	30-40	25,000

Vessel Type

Vessels can be categorized by their physical and mechanical characteristics. Physical characteristics include the hull type and vessel dimensions and affect the design of both the vessel and passenger facilities. The Society of Naval Architects and Marine Engineers has prepared a summary of a variety of hull types:(R1)

- *Monohulls* are commonly used in the United States, especially where speeds greater than 30 knots in high sea conditions are not required. The semi-planing monohull represents a low capital cost, low maintenance option for relatively protected waters.
- *Catamarans* have steadily eclipsed other hull forms as the choice of most ferry operators for all but very high-speed (greater than 40 knots) service. The catamaran offers a more stable platform than the monohull, greater maneuverability (owing to widely spaced propellers), low draft requirements at a given hull displacement, and reasonable economy of operation. Compared with monohulls of similar size, however, capital costs are higher and wider vessel berths are required. At low speeds, operating inefficiency increases, which also increases fuel consumption and fuel costs. Water jet propulsion combines relatively good fuel economy with speed and passenger comfort.

- *Hydrofoils* feature low-wake profiles, high speed, and low fuel usage. They have deep draft requirements and are susceptible to disablement by submerged or floating flotsam. Debris impacts can lead to costly and time-consuming dry-docking.
- *Small Waterplane Area Twin Hull (SWATH)* vessels are designed to reduce vessel motions during rough head seas, while sustaining normal cruising speeds. SWATH ships typically have two submarine-like lower hulls completely submerged below the water surface. Above water, a SWATH resembles a catamaran.
- *Surface Effect Ships* are propelled through the water with 85% of the hull weight lifted out of the water. These ferries operate with low fuel usage and high speeds but have a high capital cost per seat, high maintenance requirements and costs, susceptibility to speed loss in heavy sea conditions, and a less comfortable ride.
- *Hovercraft* travel above water and are propelled through the air. This hull form is attractive for shallow areas (since the vessel travels above the water and not through it) and is faster than other vessels (since it has little contact with, and hence little friction from, the surface water). For short distances, these vessels can also operate across land to sites. Negative considerations include high capital and maintenance costs, bumpy rides, and high levels of exterior noise. As of 2003, with the exception of a single vessel in the St. Petersburg, Florida area, no commercial hovercraft operate in U.S. waters today, although many operate in Europe.

Exhibit 6-3 illustrates the common North American vessel types.

Exhibit 6-3
Vessel Types

(a) Monohull (Seattle)

(b) Catamaran (Sydney, Australia)

Vessels' mechanical properties, such as propulsion, will affect the vessels' speed and the resulting travel time over a route. Types of propulsion include fixed pitch propeller or controllable pitch propeller, which are common to monohull vessels; water jet, which is common to catamarans; and cable. Some smaller vessels may also be propelled by outboard motors. Some new ferries employ a "cycloidal propulsion" system. Instead of conventional propellers and rudders, power is obtained from two vertical cycloidal propulsors, one at each end of the boat. This technology allows the ferry to make 360-degree turns or to move sideways with no forward or backward movement.

Examples of vessel types and characteristics are provided in Exhibit 6-4.

Exhibit 6-4
Examples of Vessel Types and Characteristics (2002)

Operator	Water Body	Service Type(s)	Number of Vessels by Type	Passenger Capacity	Speed (Knots)
New York City DOT	Harbor	Passenger	Monohull (5)	1,200-6,000	16
		Auto Ferry	Monohull (3)	3,500	16
Texas DOT, Port Aransas	Channel	Auto Ferry	Monohull (6)	100	10
Seajets, Palm Beach, FL*	Coastal Ocean	Passenger	Hydrofoil (2)	280	46
Blue & Gold Fleet, San Francisco	Bay	Passenger	Monohull (7)	200-700	12-15
Washington State Ferries, Seattle	Puget Sound	Passenger	Monohull (2) Catamaran (5)	250-350	25-35
		Auto Ferry	Monohull (24)	550-2,500	10-18
Hover-USA, St. Petersburg, FL	Bay	Passenger	Hovercraft (1)	17	30-35

*ceased operation in 2001

A vessel's capital and operating costs will ultimately affect the fare and, hence, the passenger demand. Generally, the power required to propel a vessel increases at a more rapid rate than does its speed. It is common for fuel consumption to double as speeds increase from 25 to 30 knots. This fuel consumption can easily increase operating costs by $100 per hour—requiring fare revenues from 20 to 40 additional passengers, or a higher fare, which may also influence demand. The paradox of this fuel consumption curve is that higher speeds make little difference in overall travel time on short routes. For example, the difference between a 25-knot vessel and a 30-knot vessel on a 7-mi (12-km) route would be about 3 minutes in travel time.(R2)

It may be feasible to initiate service on shorter routes with vessels operating at speeds down to 25 knots (30 mph or 50 km/h) if terminals are designed to maximize loading and unloading efficiency to make the total travel time competitive with driving. Although the associated costs, and hence the fares, are not within the scope of this manual, they will ultimately impact the passenger volumes and hence the achievable capacity of a ferry transit system.

Docks and Loading Facilities

Docks

Docking configurations will largely depend upon the vessel. Auto ferries are typically end-loaded and hence have dock facilities that accommodate this process, as illustrated in Exhibit 6-5. Departing vehicles are stored at the landside or dockside vehicle staging areas. Passenger ferries are typically side-loaded, which can be accommodated by parallel or linear berthing facilities. The most typical dock design has parallel berths, such as those found at Sydney's Circular Quay. Some dock facilities may have a variety of berthing arrangements to facilitate a range of vessel types.

Exhibit 6-5
Examples of Auto and Passenger Ferry Dock Configurations

(a) End Loading (Seattle)

(b) Side Loading (New Orleans)

(c) Side Loading (San Francisco)

(d) Side Loading (Sydney, Australia)

Vehicle Staging Area

A critical aspect of an auto-ferry facility is its ability to accommodate vehicle loading and unloading. A number of North American auto-ferry operators request that auto-passengers on longer-distance routes make reservations and/or arrive 30 minutes to 3 hours prior to departure. The suggested arrival time is a function of the anticipated demand and may include time for security and/or hazardous material checks. For services between Canada and the United States, the advance time may also include customs checks.

The process of vehicle loading and unloading is time consuming and hence requires adequate access facilities and circulation provisions at the terminal. One of the key facilities in this process is the vehicle staging lot. This area allows for the storage of queuing vehicles, and a smooth transition between embarking and disembarking vehicle movements. The staging areas can be located dockside or landside. A plan sketch of a typical landside staging area is shown in Exhibit 6-6 and examples are shown in Exhibit 6-7. The various components of staging areas are described below.

Exhibit 6-6
Vehicle Staging Area Diagram

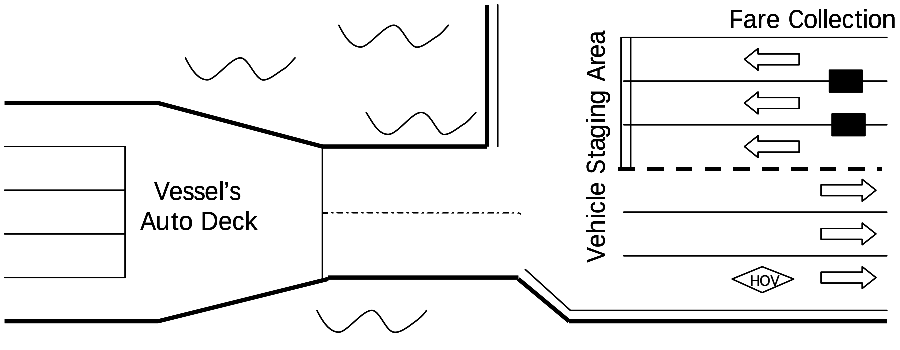


Exhibit 6-7
Vehicle Staging Area Examples


(a) Seattle (b) Bar Harbor, Maine

Vehicle Embarking

The staging lot design for embarking passengers will depend upon a number of factors. These include the following:

A vessel's capacity to transport vehicles is measured in auto equivalent units (AEUs) that reflect the amount of space used by each vehicle type.

- *Vessel auto-deck capacity:* Because the auto deck size varies considerably from one vessel to another, the concept of Auto Equivalent Units (AEUs) is commonly used to measure auto-deck capacity. Different vehicle types are weighted based on the space they occupy compared to a standard automobile. For example, the typical factor for a recreational vehicle, single-unit truck, or bus is 3, and the factor for a semi-trailer truck is 5. It is important to consider the average fully loaded volume, as some vessels may have adjustable platform decks that can be fully or partially utilized on a given sailing. If the average fully loaded sailing holds 10 autos, 5 RVs, 5 buses, and 10 semis, then the capacity is 10x1 + 5x3 + 5x3 + 5x5 = 65 AEUs.

Staging areas can be used to organize vehicles by size, weight, and destination prior to loading.

- *Loading process:* In order to keep the vessel balanced while vehicles are loaded, and to make sure that other vehicles do not block vehicles disembarking at intermediate stops, some agencies carefully manage the order of vehicle loading from the staging area. Vehicle loading will usually take place under the supervision of experienced crewmembers that are directed by the Chief Officer or Mate of the vessel. For these same reasons, vehicles that are first to board the ferry are not necessarily the first to disembark. The staging area should be designed to allow the flexibility of vehicle choice or, alternatively, staff should be available to assign vehicle types to a particular queuing bay. In some cases, such as the Lake Michigan Carferry, vehicles are loaded and unloaded by crewmembers or staff only.

The size of the staging area should, at a minimum, be sufficient to accommodate the vessel auto-deck capacity. However, an overload factor should be considered to accommodate excess vehicle demand. Washington State Ferries uses an overload factor between 1.3 and 2.2 depending on scheduled ferry headways, plus an additional two lanes for emergency and high-occupancy vehicles.

Well-designed vehicular circulation paths, with suitable signing and striping (e.g., lane numbers), are important to ensure the safe and efficient flow of traffic through the staging area. Barriers or traffic cones are often used to close off any temporary excess queue storage, so as to better define the vehicle path.

Fare Payment

Vehicle arrival patterns tend to be related to whether a particular sailing usually has excess capacity or not.

Fare payment and ticket collection practices vary depending upon the type of service. At larger ferry terminals, the fare may be collected at booths prior to entering the staging area. Smaller terminals may adopt a less formal process where the fare is purchased from staff roaming through the vehicle staging area or from a crewmember aboard the vessel. Persons traveling with their automobiles tend to adjust their behavior depending upon the demand for the service. That is, if a vessel typically has excess capacity, vehicles will arrive just before a vessel's departure. Hence, there will be a short period of high vehicle arrival volumes that may require a number of staff or ticket booths. Alternatively, if a given sailing is frequently over capacity, motorists will arrive early and there is less need to have high-capacity fare collection facilities.

Vehicle Disembarking

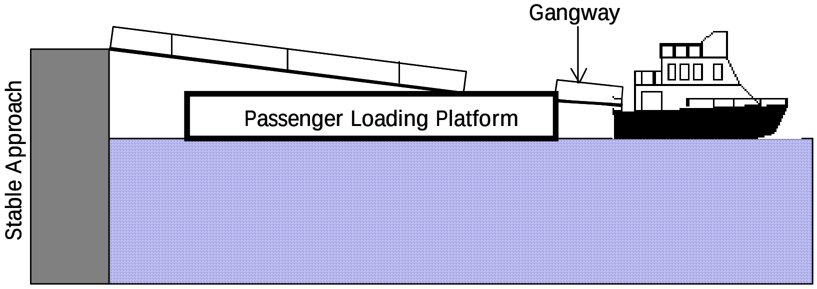
The disembarking process is commonly a straight path from the vessel auto-deck to serve vehicles in a timely manner. Some urban ferry terminal designs include special features, such as HOV lanes that feed into the urban street system.

Passenger Loading Area

To achieve minimum travel time, there must be maximum efficiency in loading and unloading passengers at the terminals. This will generally require standardized design criteria for both passenger platforms and vessels. It is also recognized that design should be a function of the peak throughput of passengers.

Passenger loading areas are generally located on a floating platform or stable approach (e.g., facilities supported by pilings), as illustrated in Exhibit 6-8. The passenger loading area also includes the gangway (between the vessel and the loading platform) and walkway facilities (between the shore and the loading platform) that accommodate loading and unloading.

Exhibit 6-8
Elements of Ferry Passenger Loading



The loading area design may vary considerably. Some examples are provided below and are illustrated in Exhibit 6-9:

- *Brisbane (Australia) CityCat:* Loading occurs from a floating platform (some covered, some not) approximately 110 ft^2 (10 m^2) in area. Passengers first disembark from a single 3-ft (1-m) wide manual gangway. When all passengers have disembarked, passengers may then embark. Fares are collected by a combination of an on-board cashier (for those paying cash), and an on-board ticket-validating machine (for those holding multiple-ride tickets and passes).
- *Sydney (Australia) Ferries:* Passenger loading at Circular Quay occurs from a large covered floating platform, which blends seamlessly from the terminal. Passengers pay their fares prior to entering the platform area. The facility design allows passengers to disembark using the upper-deck gangway, while other passengers simultaneously embark on the lower-deck gangway. The disembarking movement is connected to a fenced walkway that leads directly into the terminal.
- *Golden Gate Ferries (San Francisco):* Passenger loading occurs from a covered fare-paid area. Passenger loading occurs via one (monohull vessel) or two (catamaran) wide gangways. The latter configuration can serve hundreds of peak-direction passengers in minutes.

- *SeaBus (Vancouver)*: Gangways are located on both sides of the vessel. Passengers are unloaded from one side and loaded on the opposite side. This configuration allows the 400-passenger vessels to be loaded and unloaded within 90 seconds.

Exhibit 6-9
Examples of Passenger Loading and Unloading

(a) San Francisco (Ferry Building) (b) San Francisco (China Basin)

Passengers visible against the far wall in picture (c) have just disembarked the vessel from its opposite side.

(c) Vancouver (d) Vancouver

(e) Brisbane, Australia (f) New Orleans

There are a number of safety concerns at the platform:

- *Height difference between the stable approach and the water:* The stable approach to a passenger boarding facility is typically high enough above average water level to prevent submergence in all but the most extreme conditions. The height of the stable approach can range from several feet to over 20 feet (1 meter to over 6 meters), and is based on historical data.
- *Water level changes:* All waterfront facilities experience changes in the height of the water relative to the stable approach. Coastal facilities undergo tidal cycles, with normal ranges from little more than 1 foot to over 20 feet. Non-tidal (inland) facilities experience water level changes less frequently, as the result of rain, snowmelt, dam releases, and so forth, which tend to occur in predictable patterns. However, the changes can sometimes be more severe, with ranges in excess of 20 feet (6 meters). Extreme weather conditions can add considerably to the range at all facilities.

- *Height difference between passenger loading platform and the vessel:* When a loading platform (dock) is in the pathway between the stable approach and the vessel, the freeboard difference between the dock and the vessel is an access barrier. Because freeboards of docks and vessels vary greatly, there will be widely varied and unique height differences for dock-vessel combinations. This height difference may also vary for a particular dock-vessel pair, depending on loading and weather conditions.(R4)

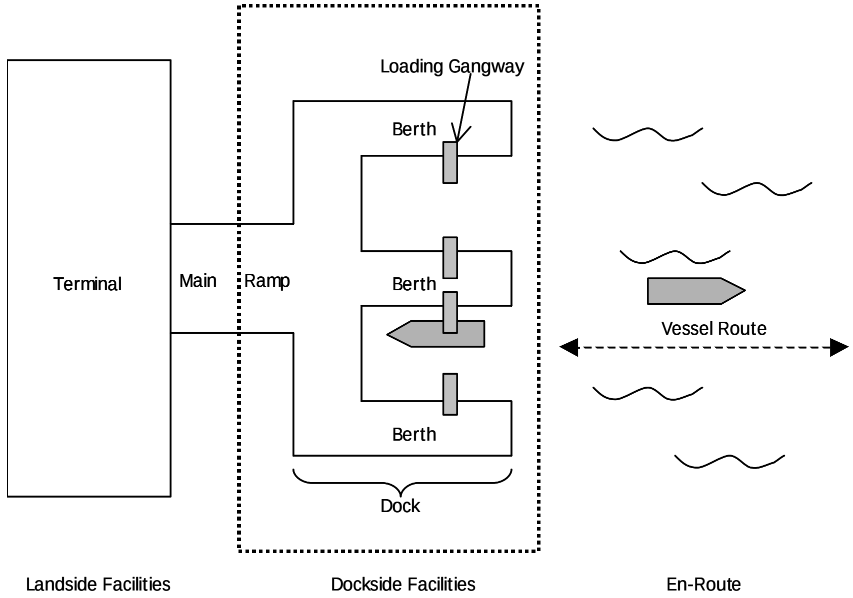
Safety features to accommodate these conditions should include:

- *Guardrails:* Guardrails are critical to ensuring passenger safety because of the inherent dangers of accidentally leaving the path of travel at a marine facility.
- *Edge treatments and detectable warnings:* Tactile edge treatments and detectable warnings for the sight-impaired are important in ensuring passenger safety.
- *Changes in slopes, heights, materials, and so forth:* The path of travel from land to vessel is likely to have frequent changes, particularly slopes. Changes in the height of the loading platform relative to the shore or the vessel, due to tides or fluctuations in river level, will need to be accounted for. Attention to the slope of the ramp must be made for passengers with disabilities.
- *Non-slip surfaces:* Most areas at a marine facility will periodically get wet or damp from water spray. The wide use and application of non-slip surfaces is important for passenger safety.
- *Assistance:* Assistance by crew for all passengers in the marine environment is standard practice due to the environment's dynamic nature. This positive tradition in the industry will be a part of the growing need for access for persons with disabilities.

VESSEL CAPACITY

Vessel capacity can be calculated for two key locations: berth (or loading area) and dock facility. A route's vessel capacity will be constrained by the lowest-capacity dock facility along the route. These locations are depicted in Exhibit 6-10.

Exhibit 6-10
Vessel Capacity Measurement Locations



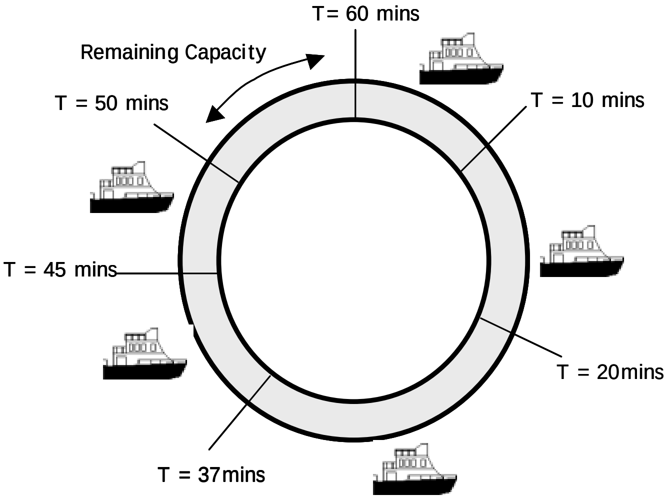
The berth, or loading area, encompasses the passenger loading platform, the gangway connecting the platform to the vessel, and any walkway facilities connecting the platform to a waiting area or the shore. The dock facility is composed of one or more berths.

Within a given hour, a ferry berth may accommodate multiple vessels. Given that each vessel uses a portion of the hour to serve passengers and/or autos and clear the berth, only a limited number of vessels can access the berth in the hour. The vessel capacity of a ferry berth is defined as the maximum number of vessels per hour that can use the berth at a given level of passenger demand.

Quantifying loading time is important even when vessel capacity is not an issue.

Ferry operators can determine how the current or planned vessel demand compares to the vessel capacity of the loading facilities, as illustrated in Exhibit 6-11. When a facility operates close to its capacity, any operating irregularities will cause delays to vessels, as they will arrive at the berth only to find it occupied by another vessel. In addition, when a facility operates close to its capacity, any growth in demand will increase each vessel's service time, and thus reduce the time within the hour available to other vessels. In this case, measures may be implemented to decrease the vessel loading and clearance time, or ultimately construct an additional berth.

Exhibit 6-11
Berth Vessel Capacity



In situations where vessel capacity is not anticipated to be an issue, quantifying the loading time enables planners and ferry operators to estimate a new route's travel time and to isolate any design issues related to the loading facilities.

The vessel capacity of the dock facility is a function of the capacity of the individual berths. The following sections present an overview of the primary factors that determine vessel capacity at each of these locations.

Berth Capacity

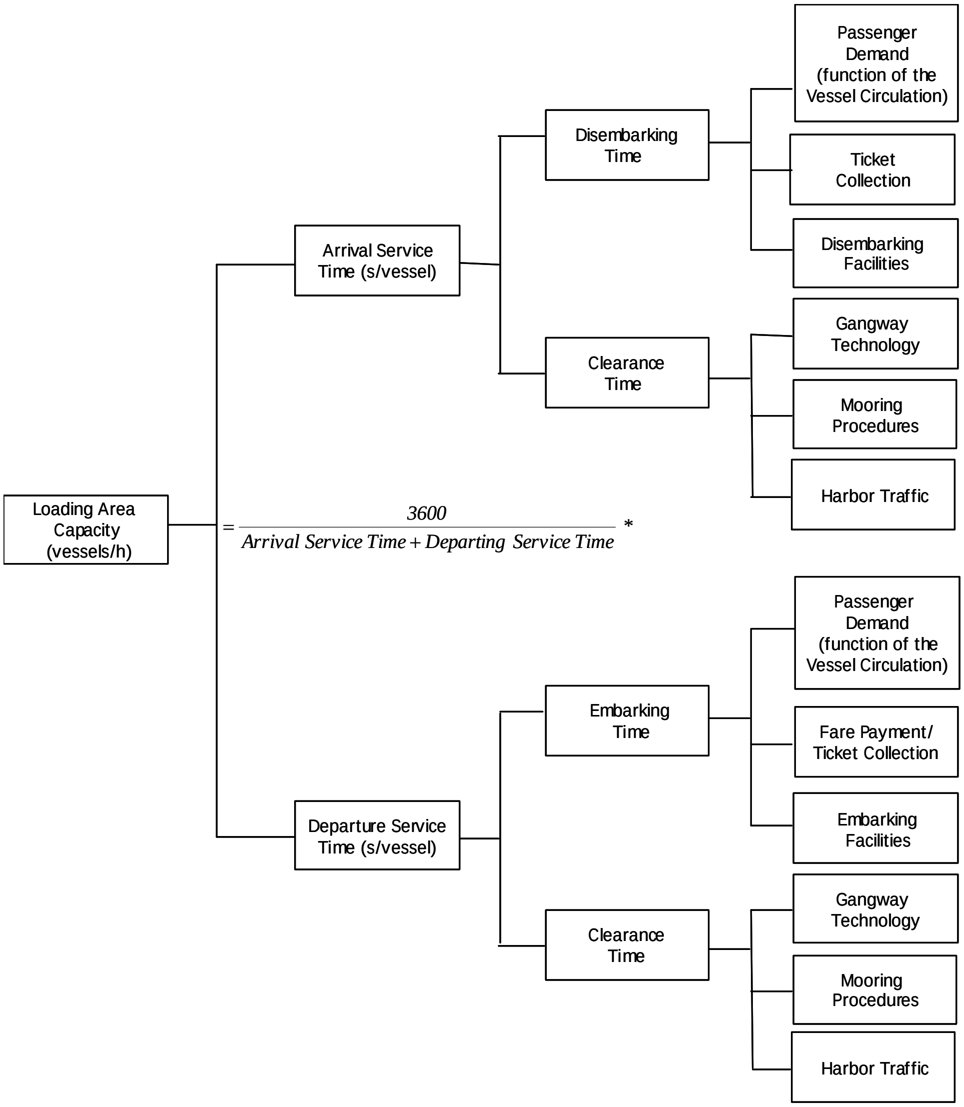
The vessel capacity of the berth, or loading area, is dependent upon two key components: the arrival service time and the departure service time. Arrival service time, given in seconds per vessel, is the sum of the vessel clearance time, plus the passenger disembarking time. Similarly, departure service time is the embarking time plus clearance time of the vessel to allow for other vessels to use the dock area.

Simultaneous passenger loading and unloading.

Disembarking and embarking time is a function of a number of factors, including passenger or auto demand, fare collection methods, and the design of the embarking and disembarking facilities, such as the dimensions of the gangways and walkways. The vessel and loading design may also enable the embarking and disembarking times to be overlapped.

The clearance time is the average time from when one vessel is ready to leave the berth to when another vessel is able to use the berth. A portion of the clearance time will be made up of the time for the vessel to maneuver out of and clear the berth area. Other factors include the gangway technology, mooring procedures, and the influence of any harbor traffic. These factors are illustrated in Exhibit 6-12 and described in more detail below.

Exhibit 6-12
Berth Capacity Factors



*Facilities may allow for the overlap of passenger disembarking and embarking, which should be accounted for accordingly.

Disembarking/Embarking Time Factors

Passenger or Auto Demand

The passenger or auto volume at a vessel's busiest entrance will control the service time.

The passenger (auto) demand is measured using the embarking and/or disembarking volume at the busiest entrance to each vessel, as this volume will control the total time needed to serve all passengers. Unless a vessel and its berth are designed to accommodate multiple gangways, this demand will be the same as the total passenger (auto) demand. For larger passenger vessels, passenger embarking and disembarking may occur simultaneously. In this case, the greater of the embarking or disembarking volume at the busiest entrance should be used to determine the loading time.

Fare payment does not affect passenger service time when fares are collected at the entrance to a fare-paid passenger waiting area.

Fare Payment

Fare payment and ticket collection procedures vary considerably in the ferry transit industry. At lower-volume terminals, passenger and auto fares are often collected at the gangway or on-board. Services that make multiple stops may also wish to collect fares on board to minimize or eliminate the need for staff at each dock. Depending on the number of bills and coins involved in paying cash fares and the potential need to issue a receipt, the time to serve each embarking passenger may be considerable. During peak tourist times on an Australian ferry, for example, fare payment has been observed to delay a vessel's departure at busy stops, as the line of passengers waiting to pay a cash fare to the on-board cashier can extend back onto the loading platform.

At larger terminals, fare payment and collection occurs in the terminal building, at the entrance to a fare-paid waiting area. Payment can be made to cashiers or through the use of ticket/token machines and fare gates. Automobile fare payment will typically occur at booths prior to entering the staging area. In either of these cases, fare payment does not affect the embarking or disembarking time.

Embarking and Disembarking Facilities

The stability and pedestrian-friendliness of the loading facilities affect the passenger disembarking and embarking time. These times also include the time to transverse the loading area facilities, which is a function of the length and width of the access walkway/roadway, and the boarding ramp or gangway.

Clearance Time Factors

- *Gangway Technology:* The gangway technology will affect the time it takes to place and remove the gangway. There are a number of current technologies:
    - Hand winch or manually placed;
    - Electric;
    - Hydraulic; and
    - Bow Loading, which offers the advantage of faster mooring and loading; however, terminals need to be configured for this system.
- *Mooring Procedures:* Mooring procedures vary considerably. Some examples are described below:
    - *Blue & Gold Fleet (San Francisco):* A three-step process involving fixing the spun line, bell line, and stern line. The mooring time is approximately 1 minute.
    - *Golden Gate Ferries (San Francisco):* The stern line is fixed and the vessel is left running to maintain tension. The 2-ton gangways rest upon the vessel to keep the vessel in place. This process takes approximately 30 seconds to complete.
    - *Staten Island Ferry (New York):* The vessel is docked with a rack system that guides the vessel. The lower-level gangway is attached with mooring hooks and the upper- and lower-level gangways are then placed on the vessel.
- *Harbor Traffic:* Small pleasure craft and windsurfers can cause delays to ferries, particularly on weekends. These conditions may result in congestion or a high-risk environment, forcing vessels to reduce travel speeds. In some cases, local authorities enforce the burden on a certain direction of travel. This means that the vessels traveling in a certain direction must yield to those vessels traveling in the other direction.

Other clearance time factors may include policy issues such as the time for staff to complete safety checks.

Berth Vessel Capacity

The maximum number of vessels per hour that a berth can accommodate, based on a given passenger demand, is given by the following expression:

Equation 6-1

$$V_b = \frac{3{,}600}{t_v}$$

where:

V_b = vessel capacity of the berth (vessels/h);

3,600 = the number of seconds in 1 hour; and

t_v = vessel service time (s/vessel), from Equation 6-2.

The service time is given by the sum of the clearance time and the embarking and/or disembarking times. An allowance for variations in embarking and disembarking times is also included, similar to the operating margin used in the bus capacity procedures presented in Part 4. This margin is based on two factors:

- *Coefficient of variation of the embarking and disembarking time* (c_v): the standard deviation of the loading/unloading time divided by the mean loading/unloading time.
- *Standard normal variable* (Z) corresponding to a desired failure rate (i.e., the probability that one vessel will arrive, only to find the previous vessel still occupying the berth), as given in Exhibit 4-6.

No default values are currently available for ferry capacity parameters; field data collection is suggested.

Discussions with various ferry operators suggests that commuter embarking and disembarking has very little variation, while tourist services experience significant variation around the mean. There are currently no ferry-related data that allow a default coefficient of variation to be given; however, one could determine this parameter from a series of field observations. Similarly, no data are currently available to provide a default clearance time; however, one could be determined from observations of current operations or from discussions with vessel captains.

If capacity will not be an issue, but it is desired to know the average time a vessel will occupy the berth (e.g., for use in estimating travel time), the operating margin (the Zc_vt_{ed} component of Equation 6-2) can be omitted.

Equation 6-2 provides the full berth service time equation.

Equation 6-2

$$t_v = t_{ed} + Zc_v t_{ed} + t_c$$

where:

t_v = vessel service time (s/vessel);

t_{ed} = average total embarking and disembarking time (s/vessel);

t_c = clearance time (s/vessel);

c_v = coefficient of variation of the embarking and disembarking time; and

Z = standard normal variable corresponding to the probability that the embarking and disembarking time will be more than c_v percent longer than average, from Exhibit 4-6.

Determining the disembarking and embarking times requires field measurements, or estimates of the number of embarking and disembarking passengers or automobiles. The following sections describe how to estimate these times when field data are unavailable, based on passenger demand, terminal and vessel design elements, and fare collection procedures. These procedures draw from the pedestrian flow procedures presented in Part 7 of the TCQSM.

Sequential Passenger Disembarking and Embarking

This section applies to situations where passengers disembark from the vessel and have cleared all walkways before passengers are allowed to embark. The service time elements in this process are as follows:

1. Passenger time to disembark the vessel over one or more gangways. This time is related to the number of gangways, the gangway width, and the passenger demand.
2. Disembarking passenger time to traverse the walkway to the dock exit. This time is related to the walkway width and the rate at which passengers exit the gangway(s).
3. If disembarking passengers arrive at the dock exit at a faster rate than the exit can process them, there will be additional delay at the exit. This could be an issue if the exit was narrower than the walkway leading to it, or if a doorway or exit gate is involved.
4. Once disembarking passengers have cleared the area, embarking passengers are allowed from the waiting area onto the walkway leading to the vessel. Entrance to the walkway could be controlled by a door, sliding gate, or other mechanism, any of which will have an associated time to serve all of the passengers in the waiting area. If fares are collected at the waiting area exit, this time should be included in the service time.
5. Embarking passenger time to traverse the walkway to the vessel. This time is related to the walkway width and the rate at which passengers exit the waiting area.
6. Time to board the vessel over its gangway(s). If passengers arrive at the gangway(s) at a faster rate than they can be processed, there will be additional delay at the gangway. If fares are collected at the gangway, this time should be included in the service time.

The total embarking and disembarking time is given by the following expression:

Equation 6-3

$$t_{ed} = 60\left(\frac{P_d}{C_d} + \frac{L_w}{v_d} + \frac{P_e}{C_e} + \frac{L_w}{v_e}\right)$$

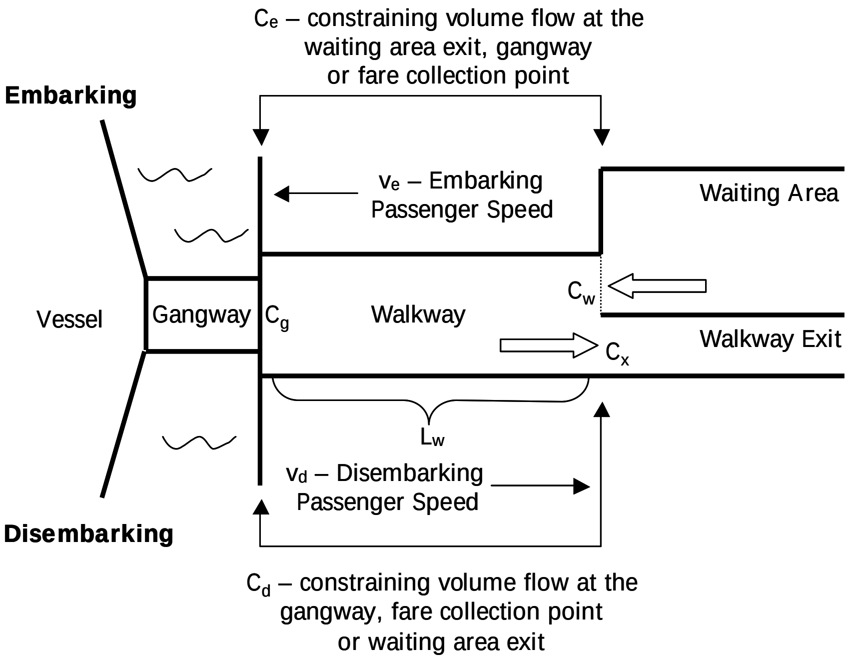
where:

t_{ed} = total embarking and disembarking time (s/vessel);
60 = number of seconds in 1 minute;
C_d = disembarking capacity at the constraining point (p/min);
C_e = embarking capacity at the constraining point (p/min);
P_d = disembarking passenger volume (p);
P_e = embarking passenger volume (p);
L_w = walkway length (ft, m);
v_d = disembarking passenger speed on walkway, from Exhibit 7-1 (U.S. customary units) or Exhibit 7-1m (metric units) (ft/min, m/min);
v_e = embarking passenger speed on walkway (ft/min, m/min);

For relatively uncongested situations (i.e., walkway LOS “C” or better), 250 ft/min (75 m/min) is a reasonable default passenger speed.

These parameters are illustrated in Exhibit 6-13.

Exhibit 6-13
Embarking and Disembarking Parameters



Note: The gangway is considered as a point and hence the time to traverse its length is not included.

Passenger speeds on the walkway can be determined using Exhibits 7-1 and 7-2, starting with a known capacity of the gangway or waiting area exit that constrains how quickly passengers can enter the walkway. For example, if the walkway is 6 feet (1.8 meters) wide and the gangway can process 60 passengers per minute, the pedestrian flow per unit width entering the walkway from the gangway is 10 pedestrians per minute per foot width (33 pedestrians per minute per meter width). Using the right (uncongested) side of the uni-directional commuter curve in Exhibit 7-2 gives a pedestrian space of approximately 26 square feet (2.5 square meters) per passenger at this pedestrian flow per unit width. Applying this result to Exhibit 7-1 gives an average pedestrian walking speed of 250 ft/min (75 m/min).

The disembarking capacity, C_d, will be constrained by the gangway capacity, fare collection time exiting the vessel (if applicable), or the capacity of the walkway exit leading to the terminal building or the shore, as shown in Equation 6-4:

Equation 6-4

$$C_d = \min \begin{Bmatrix} C_g N_{cg} \\ 60 N_f / t_f \\ C_x N_{ce} \end{Bmatrix}$$

where:

C_g = gangway capacity (p/min/channel);
N_{cg} = number of gangway channels (i.e., the number of people who can simultaneously exit the vessel);
60 = number of seconds in 1 minute;
N_f = number of fare collectors;
C_x = capacity of the walkway exit (p/min/channel);
N_{ce} = number of channels at the walkway exit; and
t_f = fare collection time (s/p).

The embarking capacity, C_e, will be constrained by the capacity of the exit from the passenger waiting area, fare collection time boarding the vessel or at the waiting room exit (if applicable), or the gangway capacity, as shown in Equation 6-5:

Equation 6-5

$$C_e = \min\begin{Bmatrix} C_g N_{cg} \\ 60N_f / t_f \\ C_w N_{cw} \end{Bmatrix}$$

where:

C_w = capacity of the waiting area exit (p/min/channel); and

N_{cw} = number of channels exiting the waiting area (i.e., the number of people who can simultaneously exit the waiting area).

Gangways can be treated as a free-entry fare gate, and their capacities can be determined from Exhibit 7-20. The capacities of other potential constraining points, such as doors or gates, can also be determined from this exhibit.

When local data on fare collection times are not available, fare collection service times can be approximated using the values for buses given in Exhibits 4-2 and 4-3.

Simultaneous Passenger Embarking and Disembarking

In the event that passenger embarking and disembarking occurs at the same time, inputs to Equation 6-3 should only include the greater of the embarking or disembarking service time. This value is not necessarily dependent upon the magnitude of the embarking or disembarking volume. Although the disembarking volume may be greater than the embarking volume, the service time for embarking passengers may be larger if passengers pay fares when boarding.

Sequential Automobile Disembarking and Embarking

When automobiles and other vehicles are carried, the time required to load and unload these vehicles will usually control the total embarking and disembarking time. This service time is constrained by the time to serve individual vehicles at the gangway, the number of gangway channels available, and the distance between the gangway and the front of the vehicle staging area, as shown in Equation 6-6:

Equation 6-6

$$t_{ed} = \frac{h_v(A_d + A_e)}{N_{ca}} + \frac{2L_r}{v_v}$$

where:

h_v = vehicle headways (s/auto);

A_d = number of disembarking autos (auto equivalent units);

A_e = number of embarking autos (auto equivalent units);

N_{ca} = number of channels for automobiles;

L_r = distance between gangway and front of vehicle staging area (ft, m); and

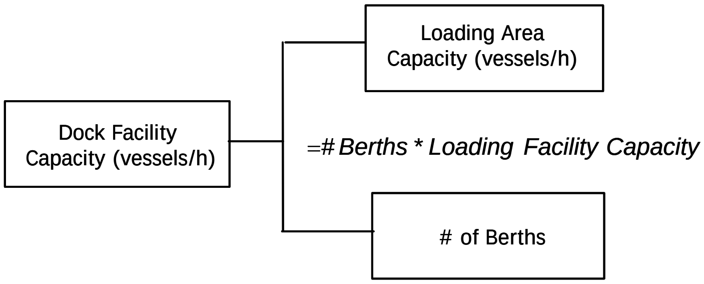
v_v = vehicle entering/exiting speed (ft/s, m/s).

There are currently no default values for headway or vehicle speed; however, these can be determined from field observations.

Dock Capacity

The vessel capacity of the dock will affect the total number of vessels that can be served at the dock facility per hour. Exhibit 6-14 illustrates the dock facility capacity relationships.

Exhibit 6-14
Dock Capacity Factors



The vessel capacity of a loading area is given by Equation 6-7:

Equation 6-7

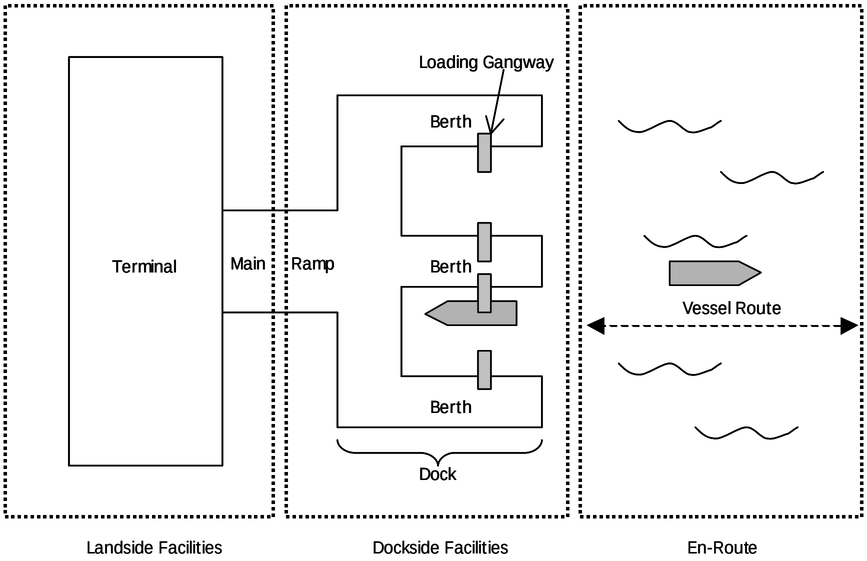
$$V = \sum_{i=1}^{N_b} V_{bi}$$

where:
V = dock vessel capacity (vessels/h);
V_{bi} = vessel capacity of berth i (vessels/h); and
N_b = number of berths at the dock.

PASSENGER AND AUTO CAPACITY

The passenger capacity can be calculated at a number of locations along the passenger's path of travel. These locations are illustrated in Exhibit 6-15 and are broken into three key components: landside, dockside, and en-route.

Exhibit 6-15
Passenger or Auto Flow Through the Ferry Transit System



Landside: The terminal capacity is described in detail in Part 7.

Dockside: The dockside facilities relate to the passenger (auto) capacity of the berth (a single loading area) or the dock (multiple loading areas). As discussed previously, ferry operators can determine how the current or planned demand compares with the vessel capacity of the loading facilities. In a similar manner, it would be useful to compare the current or planned passenger (auto) demand with the passenger (auto) capacity of the loading facilities.

The maximum number of embarking and disembarking passengers (autos) that can be served at the berth will depend upon the number of vessels serving that berth during the hour. The greater the number of vessels, the greater the total clearance time and, hence, the less time available to load and unload passengers or vehicles. If the embarking and disembarking time for all vessels at the berth exceeds the available time within the hour, then it can be concluded that the passenger (auto) demand exceeds the passenger (auto) capacity of the loading area.

The maximum number of embarking and disembarking passengers (autos) that can be served at the berth will also depend upon the distribution of embarking and disembarking at a berth for each vessel. When all passengers (autos) disembark all vessels that arrive at the berth, the embarking demand per vessel cannot exceed the vessel's passenger (auto) capacity. When vessels make multiple stops, a portion of the passengers aboard will not disembark. The difference between the vessel's passenger capacity and the number of passengers remaining aboard at a stop represents the embarking passenger capacity for each vessel.

En-Route: The en-route capacity of a ferry system is much less complicated. The capacity or the maximum number of passengers (autos) on a given route is generally based on operator policy, which includes the vessel headway and the vessels' passenger and automobile capacity. The passenger capacity is defined as the number of passengers per hour that can be accommodated based on the current headway and vessel passenger capacity.

Equation 6-8

$$P = V_c f (PHF)$$

where:

P = person (auto) capacity on the route's maximum load segment (p/h, autos/h);

V_c = passenger (auto) capacity of the vessel (p/vessel, autos/vessel);

f = vessel frequency (vessels/h); and

PHF = peak hour factor.

Licensing issues related to crew size and composition may constrain a vessel's passenger capacity.

Unlike other modes, where passenger capacity is related only to seating and standing area available, the passenger capacity on the vessel is also affected by policy and licensing issues. Some vessels may have three or four different licenses, whereby the passenger limit will depend upon the size and composition of the crew. Ferry operators may need to match the crew size and passenger license to projected passenger demand. For autos, the concept of AEUs, described earlier in this chapter, is used to measure vehicle capacity on the vessel. This is a method that weights different vehicle categories based on the space they occupy relative to an automobile.

A "peak hour factor" is used in the bus and rail sections of the TCQSM to account for the peak 15 minutes of the peak hourly demand. This ensures that the peak-within-the-peak hourly flow can be accommodated. With a few exceptions (such as Vancouver's SeaBus and New York's Staten Island Ferry), most North American passenger ferry operations are operated at headways of 30 minutes or longer. In this respect, ferry service is similar to many commuter rail operations. A peak hour factor of 0.90 to 0.95 is recommended to allow for variations in demand and to ensure that all passengers who wish to board a given trip are able to do so. Auto ferries that require advance reservations can use a PHF of 1.00, as all available vehicle space will be utilized whenever possible, and there is no passenger expectation of space being guaranteed on the next departing ferry.

CHAPTER 2. REFERENCES

1. Ad Hoc Ferry Transit Environmental Impact Panel, *Ferry Transit for the Twenty-First Century,* Society of Naval Architects and Marine Engineers (January 2000).
2. Bay Area Council, *Bay Area Water Transit Initiative* (1999). http://www.bayareacouncil.org/watertransit/bawt_actionplan.html.
3. Neill, S.M., *A Survey of Waterway Capacity and Policy Issues,* Marine Board Seminar on Waterways and Harbor Capacity (April 2001).
4. Volpe National Transportation Systems Center, *Access for Persons with Disabilities to Passenger Vessels and Shore Facilities,* Final Report, U.S. Department of Transportation, Washington, DC (July 1996). http://ntl.bts.gov/DOCS/rptfinal/rptfinal1.html.

This page is intentionally blank.

CHAPTER 3. EXAMPLE PROBLEMS

Example Problem 1

The Situation

A short passenger ferry route is planned that connects three locations along and across a river. For scheduling purposes, it is desired to know how long vessels will stop at each location.

The Question

What are appropriate vessel service times to plan for at the three stops, during the afternoon peak period?

The Facts

- The route will use a ferry with a 50-person capacity.
- Ticket machines located on the shore will be used to issue tickets; a crewmember will collect the tickets at the gangway.
- The ferry has one doorway and hence there is sequential passenger disembarking and embarking.
- The average number of embarking and disembarking passengers per stop during the afternoon peak period is forecast as follows:

Stop #	1	2	3
Disembarking Passengers	10	20	40
Embarking Passengers	30	10	10

- The docks have a gangway width of 1 meter. Sloped walkways lead from each dock onto the shore. The walkways have dimensions of 2x15 meters and each walkway ends in a pair of free-swinging gates opening outward into an uncovered waiting area. Embarking passengers are not allowed onto the walkway until the disembarking passengers have exited.

Comments

- Based on observations of a ferry operation with similar mooring operations and gangway equipment to that proposed, the clearance time is estimated to be 90 seconds (45 seconds upon arrival and 45 seconds upon departure).
- Because berth capacity is not being calculated, the operating margin component of Equation 6-2 does not need to be used.
- From Exhibit 7-24, average capacities for manual ticket collection are 30 persons per minute (i.e., 2 seconds per person). Both the gangway and the walkway exit gates can be treated as free-admission gates, which have a capacity range of 40-60 persons per minute per channel. The lower value (40 persons per minute per gate) will be assumed for the walkway exit gates, as these require physically pushing or pulling the gates to open them, or to keep them open, while the higher value (60 persons per minute per channel) will be assumed for the gangway, as passengers can pass through it freely. A 1-meter-wide gangway is the equivalent of one channel.

Outline of Solution

All input parameters are known. The vessel service time will be calculated using Equation 6-2, without the operating margin component. As passenger movement along the walkway occurs in one direction at a time, embarking and disembarking times will need to be calculated separately for each stop to determine their contribution to vessel service times.

Solution

1. Calculate the disembarking capacity using Equation 6-4. This capacity is constrained by the gangway, fare collection (not applicable for disembarking), or the walkway exit.

$$C_d = \min\begin{Bmatrix} C_g N_{cg} \\ 60N_f / t_f \\ C_x N_{ce} \end{Bmatrix}$$

$$C_d = \min\begin{Bmatrix} 60(1) \\ N / A \\ 40(2) \end{Bmatrix}$$

$$C_d = 60 \text{ p/min}$$

2. Calculate the embarking capacity using Equation 6-5. This capacity is constrained by the gangway, fare collection, or the walkway entrance.

$$C_e = \min\begin{Bmatrix} C_g N_{cg} \\ 60N_f / t_f \\ C_w N_{cw} \end{Bmatrix}$$

$$C_e = \min\begin{Bmatrix} 60(1) \\ 60(1/2.0) \\ 40(2) \end{Bmatrix}$$

$$C_e = 30 \text{ p/min}$$

3. Determine the total embarking and disembarking time from Equation 6-3.

$$t_{ed} = 60\left(\frac{P_d}{C_d} + \frac{L_w}{v_d} + \frac{P_e}{C_e} + \frac{L_w}{v_e}\right)$$

$$t_{ed} = 60\left(\frac{10}{60} + \frac{15}{75} + \frac{30}{30} + \frac{15}{75}\right)$$

$$t_{ed} = 94 \text{ s}$$

4. Calculate the vessel service time from Equation 6-2, omitting the operating margin component.

$$t_v = t_{ed} + t_c$$

$$t_v = 94 + 90$$

$$t_v = 184 \text{ s}$$

The Results

Estimated vessel service times for planning purposes are shown below for each stop:

Stop #	1	2	3
Vessel Service Time (s)	184	154	174

Changing the proposed fare collection system to avoid fare collection at the gangway would improve the vessel service time by an average of 30 seconds per stop. Improvements in the gangway or mooring technology could also be considered to improve service times, as the planned 90 seconds forms a significant portion of the total time.

Example Problem 2

The Situation

An new auto ferry route is planned to connect two locations on opposite sides of a bay. It is desired to know how long a typical ferry on this route will occupy the berth when auto demand equals or exceeds the ferry's capacity.

The Question

What is the average vessel service time when the ferry is fully loaded entering and leaving the dock?

The Facts

- The route will use a ferry with a capacity of 100 autos.
- The fare will be collected in the auto staging area prior to embarking.
- The ferry will have sequential auto disembarking and embarking.
- The gangway can accommodate two lanes of vehicles and is located 50 meters from the front of the vehicle staging area.

Comments and Assumptions

- The clearance time, based an investigation of similar mooring and gangway technology, is estimated to be 3 minutes (1.5 minutes upon arrival and 1.5 minutes upon departure).
- Because berth capacity is not being calculated, the operating margin component of Equation 6-2 does not need to be used.
- Assume that the vehicle headway is 3.0 s/auto.
- Assume that the approximate auto entry speed is 15 km/h (4.2 m/s).

Outline of Solution

The vessel service time for autos can be approximated using Equation 6-2, omitting the operating margin component of the equation. As a result, the service time calculation includes the time associated with auto embarking and disembarking, and the clearance time.

Steps

1. Determine the total embarking and disembarking time from Equation 6-3.

$$t_{ed} = \frac{h_v(A_d + A_e)}{N_{ca}} + \frac{2L_r}{v_v}$$

$$t_{ed} = \frac{3(100+100)}{2} + \frac{2(50)}{4.2}$$

$$t_{ed} = 324\text{ s}$$

2. Calculate the vessel service time from Equation 6-2, omitting the operating margin component.

$$t_v = t_{ed} + t_c$$

$$t_v = 324 + 180$$

$$t_v = 504\text{ s}\ \ (8\text{ minutes, }24\text{ seconds})$$

Example Problem 3

The Situation

A passenger ferry berth currently serves six ferries during the evening peak hour. The transit agency wishes to add another ferry during the peak hour.

The Question

Are additional berths required?

The Facts

- The observed average passenger embarking and disembarking time at the berth is 3 minutes.
- The observed clearance time is a total of 4 minutes (2 minutes upon arrival and 2 minutes upon departure).

Comments and Assumptions

- Observations indicate that c_V (the coefficient of variation in the embarking/ disembarking time) is 0.60.
- The design failure rate is 10%, which corresponds to a Z factor of 1.280 (see Exhibit 4-6).

Outline of Solution

All input parameters are known. The number of vessels per hour that can be accommodated by a single berth can be determined using Equation 6-2.

Steps

1. Calculate the vessel service time, Equation 6-2.

$$t_v = t_{ed} + Zc_v t_{ed} + t_c$$
$$t_v = 180 + (1.280)(0.6)(180) + 240$$
$$t_v = 558 \text{ s}$$

2. Determine the maximum number of vessels per hour that the berth can accommodate based on the demand, Equation 6-1.

$$V_b = \frac{3600}{t_v}$$
$$V_b = \frac{3600}{558}$$
$$V_b = 7 \text{ vessels/h}$$

The Results

One berth is sufficient to serve the six existing plus one planned ferry at the dock.

This page is intentionally blank.

PART 7
STOP, STATION, AND TERMINAL CAPACITY

CONTENTS

LIST OF EXHIBITS

CHAPTER 1. INTRODUCTION

Part 7 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents a discussion of the features and elements of transit stops, stations, and terminals and contains procedures for estimating the capacities of various elements of transit terminals.

- *Chapter 1* provides an introduction to the material presented in Part 7.
- *Chapter 2* is an overview of the different types of stops, stations, and terminals, including discussions of facility sizes and amenities.
- *Chapter 3* presents procedures for evaluating passenger circulation on walkways and stairways, and in queuing areas such as platforms. ADA and emergency evacuation needs are discussed.
- *Chapter 4* contains procedures for sizing passenger waiting areas at stops and stations and for providing passenger amenities within these areas. For bus and rail stations, procedures are provided for sizing outside transfer facilities, such as bus transfer, park-and-ride, and kiss-and-ride areas, as well as the various inside-terminal elements, such as walkways, stairways, escalators, elevators, turnstiles, ticket machines, and platforms.
- *Chapter 5* contains references for material presented in Part 7.
- *Chapter 6* presents example problems illustrating the sizing of stop, station, and terminal elements.
- *Appendix A* provides substitute exhibits in metric units for those Part 7 exhibits that use U.S. customary units.

Exhibits also appearing in Appendix A are indicated by a margin note such as this.

Although previous efforts have involved designing terminal facilities based on maximum pedestrian capacity, research has shown that a breakdown in pedestrian flow occurs when there is a dense crowding of pedestrians, causing restricted and uncomfortable movement. For this reason, many of the procedures contained in this chapter for sizing terminal elements are based on maintaining a desirable pedestrian level of service.

For larger stations and terminals, the various pedestrian spaces interact with one another such that pedestrian circulation may better be evaluated from a systems perspective. Simulation models that assess the impact of queue spillback on downstream facilities can be used to size internal spaces within a terminal facility, and thus their application is discussed in this part of the TCQSM. For stations with frequent service, the time required to clear a station platform before the arrival of a following train or bus may be a critical consideration.

Design capacity is determined by peak conditions established by peak passenger discharge loads, peak waiting loads, extra loads due to "regular" service disruptions, and emergency evacuations. Specific requirements(R11) for addressing emergency evacuation contained in the National Fire Protection Association (NFPA) standard for fixed guideway transit and passenger rail stations (NFPA 130) are reviewed.

The needs of persons with disabilities should be considered throughout the process of planning and designing transit station facilities. Both physical and cognitive disabilities should be considered and provisions for addressing these are referenced throughout the chapter. Specific requirements of The Americans with Disabilities Act of 1990 (ADA) pertinent to transit stations are discussed.

This page is intentionally blank.

CHAPTER 2. STATION TYPES AND CONFIGURATIONS

OVERVIEW

Various types of transit stops, stations, and terminals provide service tailored to the specific needs of a transit system or a particular locale. These facilities often have common features and elements but may display unique characteristics. The basic types of transit stops, stations, and terminals are presented in this chapter.

BUS STOPS

Most bus stops are located along streets and consist of a waiting area integrated with the public sidewalk, signage to mark the bus stop, and, in some cases, a bench or small shelter. Other bus stops are located on- or off-street in conjunction with transit centers, rail transit stations, or intermodal terminals.

On-street bus stops may be located on the near side of an intersection, the far side after the bus has passed through the intersection, or at a mid-block location. The choice of location is primarily related to the operational performance of the bus route and traffic, but can also be influenced by adjacent land uses and opportunities for easy transfers to crossing bus routes. For more discussion of bus stops as they relate to bus operations, refer to Part 4, *Bus Transit Capacity*.

Bus stop location factors.

There is ongoing debate about the operational advantages of near-side versus far-side placement. In general, a far-side placement will be most advantageous when buses operate in mixed traffic, while a near-side location will tend to be more feasible when buses operate in an exclusive lane. However, other factors such as signal priority for buses, location of an exclusive lane, and turning traffic patterns also factor into this choice. With a far-side stop location at signalized intersections, it is highly desirable to be able to pull buses into an adjacent parking lane or bus pullout so that traffic does not back up into the intersection. If such an area is not available, a near-side stop might be preferable. With a near-side location in mixed traffic, vehicles waiting for the signal prevent the bus from reaching its stop, and buses stopping to pick up or drop off passengers during a green phase block other traffic.

These factors tend not to apply when buses operate in an exclusive lane. Locating the stop on either the far or the near side in this situation results in a slower, safer operating speed through the intersection, which is particularly relevant for buses (or light rail vehicles) operating on an exclusive lane. A mid-block location may be called for when additional space is available or when a particular destination is located at mid-block. However, issues with pedestrian crossing safety may need to be addressed.

TRANSIT CENTERS

The term *transit center* is normally applied to facilities where multiple bus routes converge, offering transfers between lines. The term can also apply to intermodal stations that may combine local bus services with other transit services, intercity bus or rail, and associated services such as taxi stands, concessions, and ticket sales. Both types of facilities are normally located wholly or partially off-street and frequently include a more elaborate and extensive shelter and more passenger amenities than ordinary bus stops.

BUSWAY STATIONS

Busway stations are located along roadways dedicated for buses and are frequently larger and more elaborate than typical bus stops, but are shorter than most light rail stations. Like the busways they serve, these stations may be either off-street or on-street. The length of a busway station is generally 40 to 100 ft (12 to 30 m) but some extend to 400 ft (120 m) to serve multiple routes and services. Amenities may be very limited, consisting of just a paved area and sign, or much more elaborate, with shelters, seating, ticket machines, and other amenities. Busway stations in some South American cities (such as Bogotá, Curitiba, and Quito) are enclosed with fare collection at the station and high-level bus boarding.

TCRP Report 90, Volume 2,(R9) provides guidance on designing busway stations.

Busway stations usually consist of side platforms boarded from the right side of the bus, but some center platform stations are used with boarding from either the left or right side of the bus (this requires buses designed with doors on both sides). Center platforms can also be used when the bus lanes operate contraflow. Busway stations may have a single lane in each direction, or a passing lane can be provided at stations to increase operational capacity and allow for multiple services that skip some stations.

LIGHT RAIL STATIONS

Light rail stations are typically 180 to 400 ft (55 to 120 m) long. Various platform configurations are possible, including center, side, or split on opposite sides of an intersection. Stations may be on-street, off-street, along a railroad right-of-way, or on a transit mall. High and low platforms have been used, although the trend in recent years has been the increasing use of an intermediate height for platforms that is approximately 14 in. (0.35 m) above the top of the rail to match the floor height of low-floor light rail vehicles. Light rail stations usually include canopies over part of the platform, limited seating, and ticket vending machines. Fare collection on light rail systems is typically by the proof-of-payment system, so stations do not have fare gates or barriers.

HEAVY RAIL STATIONS

Stations on heavy rail, rapid transit, or metro systems are usually more elaborate than light rail or many commuter rail stations. Due to the presence of third-rail power in many of these systems, and to prevent passengers from entering the trackway, these stations always have high-level platforms. Stations are most often located underground or elevated, and frequently have intermediate mezzanine levels between the street and platform levels. Both center or side platform configurations are used, and some stations have more than two tracks. Special configurations allow cross-platform transfers or reflect location-specific conditions. Heavy rail stations are generally 600 to 800 ft (180 to 240 m) long. Most heavy rail stations have fare control arrays and enclosed paid zones, although some European systems use proof-of-payment systems.

COMMUTER RAIL STATIONS

Commuter rail stations range from suburban locations with one or two platforms, limited service, and relatively small passenger volumes to major urban terminals with many tracks and platforms offering a variety of local and express services to various destinations. These stations may use either center or side platforms or a combination of both in larger terminals. Higher-volume systems tend to use high platforms, while lower-volume systems tend to use low or intermediate height platforms. In some cases, passenger and freight trains share the same tracks. Horizontal clearance requirements for freight cars may be greater than for passenger equipment and thus can impact the placement of platform features such as wheelchair ramps. Platforms in these stations can range from 300 to more than 1,000 ft (90 to over 300 m) long.

Passenger flow on commuter rail platforms can be more complex if multiple routes and services share the same platform and waiting areas. Where that is the case, not all passengers waiting on platforms will board a train when it arrives, leaving residual passenger volumes on platforms. Commuter rail cars typically have fewer doors than heavy rail cars and may fully load or unload at a single major terminal, increasing their boarding, alighting, and dwell times at those stations.

FERRY DOCKS AND TERMINALS

Ferry docks and terminals can vary from simple waterside facilities with limited shelters and relatively small passenger flow volumes to major terminals with multiple ferries receiving and discharging large numbers of passengers and vehicles. Since waterside locations are particularly exposed to the weather, protection from the climate can be an important factor in providing a good quality of travel. The effect of tides, changing river levels, and waves must be adequately addressed and poses unique challenges for passenger access, especially where extreme height changes are experienced, potentially requiring long or steep ramps to reach the vessel.

INTERMODAL TERMINALS

The term "intermodal terminals" refers to a variety of stations and terminals that provide key transfers between transit modes. Combinations may include local bus, bus rapid transit, intercity bus, light rail, heavy rail, commuter rail, intercity passenger rail, ferry, or automated guideway transit. Such facilities may have a variety of other services and connections, including parking, drop-off, ticket vending, and information booths, and may be integrated with retail shopping, services, and entertainment.

This page is intentionally blank.

CHAPTER 3. PASSENGER CIRCULATION AND LEVEL OF SERVICE

PEDESTRIAN CIRCULATION CONCEPTS

An important objective of a transit stop or station is to provide adequate space and appropriate facilities to accommodate projected peak pedestrian demands while ensuring pedestrian safety and convenience. Early efforts involved designing transit stations based on maximum pedestrian capacity without consideration of pedestrian comfort and convenience. Research has shown, however, that capacity is reached when there is a dense crowding of pedestrians, causing restricted and uncomfortable movement.(R6)

The procedures for estimating capacity presented in this section are based on a relative scale of pedestrian comfort and convenience. Procedures for evaluating pedestrian capacity and level of service (LOS) are contained in Fruin's *Pedestrian Planning and Design.*(R6) Procedures for analyzing pedestrian circulation on sidewalks, street corners, and crosswalks are presented in the 2000 *Highway Capacity Manual* (HCM).(R8)

Procedures in this chapter are based on providing a suitable passenger LOS rather than designing for maximum capacity.

Pedestrian Capacity Terminology

Terms used in this chapter for evaluating pedestrian circulation are defined as follows:

- *Pedestrian capacity*: the maximum number of people who can occupy or pass through a pedestrian facility or element, expressed as persons per unit of area or as persons per unit of time. Both a maximum capacity reflecting the greatest possible number of persons who can pass through and a "design" capacity representing the maximum *desirable* number of pedestrians are applied in appropriate ways. Higher "theoretical" capacities are sometimes identified (e.g., for escalators and moving walkways), but are not based on practical experience and are not generally applicable in analysis or design.
- *Pedestrian speed*: average pedestrian walking speed, generally expressed in units of feet or meters per second.
- *Pedestrian flow rate*: number of pedestrians passing a point per unit of time, expressed as persons per minute, 15 minutes, or other time period; "point" refers to a line across the width of a walkway, stairway, or doorway, or through a pedestrian element such as an escalator or fare control gate.
- *Pedestrian flow per unit width*: average flow of pedestrians per unit of effective walkway width, expressed as persons per inch, foot, or meter per minute.
- *Pedestrian density*: average number of persons per unit of area within a walkway or queuing area, expressed as persons per square foot or meter.
- *Pedestrian space*: average area used by or provided for each pedestrian in a walkway or queuing area, expressed in terms of square feet or meters per pedestrian; this is the inverse of density, but is a more practical unit for the analysis of pedestrian facilities. The space normally required by people varies according to the activity they are engaged in and increases with walking speed. It is important to consider the type and characteristics of the pedestrians. For example, the area required by a person using a wheelchair or transporting luggage or packages is greater than for a person standing without items.

- *Pedestrian time-space*: the space normally required by pedestrians for various activities (walking, queuing, conversing, shopping, etc.) multiplied by the time spent doing the activity within a specific area.
- *Effective width or area*: the portion of a walkway or stairway's width or the area of a space that is normally used by pedestrians. Areas occupied by physical obstructions and buffer spaces adjacent to walls and obstructions are excluded from effective width or area.

Principles of Pedestrian Flow

The relationship between density, speed, and flow for pedestrians is described in the following formula:

Equation 7-1

$$v = S \times D$$

where:
v = pedestrian flow per unit width (p/ft/min, p/m/min);
S = pedestrian speed (ft/min, m/min); and
D = pedestrian density (p/ft^2, p/m^2).

The flow variable used in this expression is the "flow per unit of width" defined earlier. An alternative and more useful expression can be developed using the reciprocal of density, or *space*, as follows:

Equation 7-2

$$v = S / M$$

Refer to Exhibits 3-25 or 5-22 for data on the space occupied by pedestrians.

where:
v = pedestrian flow per unit width (p/ft/min, p/m/min);
S = pedestrian speed (ft/min, m/min); and
M = pedestrian space (ft^2/p, m^2/p), adjusted as appropriate for pedestrian characteristics.

Pedestrian Level of Service

Pedestrian levels of service provide a useful means of evaluating the capacity and comfort of an active pedestrian space. Pedestrian LOS thresholds related to walking are based on the freedom to select desired walking speeds and the ability to bypass slower-moving pedestrians. Other considerations related to pedestrian flow include the ability to cross a pedestrian traffic stream, to walk in the reverse direction of a major pedestrian flow, and to maneuver without conflicts with other pedestrians or changes in walking speed.

Levels of service for queuing areas are based on available standing space, perceived comfort and safety, and the ability to maneuver from one location to another. Since pedestrian LOS is based on the amount of pedestrian space available, the LOS thresholds can be used to specify desirable design features such as platform size, number and width of stairs, corridor width, and so forth.

CIRCULATION ON WALKWAYS

The capacity of a walkway is controlled by the following factors:

- pedestrian walking speed;
- pedestrian traffic density;
- pedestrian characteristics, bikes or strollers present, and wheelchair users; and
- effective width of the walkway at its narrowest point.

Speed

Normal walking speeds of pedestrians vary over a wide range, depending on many factors. Walking speeds have been found to decline with age. Studies have also shown that male walking speeds are typically faster than female walking speeds. Other factors influencing a pedestrian's walking speed include the following:

- time of day;
- weather and temperature;
- pedestrian traffic composition, including wheelchair users;
- trip purpose; and
- reaction to surrounding environment.

Free-flow walking speeds have been shown to range from 145 ft/min (45 m/min) to 470 ft/min (145 m/min). On this basis, speeds below 145 ft/min (45 m/min) would constitute restricted, shuffling locomotion, and speeds greater than 470 ft/min (145 m/min) would be considered as running. A pedestrian walking speed typically used for design is 250 ft/min (75 m/min).

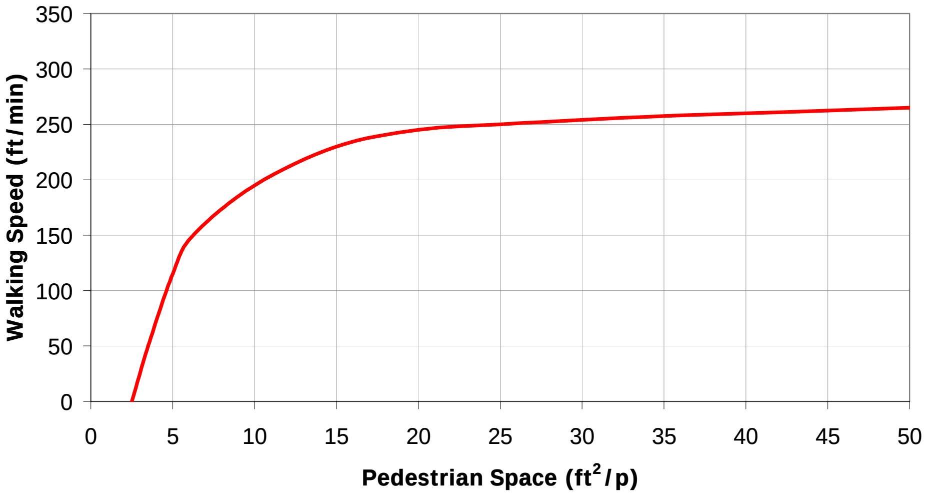
Density

Density is the most significant factor influencing pedestrian walking speed.

Perhaps the most significant factor influencing pedestrian walking speed is density. Normal walking requires sufficient space for unrestricted pacing, sensory recognition, and reaction to potential obstacles. Increasing density reduces the available space for walking and increases conflicts between pedestrians, and therefore, reduces walking speeds. This is an even greater concern for people who use mobility aids such as crutches, canes, and wheelchairs.

Exhibit 7-1 shows the relationship between walking speeds and average pedestrian space (inverse of density). Observing this exhibit, pedestrian speeds are free-flow up to an average pedestrian space of 25 ft^2 (2.3 m^2) per person. For average spaces below this value, walking speeds begin to decline rapidly. Walking speeds approach zero, becoming a slow shuffle, at an average pedestrian space of approximately 5 ft^2 (0.5 m^2) per person.

Exhibit 7-1
Pedestrian Speed on Walkways[R6]



An alternative figure using metric units appears in Appendix A.

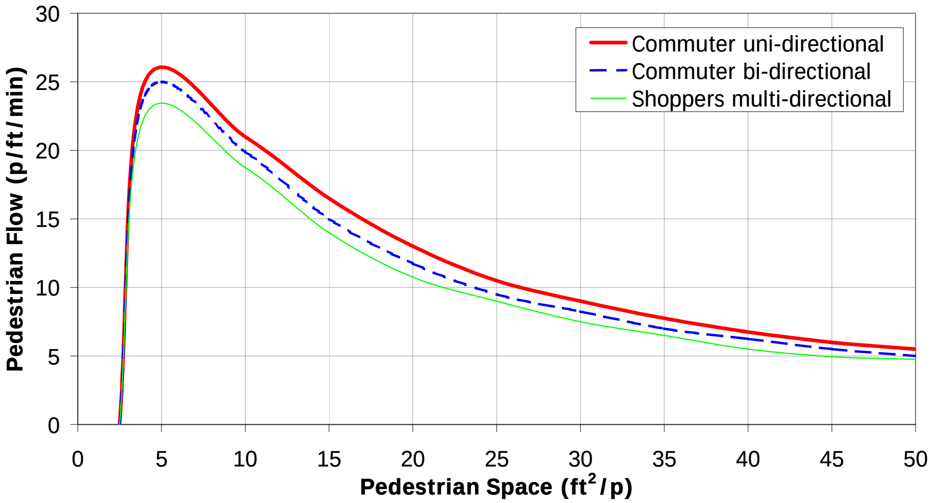
Effective Walkway Width

The full walkway width will not be used by pedestrians.

The final factor affecting a walkway's capacity is the effective width available. Studies have shown that pedestrians keep as much as an 18-in. (0.5-m) buffer between themselves and adjacent walls, street curbs, platform edges, and other obstructions, such as trash receptacles, sign posts, and so forth. In practice, the width of the unused buffer depends on the character of the wall or obstruction, the overall width of the available walkway, and on the level of pedestrian congestion. In general, 18 in. (0.5 m) should be deducted next to walls and platform edges and 12 in. (0.3 m) should be deducted next to other obstructions, including walls up to about 3 feet (1 m) tall.

Exhibit 7-2 shows the relationship between pedestrian flow per unit of effective walkway width and average pedestrian space. Curves are shown for one-directional, bi-directional, and multi-directional (cross-flow) pedestrian traffic. As this exhibit shows, there is a relatively small range in variation between the three curves. This finding suggests that reverse and cross-flow traffic do not significantly reduce pedestrian flow rates.

Exhibit 7-2
Pedestrian Flow on Walkways by Unit Width and Space(R6)



An alternative figure using metric units appears in Appendix A.

As shown in Exhibit 7-2, the maximum average peak flow rates (26.2, 24.7, and 23.3 p/ft/min, or 86.0, 81.0, and 76.4 p/m/min, for one-directional, bi-directional, and multi-directional flow, respectively) occur at an average occupancy of 5 ft^2 (0.5 m^2) per person. While this represents the maximum possible throughput, it represents a condition of extreme congestion, does not reflect the needs of mobility impaired persons, and creates a potentially unsafe condition. Therefore, it should not be used as a basis for design. Instead, the LOS approach should be used for designing pedestrian spaces.

Levels of Service for Walkways

Exhibit 7-3 lists the criteria for pedestrian LOS on walkways in transit facilities. These levels of service are based on average pedestrian space and average flow rate. Average speed and volume-to-capacity ratio are shown as supplementary criteria. Graphical illustrations and descriptions of walkway levels of service are shown in Exhibit 7-4. Capacity is taken to be 25 p/ft/min (82 p/m/min), corresponding to LOS "E."

LOS thresholds for walkways are not the same as the HCM's thresholds for sidewalks.

Note that the LOS thresholds shown here differ from those shown in the HCM2000. Thresholds shown in the HCM2000 are intended primarily for sidewalks and street corners, while those shown here are typically used for transit facilities, whether on-street or off.

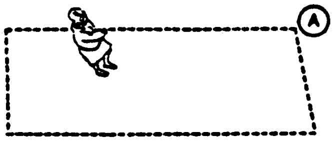
Exhibit 7-3
Pedestrian Level of Service on Walkways(R6)

		Expected Flows and Speeds		
LOS	**Pedestrian Space (ft^2/p)**	**Avg. Speed, S (ft/min)**	**Flow per Unit Width, v (p/ft/min)**	**v/c**
A	≥ 35	260	0-7	0.0-0.3
B	25-35	250	7-10	0.3-0.4
C	15-25	240	10-15	0.4-0.6
D	10-15	225	15-20	0.6-0.8
E	5-10	150	20-25	0.8-1.0
F	< 5	< 150	*Variable*	*Variable*

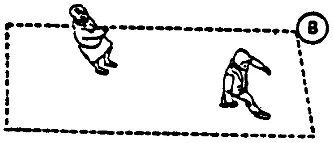
		Expected Flows and Speeds		
LOS	**Pedestrian Space (m^2/p)**	**Avg. Speed, S (m/min)**	**Flow per Unit Width, v (p/m/min)**	**v/c**
A	≥ 3.3	79	0-23	0.0-0.3
B	2.3-3.3	76	23-33	0.3-0.4
C	1.4-2.3	73	33-49	0.4-0.6
D	0.9-1.4	69	49-66	0.6-0.8
E	0.5-0.9	46	66-82	0.8-1.0
F	< 0.5	< 46	*Variable*	*Variable*

v/c = volume-to-capacity ratio

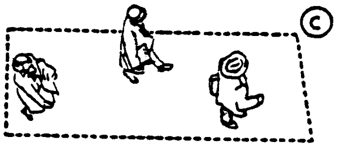
Exhibit 7-4
Illustration of Walkway Levels of Service(R6)



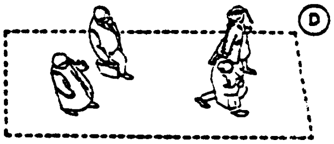
LEVEL OF SERVICE A
Walking speeds freely selected; conflicts with other pedestrians unlikely.



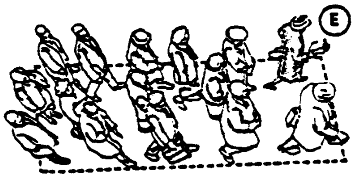
LEVEL OF SERVICE B
Walking speeds freely selected; pedestrians respond to presence of others.



LEVEL OF SERVICE C
Walking speeds freely selected; passing is possible in unidirectional streams; minor conflicts for reverse or cross movement.



LEVEL OF SERVICE D
Freedom to select walking speed and pass others is restricted; high probability of conflicts for reverse or cross movements.



LEVEL OF SERVICE E
Walking speeds and passing ability are restricted for all pedestrians; forward movement is possible only by shuffling; reverse or cross movements are possible only with extreme difficulty; volumes approach limit of walking capacity.

LEVEL OF SERVICE F
Walking speeds are severely restricted; frequent, unavoidable contact with others; reverse or cross movements are virtually impossible; flow is sporadic and unstable.

CIRCULATION ON STAIRWAYS

A stairway's capacity is largely affected by its width.

The capacity of a stairway is largely affected by the stairway width. Unlike walking on a level surface, people tend to walk in lines or lanes when traversing stairs. The width of a stairway determines both the number of distinct lines of people who can traverse the stair and the side-to-side spacing between people, affecting pedestrians' ability to pass slower-moving pedestrians and the level of interference between adjacent lines of people. The consequence is that meaningful increases in capacity are not directly proportional to the width, but occur in increments of about 30 in. (0.75 m).

Unlike on walkways, a minor pedestrian flow in the opposing direction on a stairway can result in a capacity reduction disproportionate to the magnitude of the reverse flow. As a result, a small reverse flow should be assumed to occupy one pedestrian lane or 30 in. (0.75 m) of the stair's width. For a stair 60 in. (1.5 m) wide, a small reverse flow could consume half its capacity.

Critical passenger flows on stairways occur in the ascending direction.

Because pedestrians are required to exert a higher amount of energy to ascend stairs as compared with descending stairs, lower flow rates typically occur in the ascending direction. For this reason, when stairs serve both directions simultaneously or when the same stair will be used primarily in the up direction during some time periods and primarily in the down direction during other time periods, the lower up flow rate should be used for analysis and design.

Ascending speeds on stairs have been shown to range from 41 ft/min (12 m/min) to 68 ft/min (21 m/min), measured in the vertical dimension. Descending speeds on stairs have been shown to range from 56 ft/min (17 m/min) to 101 ft/min (31 m/min), measured in the vertical dimension. Ascending speeds are also slower on longer stairs because pedestrians slow as they reach the top. For general planning and design purposes, average speeds of 50 ft/min (15 m/min) in the up direction and 60 ft/min (18 m/min) in the down direction, measured in the vertical dimension (as opposed to measuring along the incline), are considered reasonable. The angle of a stair's incline affects pedestrian comfort, safety, and speeds. While less-steep stairs decrease pedestrian speed measured on the vertical dimension, they increase speeds measured along the horizontal and diagonal dimensions and improve passenger comfort and safety. The vertical dimension is the overall height or rise of a stair; the horizontal dimension is the length or run of the stair; and the diagonal dimension is the length of the stair measured along the incline.

Exhibit 7-5 illustrates the relationship between ascending speeds and pedestrian space. This exhibit reveals that normal ascending speeds on stairs are approached at an average pedestrian space of approximately 10 ft^2/p (0.9 m^2/p). Above approximately 20 ft^2/p (1.9 m^2/p), faster walking pedestrians are able to approach their natural unconstrained stair climbing speed and pass slower-moving people.

Exhibit 7-6 illustrates the relationship between flow rate on stairs in the ascending direction and pedestrians' space. As observed in this exhibit, the maximum ascending flow rate occurs at a pedestrian space of approximately 3 ft^2/p (0.3 m^2/p). For this lower pedestrian space, ascending speeds are at the lower limit of the normal range. In this situation, forward progress is determined by the slowest moving pedestrian. Although the maximum flow rate represents the capacity of the stairway, it should not be used as a design objective (except perhaps for emergency situations). At capacity, ascending speeds are restricted and there is a high probability of intermittent stoppages and queuing.

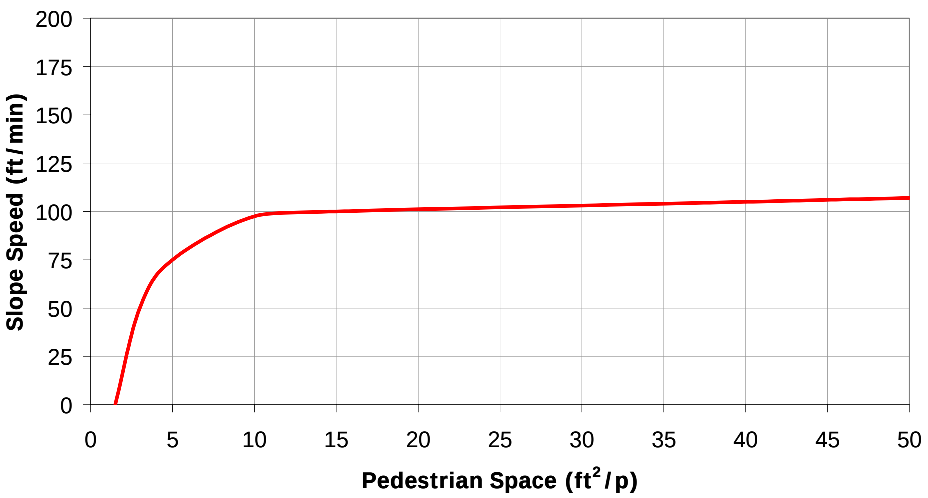


Exhibit 7-5
Pedestrian Ascent Speed on Stairs(R6)

An alternative figure using metric units appears in Appendix A.

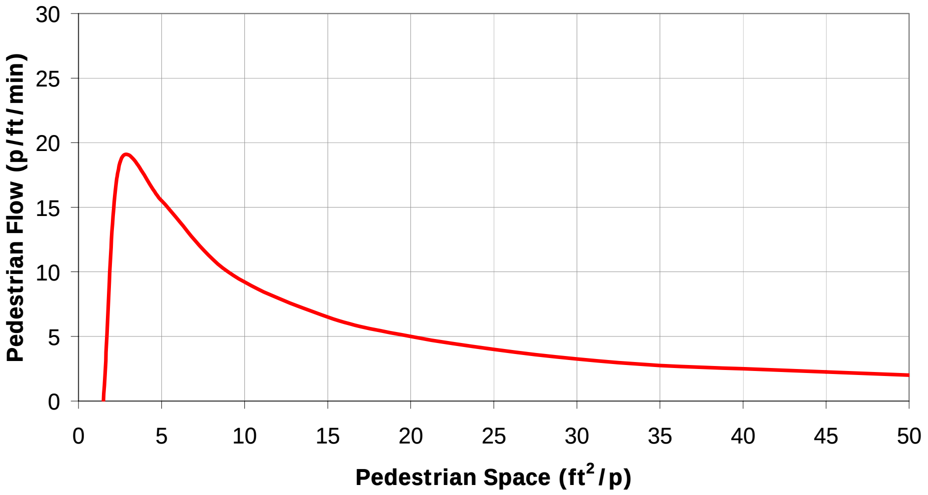


Exhibit 7-6
Pedestrian Flow Volumes on Stairs(R6)

An alternative figure using metric units appears in Appendix A.

Pedestrian queuing can also occur at the "destination" end of stairways, if people are forced to converge on too constricted a space. This can be a serious design deficiency in certain station facilities, with potential effects on pedestrian safety.

Levels of Service for Stairways

The required width of a stairway is based on maintaining a desirable pedestrian LOS. Stairway levels of service are based on average pedestrian space and average flow rate. Exhibit 7-7 summarizes the LOS criteria for stairways. The threshold from LOS "E" to "F" (17 p/ft/min or 56 p/m/min) represents the capacity of a stairway. Note that these thresholds differ from those given in the HCM2000; the thresholds given in Exhibit 7-7 are ones typically used for transit facilities.

Stairway LOS thresholds for transit facilities are different from those given in the HCM.

Exhibit 7-7
Level of Service Criteria for Stairways(R6)

LOS	Avg. Ped. Space (ft²/p)	(m²/p)	Flow per Unit Width (p/ft/min)	(p/m/min)	Description
A	≥ 20	≥ 1.9	≤ 5	≤ 16	Sufficient area to freely select speed and to pass slower-moving pedestrians. Reverse flows cause limited conflicts.
B	15-20	1.4-1.9	5-7	16-23	Sufficient area to freely select speed with some difficulty in passing slower-moving pedestrians. Reverse flows cause minor conflicts.
C	10-15	0.9-1.4	7-10	23-33	Speeds slightly restricted due to inability to pass slower-moving pedestrians. Reverse flows cause some conflicts.
D	7-10	0.7-0.9	10-13	33-43	Speeds restricted due to inability to pass slower-moving pedestrians. Reverse flows cause significant conflicts.
E	4-7	0.4-0.7	13-17	43-56	Speeds of all pedestrians reduced. Intermittent stoppages likely to occur. Reverse flows cause serious conflicts.
F	≤ 4	≤ 0.4	*Variable*	*Variable*	Complete breakdown in pedestrian flow with many stoppages. Forward progress dependent on slowest moving pedestrians.

OCCUPANCY IN QUEUING AND WAITING AREAS

For queuing and waiting areas, the primary measure for defining LOS is the average space available to each person. In addition to the feeling of comfort provided by desired spacing, there is a also a direct relationship between the average space available to each person and the degree of mobility allowed. In dense standing crowds, there is little room to move, but limited circulation is possible as the average space per pedestrian increases.

Levels of Service for Queuing and Waiting Areas

Passenger waiting area LOS concepts are comparable with the street corner queuing concepts presented in the *Highway Capacity Manual.*

Levels of service for passenger queuing and waiting areas are shown in Exhibit 7-8. The thresholds were developed based on average pedestrian space, personal comfort, and degrees of internal mobility. LOS is presented in terms of average area per person and average interpersonal space (distance between people).

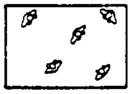
The LOS required for waiting within a facility is a function of the amount of time spent waiting, the number of people waiting, and a desired level of comfort. Typically, the longer the wait, the greater the space per person required. A person's tolerance of a level of crowding will vary with time. People will accept being tightly packed on an elevator for 30 seconds, but not in a waiting area for 15 minutes.(R8)

A person's acceptance of close interpersonal spacing will also depend on the characteristics of the population, the weather conditions, and the type of facility. For example, commuters may be willing to accept higher levels or longer periods of crowding than intercity and recreational travelers.(R8)

Exhibit 7-8
Levels of Service for Queuing Areas(R8)

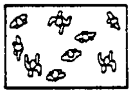
LOS	Average Pedestrian Area (ft²/p)	(m²/p)	Average Inter-Person Spacing (ft)	(m)
A	≥ 13	≥ 1.2	≥ 4.0	≥ 1.2
B	10-13	0.9-1.2	3.5-4.0	1.1-1.2
C	7-10	0.7-0.9	3.0-3.5	0.9-1.1
D	3-7	0.3-0.7	2.0-3.0	0.6-0.9
E	2-3	0.2-0.3	<2.0	<0.6
F	< 2	< 0.2	*Variable*	*Variable*

Exhibit 7-9
Illustration of Queuing Area Level of Service[(R8)]

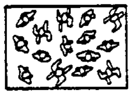


LEVEL OF SERVICE A
Standing and free circulation through the queuing area possible without disturbing others within the queue.

LEVEL OF SERVICE B
Standing and partially restricted circulation to avoid disturbing others within the queue is possible.

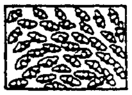


LEVEL OF SERVICE C
Standing and restricted circulation through the queuing area by disturbing others is possible; this density is within the range of personal comfort.



LEVEL OF SERVICE D
Standing without touching is impossible; circulation is severely restricted within the queue and forward movement is only possible as a group; long-term waiting at this density is discomforting.

LEVEL OF SERVICE E
Standing in physical contact with others is unavoidable; circulation within the queue is not possible; queuing at this density can only be sustained for a short period without serious discomfort.



LEVEL OF SERVICE F
Virtually all persons within the queue are standing in direct physical contact with others; this density is extremely discomforting; no movement is possible within the queue; the potential for pushing and panic exists.

MULTI-ACTIVITY PASSENGER CIRCULATION AREAS

Time-space analysis is used to study complex passenger circulation patterns involving multiple activities.

Some areas of transit stations include a variety of pedestrian activities within the same general space. People may be walking through, standing in line to buy tickets, waiting to meet someone, and shopping within the same space. Portions of these spaces may also be of little use to pedestrians, such as a corner beyond the major flow of pedestrians or concentrations of other activities.

Exhibit 7-10
Examples of Multiple Pedestrian Activities Within a Transit Station

(a) Grand Central Terminal (New York)

(b) Victoria Station (London)

In such cases, the method of pedestrian analysis is referred to as time-space analysis.(R3) Time-space analysis incorporates the space per person thresholds embodied in the LOS approach and factors them by the time spent engaging in a specific activity within a given space.

The space required for a particular activity is represented by the formula:

Equation 7-3

$$TS_{req} = \Sigma\, P_i \times S_i \times T_i$$

where:

TS_{req} = time-space required (ft^2-s, m^2-s);
P_i = number of people involved in activity i;
S_i = space required for activity i (ft^2, m^2); and
T_i = time required for activity i (s).

The total time space requirements of all of the activities are then compared with the time-space available, represented by the formula:

Equation 7-4

$$TS_{avail} = S_{avail} \times T_{avail}$$

where:

TS_{avail} = time-space available (ft^2-s, m^2-s);

S_{avail} = space available within the area analyzed (ft^2, m^2); and

T_{avail} = time available as defined for the analysis period (s).

The approach to applying time-space analysis varies depending on the situation being analyzed and the specific issues or options to be addressed. A typical application might involve the following steps:

Steps for applying a time-space analysis.

1. Establish pedestrian origins and destinations within and at the edges of the space analyzed.
2. Assign pedestrian routes through the pedestrian network for each origin-destination pair.
3. Sum the volumes of persons passing through each analysis zone.
4. Identify the walking time within each zone for pedestrians. This may vary depending on their route through each zone.
5. Determine the percentage of people passing through each zone who stop and dwell in that zone for various specific purposes, such as waiting for a train, buying tickets, shopping, etc.
6. Determine the time spent dwelling in each zone for each purpose.
7. Calculate the time-space demand by multiplying the number of persons and the number dwelling by the time for walking through and the dwell time for various activities and by the space used by a person engaged in each activity.
8. Calculate the time-space available by multiplying the usable floor area by the duration of the analysis period.
9. Calculate the demand-supply ratio by dividing time-space demand by time-space available.
10. Apply an LOS based on ranges of demand-supply ratios.

Computer simulation models for pedestrian circulation are under development, but to date have generally involved significant manual input or have been limited in their ability to represent the complex multi-directional movements of pedestrians. Two approaches are possible. In the first, pedestrians are assigned to discrete pedestrian spaces through which they would pass, as defined by the analyst. A time-space analysis is then performed for each discrete space based on the number of pedestrians passing through and their activities within each space. The second approach utilizes micro-simulation methods to follow the movements of individual pedestrians and analyzes congestion and queuing. The latter approach has been developed for evacuation analyses, where pedestrians have a single purpose, but has not yet been successfully applied to general circulation.

ACCESS FOR PERSONS WITH DISABILITIES

The ADA requires all new transit stations in the United States to be accessible to persons with disabilities. It also requires that key stations in existing systems be made accessible and that major remodeling of any station incorporate accessible features. The act includes provisions both for persons with mobility impairments, who may use wheelchairs, and for persons with other sensory or cognitive impairments, including visual and hearing limitations.

Specific regulations relating to transit stations, including provision of accessible routes, appropriate architectural features, and accessible communications elements and features are contained in the Architectural Barriers Act of 1999(R1).

Rather than being an afterthought or an add-on in the planning of a transit station, these issues should be addressed at each stage of the planning and design process. For example, opportunities may be found to incorporate ramps into the design that serve passengers with disabilities, but that also serve movement by other passengers. Elements addressing the needs of persons with disabilities can be worked into a facility's overall aesthetic design.

EMERGENCY EVACUATION

Provisions for evacuation during an emergency are an important consideration in the design of transit stations and terminals. Design and performance standards for emergency evacuation are presented in NFPA 130.

NFPA 130 establishes standards for the evacuation of fixed guideway transit and passenger rail stations.

The key provisions of NFPA 130 (2000 edition) related to station capacity are summarized as follows:(R11)

1. Sufficient exit capacity shall be provided to evacuate station occupants (including those on trains) from platforms in 4.0 min or less.
2. Sufficient exit capacity shall be provided to permit evacuation from the most remote point on a platform to a point of safety in 6.0 min or less.
3. A second means of egress at least 44 in. (1.12 m) wide and remote from the major egress route shall be provided from each platform.
4. The maximum distance to an exit from any point on a platform shall be not more than 300 ft (91.4 m).
5. Escalators shall not provide more than half of the exit capacity from any level and one escalator, resulting in the most adverse exiting condition, shall be assumed to be out of service and unavailable for egress.

Consult the current edition of NFPA 130 for more detailed information on the evacuation standards and calculation procedures. In particular, note that the standard specifies design capacities and pedestrian travel speeds that should be used for evacuation analysis. These capacities and speeds are often different than those presented in Part 7 of the TCQSM for designing for daily passenger circulation.

NFPA 130 specifies facility element capacities and pedestrian speeds to be used in evacuation analysis.

Evacuation analysis should be performed in conjunction with analysis and planning for daily circulation patterns. While in some cases the overall requirements for evacuation exceed the requirements for daily circulation, the two circulation patterns are dramatically different and each may result in different requirements at particular points in a station. While evacuation must be provided, this represents a rare circumstance, with daily circulation defining the passengers' normal experience; hence, evacuation should not be the only consideration in station design.

The requirements of daily passenger circulation and emergency evacuation should be considered in tandem both in overall station planning and in the design of individual station systems, such as vertical circulation or mezzanines, and in the design of individual elements. One example of overall station planning where both requirements need to be addressed is the issue of center versus side platforms. In more complex or higher-capacity stations, the number of platforms may also need to be addressed from both daily use and emergency perspectives. The number and configuration of platforms directly affects potential platform access, particularly when vertical circulation is required to access and egress platforms.

When multi-level stations are considered, the typical peak period circulation pattern may differ greatly from an emergency situation. For example, the daily flow pattern in a particular rail transit station may emphasize intra-station transfers and large numbers of passengers passing through on trains without boarding or alighting. During an emergency, the same station would experience much higher exiting volumes than normal, including the normal exiting volumes, those passengers who normally remain on trains passing through the station, and passengers who transfer at the station but normally do not exit there.

Circulation elements that are normally used for entering a station can largely be used for exiting during an emergency condition. Thus, stairs normally used by entering passengers can be used by those exiting, and inbound-moving escalators can be turned off or switched to the outbound direction. Although not specified in NFPA 130, some consideration should be given to the need for emergency crews to enter a station as it is being evacuated.

SECURITY

Public security in transit stations has important consequences for transit ridership. Both actual security, as measured by reported and unreported incidents, and perceived security are important for passengers. If passengers feel that a station is unsafe, they will try to avoid it, even if the actual level of crime is low.

Law enforcement personnel, video cameras, and emergency call boxes can play an active role in station security. However, factors such as visibility, lighting, and the presence of other people also play key roles. Visibility applies both within an enclosed station and from a street or other nearby land uses into a station. *TCRP Synthesis 21*(R13) provides summaries of strategies that transit agencies have used effectively to reduce crime and/or improve passengers' perceptions of security.

http://transit-safety.volpe.dot.gov/

Acts of violence on transit property have increased worldwide since the 1980s. *TCRP Synthesis 27*(R4) provides information on practices of transit agencies to prevent and respond to these acts. The FTA's Office of Safety and Security can provide additional information developed in the wake of the 2001 World Trade Center attack.

CLARITY OF STATION LAYOUT AND WAYFINDING

In more complex transit stations and terminals, the passengers' ease in finding their way around the station becomes important. While signage is an indispensable element in wayfinding, station layout and design can do much to make a station more understandable and easier to navigate. For example

- Open ceilings and glass walls can provide visual connections to other levels and between points inside and outside the station;
- Alternate materials and colors can distinguish between alternate routes or services; these should be used consistently systemwide;
- Center platforms allow passengers who have missed their intended stop to easily reverse direction and do not require passengers to identify the correct platform before reaching it, reducing confusion;
- Tactile signage and audible information offers direction and information to persons with visual impairments;
- Cross-platform transfers for dominant passenger movements reduce passenger demand on vertical circulation elements, shortens passenger walking distances, and makes connections easier to find; and
- The same design elements that contribute to wayfinding can also contribute to real and perceived safety within the station and passenger comfort.

COMPREHENSIVE ANALYSIS OF PASSENGER CIRCULATION

Comprehensive analysis of passenger flow in a station applied using a systems approach.

The more complex a station and its functions, the more complex its planning and design will be. A systematic approach can be taken with more complex stations. Multiple levels in a station present particular challenges, but also opportunities. The capacity of a station and its elements to carry passenger volumes are important. However, other aspects should be considered as well, including the clarity of station layout and wayfinding, access for persons with disabilities, and integrating the station with the surrounding community.

Pedestrian System Requirements

An initial step in evaluating a transit station design is to outline the pedestrian system requirements. Determining passenger circulation and queuing requirements begins with a detailed understanding of the pedestrian flow process through a station in the form of a flowchart. Exhibit 7-11 presents a sample flow diagram, although the elements and their order depend on the particular station. Properly done, the system diagram serves as a checklist and a reminder of the interrelationship of the various functional elements of the station. Exhibit 7-12 shows possible elements and components to be considered in a system diagram for the evaluation of pedestrian flows at a transit station.

Exhibit 7-11
Sample Pedestrian Flow Diagram Through a Transit Terminal[(R5)]

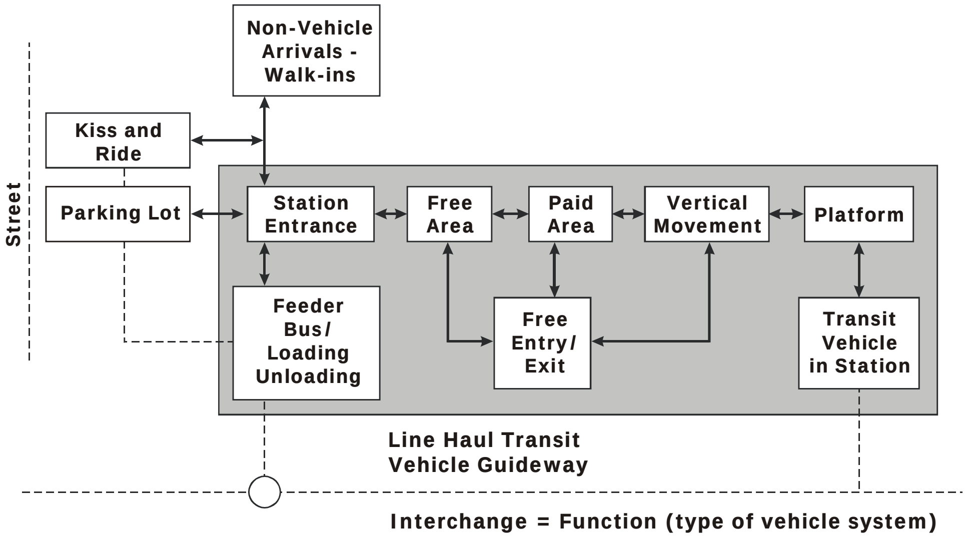


Exhibit 7-12
Elements of Passenger Circulation in a Transit Station[(R6)]

Element	Components
Train Arrival	On- or off-schedule; train length; number and locations of doors
Passengers	Number boarding and alighting; boarding and alighting rates, passenger characteristics; mobility device use, baggage or packages carried, bicycles and strollers, etc.
Platform	Length, width, and effective area; locations of columns and obstructions; system coherence: stair and escalator orientation, lines of sight, signs, maps, and other visual information
Pedestrians	Walking distance and time; numbers arriving and waiting; effective area per pedestrian; levels of service
Stairs	Location; width; riser height and tread; traffic volume and direction; queue size; possibility of escalator breakdown
Escalators	Location; width; direction and speed; traffic volume and queue size; maintainability
Elevators	Location; size and speed; traffic volume and queue size; maintainability; alternate provisions for disabled passengers when elevator is non-functioning

After the system elements have been described schematically, they should be described quantitatively. Often this can be done following the same basic format and sequence as the system description. Pedestrian volumes can be scaled to size and plotted graphically to illustrate volume and direction. Pedestrian walking times, distances, and waiting and service times can also be entered into this diagram.

The characteristics of users at a particular station should be assessed and considered in planning and design. Passenger characteristics include such factors as trip purpose, regular use (commuters) versus new or infrequent users, persons with disabilities, age stratification, and so forth. Trip purpose will relate to whether passengers carry luggage, packages, recreational equipment, or other items.

Comprehensive Passenger Circulation Analysis

The proximity of various station components to each other and the number of transit passengers those components must process impact station capacity. To allow a comprehensive assessment of the interaction of different station components on capacity, a broader evaluation of the pedestrian network should be conducted for larger, more complex stations. Simulation models, with varying degrees of manual input, can assist in the evaluation of alternate transit station designs as to their ability to effectively process transit passengers within certain LOS parameters.

Platform exit capacity is a key consideration in heavily used stations.

A key capacity analysis for larger transit stations is the platform exit capacity needed to accommodate passenger demands during the peak period. This capacity ensures that each station platform is clear before the next train arrives. The general solution is as follows:

Equation 7-5

$$\frac{\text{Passengers/train}}{\text{Capacity (passengers/minute)}} \leq \text{Train headway (minutes)}$$

or

Equation 7-6

$$\text{Capacity (passengers/minute)} \geq \frac{\text{Passengers/train}}{\text{Train headway (minutes)}}$$

Because people may not use, or be able to use, all available exits, some safety factor is needed. This could be as much as 20 to 30%.

Manual Method/Input to Simulation Models

In the absence of a transit station simulation model, a basic assessment of the interactions of different station components on capacity can be assessed by establishing and evaluating a link-node network.(R7) These network data also serve as typical inputs into computer simulation models. The methodology includes the steps described below.

Step 1: Define the System as a Link-Node Network

Paths passengers take through a terminal (origin-destination pairs) are transformed into a network of links and nodes. Each link, representing a horizontal and/or vertical circulation element, is described by four factors: (1) type—walkway, ramp, stairway, escalator, or elevator; (2) movements allowed—one-way or two-way (shared or not shared); (3) length—in feet or meters; and (4) minimum width—in feet or meters. Nodes are queuing points and/or decision points. They are typically fare collection devices, doors, platform entrances or exits, and junctions of paths.

Step 2: Determine Pedestrian Volumes for the Identified Analysis Period

For each pedestrian origin-destination pair within a station, a pedestrian volume is assigned for the identified analysis period (typically the peak hour or the peak 5 to

15 minutes within the peak hour). Origin-destination pairs distinguish between inbound and outbound passengers. Adjustments may be made as appropriate for passenger characteristics.

Step 3: Determine Path Choice

The particular path or alternate paths that a passenger can or must traverse between a particular origin and destination pair (for both inbound and outbound passengers) are identified.

Step 4: Load Inbound Passengers onto the Network

Inbound passenger volumes for the analysis period are assigned to applicable links and nodes.

Step 5: Load Outbound Passengers onto the Network

Outbound passenger volumes for the analysis period are assigned to applicable links and nodes.

Step 6: Determine Walk Times and Crowding on Links

In order to calculate the walk times and crowding measures on a link, the flow on that link should be adjusted to reflect peak-within-the-peak-hour conditions (typically 5 to 15 minutes).

Effective widths of links and nodes are the actual minimum widths or doorway widths. When a wall is located on one side of a corridor, 1.5 ft (0.5 m) is typically subtracted. A buffer of 2 ft (0.6 m) is typically subtracted for obstructions placed in corridors, such as trashcans and lockers. A buffer of 1 ft (0.3 m) is typically subtracted for walls in stairwells because transit users on the outside often use handrails. Finally, 3 ft (1 m) is typically subtracted to compensate for two-way movements on stairs.

The adjusted flow is divided by the effective width to determine the number of pedestrians per foot or meter width per minute. For a given LOS, the average space mean speed can be identified from Exhibit 7-3 for walkways, Exhibit 7-7 for stairways, and Exhibit 7-20 for escalators.

Step 7: Determine Queuing Times and Crowding at Nodes

Passenger queues at critical nodes can be estimated either by observation or analytical means. Queuing patterns vary depending on specific conditions at each location, particularly the arrival pattern of people at the constrained point. For example, queuing may occur at platform stairs immediately after a train or bus arrives, but it may be of short or long duration.

Step 8: Determine Wait Times for Transit Vehicles

Wait times for transit vehicles are a key input to determining required queuing areas on platforms. A typical assumption used, when service is frequent (10 minute headways or less), is that wait time is half the bus or train headway.

Step 9: Add Travel Time Components and Assess Overall Level of Service

Overall travel times for different origin-destination pairs can be totaled and averaged to identify an average passenger processing time through a particular transit station. This can then be translated into an overall passenger processing LOS.

This page is intentionally blank.

CHAPTER 4. STATION ELEMENTS AND THEIR CAPACITIES

ON-STREET BUS STOPS

Design Factors

On-street bus stops typically share sidewalk space with other activities. The objective of analyzing the area needed or available for a bus stop is to provide adequate space both for those who are waiting for a bus and for those who are passing by. The recommended procedures for computing the size of passenger waiting areas is based on maintaining a desirable LOS. Depending on passenger volumes and available space, a bus stop may be as simple as a signpost along a sidewalk of minimal width, or more complex, with a larger paved area with a shelter and other amenities.

Waiting Area Level of Service

Passenger waiting area LOS utilizes concepts from the *Highway Capacity Manual.*

Levels of service for passenger waiting areas applicable to bus stops are shown in Exhibit 7-8. The LOS desired for waiting at a bus stop is a function of the amount of time spent waiting, the number of people waiting, and the surrounding conditions. Typically, the longer the wait, the greater the space per person required. Also, the required space per person may vary over time. For example, those waiting in the beginning will want a certain amount of space initially, but will be willing to accept less space as additional people arrive.(R8)

A person's acceptance of interpersonal spacing will also depend on the characteristics of the population, the weather conditions, and the type of facility. For example, a small number of passengers at a sidewalk bus stop may spread out more than a larger number that form an ordered queue at an urban bus stop.

The presence of passengers who use wheelchairs, strollers, or bicycles, or carry large luggage or packages should be assessed and suitable provision made in station space. Studies have shown that pedestrians keep as much as an 18-in. (0.5-m) buffer between themselves and the edge of a street curb. This suggests that the effective width of a bus stop should be computed as the total width minus 18 in. (0.5 m).

Evaluation Procedures

Determining Required Passenger Waiting Area

As discussed above, the procedures to determine passenger waiting areas at bus stops are based on maintaining a desirable pedestrian LOS. For most bus stops, the design LOS should be "C" to "D" or better. The following is a list of steps recommended for determining the desired bus stop size:

1. Based on the desired LOS, choose the average passenger space from Exhibit 7-8.
2. Estimate the maximum demand of passengers waiting for a bus at a given time.
3. Calculate the effective waiting area required by multiplying the average passenger space by the maximum passenger demand.
4. Calculate the total required waiting area by adding an 18-in. (0.5-m) buffer width (next to the roadway) to the effective waiting area.

OFF-STREET BUS STOPS

Design Factors

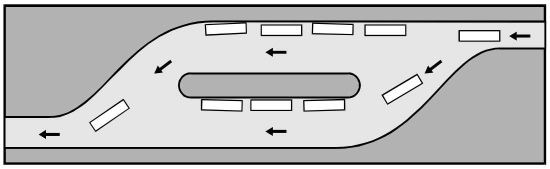
Larger bus stops, serving multiple bus routes, are often located off-street. They may be part of an all-bus transit center or may be provided in conjunction with a rail transit station, providing transfer to and from the rail service. For small transit stations, the number of loading areas (berths) is small, with a fairly simple access and layout configuration. For larger terminals, numerous berths and more sophisticated designs are applied. The Transbay Bus Terminal in San Francisco, for example, has 37 berths (not all currently used), serving 20,000 peak-hour passengers, while the Port Authority Bus Terminal in New York has 210 gates serving 200,000 passengers on a typical weekday.

Exhibit 7-13 illustrates various loading area arrangements. Four types of bus berths are typically applied: linear, sawtooth, angled, and drive-through.

Exhibit 7-13
Bus Loading Area (Berth) Designs and Examples

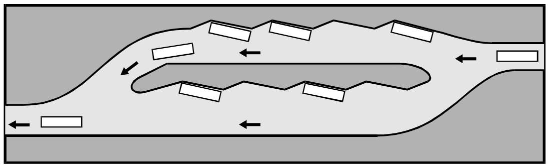
(a) Linear

Linear berths are less efficient than other berth types and are typically used when buses will occupy the berth for a short time (for example, at an on-street bus stop).



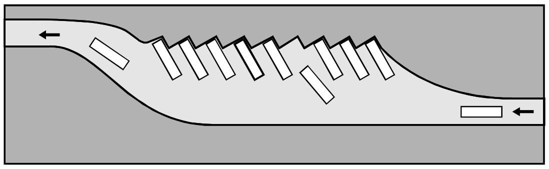
(b) Sawtooth

Sawtooth berths allow independent movements by buses into and out of berths and are commonly used at bus transfer centers.



(c) Angled

Angled berths require buses to back out, but allow a number of berths in a compact area. They are typically used when buses will occupy the berth for a long time (for example, at an intercity bus terminal).



(d) Drive-Through

Drive-through berths allow bus stops to be located in a compact area, and also can allow all buses to wait with their front destination sign facing the direction passengers will arrive from (e.g., from a station exit).

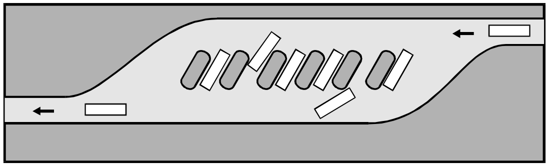


Photo locations:
(a) Newport, Rhode Island
(b) Olympia, Washington
(c) Newark Airport, New Jersey
(d) Vail, Colorado

Linear berths can operate in series and have capacity characteristics similar to on-street bus stops. Angled berths are limited to one bus per berth, and they require buses to back out. Drive-through berths can accommodate multiple vehicles. Shallow "sawtooth" berths are popular in urban transit centers and are designed to permit independent movements into and out of each berth. Individual berths may serve only one bus route, especially where service on the route is frequent, or they may serve more than one route where frequencies on each route are long enough to avoid conflict at the bus stop.

Example Problem 1 illustrates limiting the number of routes using a single berth.

The National Transportation Safety Board recommends that transit facility designs incorporating sawtooth berths, or other types of berths that may direct errant buses towards pedestrian-occupied areas, should include provisions for positive separation (such as bollards) between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area.(R12)

Waiting Area Level of Service

Levels of service for passenger waiting areas at off-street bus stops are the same as those for on-street bus stops (see Exhibit 7-8). However, because off-street facilities are larger and more complex, they incorporate spaces for pedestrian circulation that may be analyzed using the walkway thresholds presented in Exhibit 7-3.

Evaluation Procedures

The bus stop capacity procedures given in Part 4 are only applicable for relatively low bus dwell times (3 minutes or less). These procedures are applicable to off-street stops in the case of through-routed buses that do not layover at the stop, and for buses that coordinate their arrival times with certain train or express bus arrivals. When applying Equation 4-7, a *g/C* ratio of 1.00 is applicable when no traffic signals prevent buses from pulling into or out of the off-street facility. In addition, the minimum 10-second clearance time is applicable, representing the minimum time required for a bus to accelerate out of and clear the loading area, and for the next bus to pull in. Exhibit 7-14 identifies the estimated maximum loading area (berth) capacity under this condition.

Exhibit 7-14
Maximum Capacity of Off-Street Bus Berths Under Low Dwell Time Conditions

Dwell Time (s)	Berth Capacity (bus/h)
15	116
30	69
45	49
60	38
75	31
90	26
105	23
120	20
180	14

NOTE: Assumes 10-second clearance time, 25% failure rate, 60% coefficient of variation, and *g/C* ratio of 1.0. For multiple linear berths, multiply the above values by the number of equivalent berths, from Exhibit 4-14. For multiple sawtooth or drive-through berths, multiply the above values by the number of berths.

Note that these are maximum capacities based on a 25% failure rate. Lower failure rates may be desirable to provide better schedule reliability, resulting in lower capacities.

For larger bus stations, and for bus routes laying over or terminating at a station, the typical design practice is to provide for individual berths for each route direction. In these cases, Exhibit 7-14 does not apply, and the number of berths required will be the sum of the number of routes terminating at the station, plus twice the number of routes passing through the station (in order to provide separate berths for each direction).

STATION PLATFORMS

Design Factors

Transit platforms function as queuing areas for passengers waiting for a transit vehicle to arrive and as circulation areas for both departing and arriving passengers. The effective platform area required is based on maintaining a minimum LOS for queuing and circulation. It is important to note that transit platforms have critical passenger holding capacities, which if exceeded, could result in passengers being pushed onto tracks or roadways. It is important to consider the characteristics of passengers and provide for passengers who may require additional space. Exhibit 7-15 illustrates typical side and center platform configurations at stations.

Exhibit 7-15
Transit Station Platform Configurations

(a) Center Platform (Philadelphia)

(b) Side Platform (Boston)

ADA considerations for station platforms.

The ADA affects the design of various platform elements, including platform edge treatments. For example, stairs with an open sloping underside must be protected so that persons with a visibility impairment will encounter a barrier before potentially striking their head against the sloped bottom of the stairway. ADA does not directly affect the overall area or width required for a platform, but an accessible route at least 36 in. (915 mm) wide must be maintained along the platform. When the accessible route is next to the platform edge, the 24-in. (610-mm) platform edge treatment area is not included, so the clear width along a platform edge must be 60 in. (1,525 mm).

Similarly, NFPA 130 does not directly affect overall platform area unless obstacles require additional platform width to provide egress capacity past the obstacle, such as a stairway.(R11) The standard does specify, however, that egress routes must be at least 5 feet 8 in. (1.73 m) wide. When such a route passes between the edge of a platform and an obstacle, such as a stairway, an additional width of 1 foot 6 in. (457.2 mm) must be provided at the platform edge and 1 foot (304.8 mm) must be provided next to the obstruction, so that a minimum clear width of 8 feet 2 in. (2.5 m) is required in such a case.

Waiting Area Level of Service

Queuing area levels of service for transit platforms are the same as for bus stop waiting areas, and are defined in Exhibit 7-8. The LOS thresholds are based on average space per person, personal comfort, and degrees of internal mobility. Passenger congestion in the LOS “E” range is experienced only on the most crowded elevators or transit vehicles. LOS “D” represents crowding with some internal circulation possible; however, this LOS is not recommended for long-term waiting periods.

Evaluation Procedures

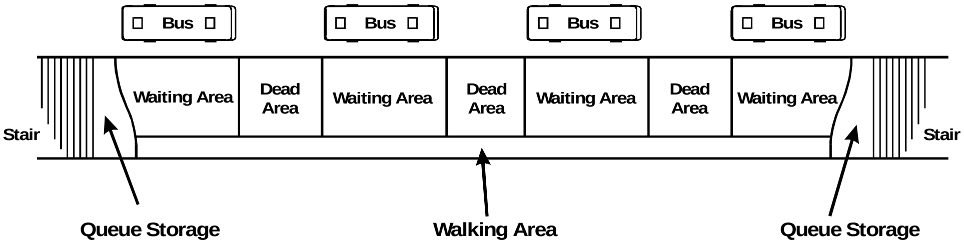
The shape and configuration of a platform is dictated by many system-wide factors. Platform length is typically based on transit vehicle length and the number of transit vehicles using the platform at any one time. Platform width is dependent upon structural considerations, passenger queuing space, circulation requirements, and entry/exit locations.

Transit platforms can be divided into the following areas:(R3)

- Walking areas;
- Waiting areas;
- Waiting area buffers (adjacent to the platform edge and to waiting areas), with the platform edge denoted by a 18-in. (0.5-m) detectable warning strip;
- Dead areas between bus loading areas or train doors;
- Space taken up by seats, pillars, and other obstructions; and
- Queue storage.

Exhibit 7-16 illustrates the use of these areas for a transit platform serving buses.

Exhibit 7-16
Transit Platform Areas(R3)



There are several different platform components which impact capacity and size requirements.

Walking and waiting do not occur evenly over the platform area. Some areas are used primarily for walking (e.g., near entry/exit locations and along the back edge of the platform) while other areas are used primarily for waiting (e.g., loading areas). Areas that are generally not used by passengers are termed "dead areas." These areas are typically present between buses at a bus terminal or in front of or behind a train at a rail terminal. Dead areas should be taken into consideration when choosing the size and configuration of a platform.

Platform Sizing

The procedures to determine the size of a transit platform are based on maintaining a desirable pedestrian LOS. For transit platforms, the design LOS should be "C" to "D" or better. The following is a list of steps recommended for determining the desired platform size:

1. Based on the desired LOS, choose the average pedestrian space from Exhibit 7-8;
2. Adjust as appropriate for passenger characteristics;
3. Estimate the maximum passenger demand for the platform at a given time;
4. Calculate the required waiting space by multiplying the average space per person by the maximum passenger demand;
5. Calculate the additional walkway width needed by using the appropriate procedures for walkways described previously;
6. Calculate the queue storage space required for exit points (at stairs, escalators, and elevators) by using the appropriate procedures described in the following sections;

7. Consider the additional platform space that will be unused, including dead areas and physical obstructions;
8. Add a 3-ft (1-m) buffer zone (18 in., or 0.5 m, on each side) to the width of the platform; and
9. Calculate the total platform area by summing the required waiting space, walkway width, queue storage at exit points, dead areas, and buffer zone width.

SHELTERS, WAITING ROOMS, AND SEATING

Design Factors

Shelters provide protection from rain, wind, and sun.

Shelters are typically used with bus stops or transit stations that are largely unenclosed to provide protection from rain, wind, and sun. In some cases they may also be heated. The design of shelters is influenced both by local climate and the desired level of amenity. For example, in colder, windier climates, shelters may be more enclosed with walls whereas in milder climates they may have only partial walls to act as a wind break. In a bus rapid transit system, station shelters may incorporate the additional function of providing a fare-controlled area and may encompass a raised platform to provide high-level boarding.

Waiting rooms are typically associated with larger bus terminals or rail stations and tend to provide a greater degree of climate control than shelters. While shelters may have a very limited number of seats or benches, waiting rooms tend to provide more. Waiting rooms may also contain ticket windows, ticket machines, telephones, and vending machines, and may provide a climate-controlled area for passengers to use those facilities.

Seating may be provided anywhere in a station. Providing seating in different areas, such as on a platform and in a waiting room, offers passengers the opportunity to select seating most convenient to them. Seating is particularly useful for the elderly and when transit service is less frequent, resulting in increased passenger waiting times in a station. When designing seating and determining the desired number of seats, it should be recognized that closely spaced seats may not be used due to discomfort at close interpersonal spacing or partial occupancy by a person sitting in the next seat, even though additional people may wish to sit.

Shelter or Waiting Room Level of Service

No specific LOS has been suggested for shelters, waiting rooms, or seating. The space provided within shelters or waiting rooms can be assessed using the LOS thresholds for queuing spaces, as presented in Exhibit 7-8. These thresholds are based on average pedestrian space, personal comfort, and degrees of mobility within the space. However, local circumstances must be taken into consideration when determining what the projected or desirable occupancy is, since such spaces are rarely used by all passengers and may only be used to the maximum extent on limited days of the year, depending on local climates. For example, shelters may be used on a daily basis for 6 months of the year in a colder northern climate but may be used only a few days a month in warmer, dryer climates. As a result, it may be more desirable to handle full stop or station loads in the more adverse climate, but provide more limited capacity relative to station passenger volumes where the shelter is used less often.

Evaluation Procedures

The LOS for persons standing in a shelter or waiting room may be assessed using the LOS criteria for queuing spaces, as presented in Exhibit 7-8. In larger waiting rooms where circulation is to be maintained or other activities such as ticket selling are occurring, the time-space analysis approach described in Equations 7-3 and 7-4 can be applied. A simpler analysis could be conducted using a space per pedestrian that is between the walking criteria shown in Exhibit 7-3 and the queuing criteria presented in Exhibit 7-8.

The desirable number of seats is a question of the maximum number of people who would choose to sit and such design issues as the space available for seating and the cost of installing and maintaining seats. One approach to assessing the desired number of seats in an existing station is to temporarily locate more than the anticipated number of seats in a station, using movable stacking chairs, and count the number of people who choose to sit in them during peak periods. The temporary seats can then be replaced with permanently mounted seats and benches.

WALKWAYS

Design Factors

The capacity of a walkway is controlled by the following factors:

- Pedestrian walking speed,
- Pedestrian traffic density, and
- Walkway width.

It is not desirable to design walkways based on total capacity, but on a desired pedestrian LOS. The desirable pedestrian environment allows sufficient space for the pedestrian to

- Walk at a preferred speed,
- Bypass slower pedestrians,
- Avoid conflicts with oncoming or crossing pedestrians, and
- Interact visually with surroundings.

For daily circulation, design walkways based on a desired pedestrian level of service, not capacity.

The levels of service given in Exhibit 7-3 provide a relative scale for achieving this desirable pedestrian environment.

Pedestrian Demand

When estimating the pedestrian demand for a particular facility, it is important to consider short peak periods and surges within the peak. For general design purposes, a 15-minute peak period is usually recommended. However, because micro-peaks (temporary higher volumes) are likely to occur, consequences of these surges within the peak should be considered. Due to the incidence of intensive peaks just after a transit vehicle arrives and discharges passengers, analysis of a shorter time period may be appropriate for walkway segments close to a transit platform. Where headways are very close, the time between trains or buses may define the period of analysis on these segments. Micro-peaking may result in increased crowding for a given time period, but the short duration may justify the temporary increase in congestion and short duration queuing.

Evaluation Procedures

Determining Required Walkway Width

The procedures to determine the required walkway width for a transit terminal corridor are based on maintaining a desirable pedestrian LOS. Exhibit 7-3 lists the criteria for pedestrian LOS on walkways. These levels of service are based on average pedestrian spaces and average flow rates. It is generally desirable for peak-period pedestrian flows at most transit facilities to operate at LOS "C" or above. The following is a list of steps recommended for determining the required walkway width:

1. Based on the desired LOS, choose the maximum pedestrian flow rate (p/ft/min or p/m/min) from Exhibit 7-3.
2. Estimate the peak 15-minute pedestrian demand for the walkway.
3. Multiply by an appropriate adjustment factor to account for pedestrians who use additional space, such as wheelchair users and those transporting large items. Consideration should also be given for pedestrians who use service animals.
4. Compute the design pedestrian flow (p/min) by dividing the 15-minute demand by 15.
5. Compute the required effective width of walkway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.
6. Compute the total width of walkway (in feet or meters) by adding 3 ft (1 m), with an 18-in. (0.5-m) buffer on each side to the effective width of walkway.

Refer to Exhibits 3-25 or 5-22 for data on the space occupied by pedestrians.

Determining Walkway Capacity

The capacity of a walkway is taken to be 25 p/ft/min (82 p/m/min), corresponding to LOS "E." Therefore, for a given walkway width, the following steps may be used to compute the capacity:

1. Compute the effective width of walkway (ft or m) by subtracting 3 ft (1 m) or other appropriate buffer zones from the total walkway width.
2. Compute the design pedestrian flow (p/min) by multiplying the effective width of walkway by 25 p/ft/min (82 p/m/min).
3. Adjust for special pedestrian characteristics, as appropriate.
4. Compute the pedestrian capacity (p/h) by multiplying the design pedestrian flow by 60.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 capacity and pedestrian travel speed values for platform, corridor, and ramps of 4% slope or less should be used in place of the values presented above. In the 2000 edition, these values were a pedestrian flow rate of 2.27 p/in/min (27.2 p/ft/min, or 89.3 p/m/min), and a travel speed of 200 ft/min (61 m/min).(R11) The larger walkway width resulting from the two calculations—design LOS or emergency evacuation—should be selected.

DOORWAYS

Design Factors

Doorways or constrictions in the width of a walkway limit the capacity of a walkway by imposing restricted lateral spacing. Because of this restriction on capacity, doorways will impact the overall capacity of a pedestrian walkway within a transit station, and therefore will require additional design considerations. Doorways are required to comply with the ADA Accessibility Guidelines. Revolving doors or gates are not considered part of an accessible route.

http://www.access-board.gov/adaag/html/adaag.htm

The effect of doorways on pedestrian flow will depend on the headway between pedestrians. When a pedestrian reaches a doorway, there must be sufficient time-headway separation to allow that pedestrian to pass through the doorway or fare gate before the next pedestrian arrives. If time-headways between successive pedestrians are too close, a pedestrian queue will develop.

The capacity of a doorway is therefore determined by the minimum time required by each pedestrian to pass through the entrance. Exhibit 7-17 summarizes observed average headways for different types of doorways. Although it is recommended that headways be recorded at doorways similar in design and operation to the one under investigation, the values in Exhibit 7-17 may be used if field data are not available, with the lower value representing closer to a minimum headway.

Exhibit 7-17
Observed Average Doorway Headway and Capacity(R6)

Type of Entrance	Observed Average Headway (s)	Equivalent Pedestrian Volume (p/min)
Free-Swinging	1.0-1.5	40-60
Revolving, per direction	1.7-2.4	25-35

Doorway Level of Service

The LOS criteria used for evaluating doorways are the same as those used for evaluating walkways (see Exhibit 7-3). The objective is to maintain a desirable average pedestrian flow rate (or walking speed) throughout the walkway system. The capacity of a doorway will be based solely on the width of the doorway if it is normally open, but will be reduced if the door is normally closed so that pedestrians have to open it. The capacity of a normally closed door is thus further affected by the difficulty of opening the door, although this effect is reduced if a steady flow of pedestrians keeps the door open for extended periods.

Evaluation Procedures

Determining the Number of Doorways

Similar to the evaluation procedures for walkways, the procedure to determine the required number of doorways is based on maintaining a desirable pedestrian LOS. Consideration should be made of pedestrian characteristics, including provisions for passengers with luggage, bicycles, strollers, wheelchairs, or other mobility aids. The following is a list of steps recommended for determining the required number of doorways:

1. Based on the desired LOS, choose the maximum pedestrian flow rate from Exhibit 7-3.
2. Estimate the peak 15-minute pedestrian demand.
3. Compute the design pedestrian flow (persons per minute) by dividing the 15-minute demand by 15.

4. Compute the required width of the doorway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.
5. Compute the number of doorways required by dividing the required entrance width by the width of one doorway (always round up).
6. Determine whether the design pedestrian flow exceeds the entrance capacity by following the procedures below.

Determining Doorway Capacity

As discussed above, the capacity of a doorway is based on the width of the doorway and the number of people who can pass through per minute. The following steps may be used to compute the capacity for a given number of entrances:

1. Determine the number of pedestrians who can pass through in 1 minute. Since doorways may display different characteristics, this should be done through field observations at the doorway or one of similar configuration. If field observations are not possible, the lower volume value from Exhibit 7-17 may be used.
2. Compute total entrance capacity (persons per minute) by multiplying the equivalent pedestrian volume by the number of doorways.
3. Adjustments should be made as appropriate to reflect special pedestrian characteristics.
4. Compute hourly pedestrian capacity by multiplying the total doorway capacity by 60.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 capacity value for doors and gates should be used in place of the values presented above. In the 2000 edition, this value was a pedestrian flow rate of 2.27 p/in/min (27.2 p/ft/min, or 89.3 p/m/min), with a minimum door width of 36 in. (914.4 mm).(R11) The larger number of doorways resulting from the two calculations—design LOS or emergency evacuation—should be selected.

STAIRWAYS

Design Factors

In stations where the platform area is grade-separated from the rest of the station and the adjacent outside area, stairways traditionally have been applied as the primary vertical pedestrian movement system. Exhibit 7-18 shows typical treatments.

Exhibit 7-18
Stairway Examples

(a) Los Angeles (b) Portland, Oregon

The capacity of a stairway is largely affected by its width. The width of stairway affects the pedestrians' ability to pass slower-moving pedestrians and to choose a desirable speed. Unlike walkways, a minor pedestrian flow in the opposing direction on a stairway can cut capacity in half; therefore, stairway design should consider directionality of flow.

Passenger queuing can occur at the "destination" end of stairways, if people are forced to converge on too constricted a space. This can be a serious design deficiency in certain terminal facilities, with potential liability exposure. This is at least as important as ensuring that adequate space is provided at entry points.

Critical passenger flows on stairways occur in the ascending direction.

Evaluation Procedures

The LOS thresholds for stairways are based on average flow rate. Exhibit 7-7 summarizes the LOS criteria for stairways. The threshold between LOS "E" and "F" (17 pedestrians per foot of width per minute or 55.8 p/m/min) represents the maximum capacity of a stairway.

When designing stairways, the following factors should be taken into consideration:(R6)

- Clear areas large enough to allow for queuing pedestrians should be provided at the approaches to all stairways;
- Riser heights should be kept below 7 in. (0.18 m) to reduce energy expenditure and to increase traffic efficiency; and
- When a stairway is placed directly within a corridor of the same width, the stairway will have a lower pedestrian capacity than the corridor and will be the controlling factor in the design of the walkway section.

When minor, reverse-flow traffic volumes frequently occur on a stair, the effective width of the stair for the major-direction design flow should be reduced by a minimum of one traffic lane, or 30 in. (0.75 m).

The following are the steps necessary to calculate the width of stairway, stairway capacity, and queuing area required for a given peak pedestrian volume.

Stairway Width

The procedures to determine the required stairway width are based on maintaining a desirable pedestrian LOS. For normal use, it is desirable for pedestrian flows to operate at or above LOS "C" or "D." However, in most modern terminals, escalators would be provided to accommodate pedestrians. Stairs, therefore, are typically provided as a supplement to the escalators to be used when the escalators are over capacity or out of service due to a mechanical failure, maintenance outage, or power failure. Under these circumstances, maximum stair capacity, or LOS "E" (17 p/ft/min or 51.8 p/m/min) may be assumed. Consideration of pedestrian characteristics at a stair location should be incorporated into the analysis.

The following is a list of steps recommended for determining the required stairway width:

1. Based on the desired LOS, choose the maximum pedestrian flow rate from Exhibit 7-7.
2. Estimate the directional peak 15-minute pedestrian demand for the stairway.
3. Compute the design pedestrian flow (persons/minute) by dividing the 15-minute demand by 15.
4. Compute the required width of stairway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.

5. Increase the stairway width by a minimum of one traffic lane (30 in., or 0.75 m) when minor, reverse-flow pedestrian volumes occur frequently.

Stairway Capacity

As discussed above, the capacity of a stairway is taken to be 17 p/ft/min (51.8 p/m/min), or LOS "E." Therefore, for a given stairway width, the following steps may be used to compute the capacity:

1. Compute the design pedestrian flow (ped/min) by multiplying the width of stairway by 17 p/ft/min (51.8 p/m/min).
2. Adjust for friction due to bi-directional flows by deducting 0 to 20%, depending on the pattern of flows. Little or no deduction should be applied when all flow is in one direction or when flows are fairly balanced. Up to a 20% deduction may be appropriate for conditions with a relatively small reverse direction flow.
3. Compute the pedestrian capacity (p/h) by multiplying the design pedestrian flow by 60.

Size of Stair Queuing Area

1. Compute the capacity of the stairway using the above procedures.
2. Compute the maximum demand by determining the maximum number of pedestrians arriving at the approach of the stairway at one time.
3. Determine the number of arriving pedestrians exceeding capacity by subtracting the capacity from the demand.
4. Compute the required queue area by multiplying the number of pedestrians exceeding capacity by 5 ft^2 (0.5 m^2) per pedestrian.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 capacity and pedestrian travel speed values for stairs, stopped escalators, and ramps over 4% slope should be used in place of the values presented above. In the 2000 edition, these values were the following for the up direction: a pedestrian flow rate of 1.59 persons per inch per minute (19.1 p/ft/min or 62.6 p/m/min), and a vertical component of travel speed of 50 ft/min (15.24 m/min). In the down direction, the values were a pedestrian flow rate of 1.82 p/in/min (21.8 p/ft/min or 71.6 p/m/min) and a vertical component of travel speed of 60 ft/min (18.3 m/min).(R11) Exit stairs should be a minimum 44 in. (1.12 m) wide; 48 in. (1.22 m) wide if adjacent to an "area of rescue assistance" as defined by the ADA. The larger walkway width resulting from the two calculations—design LOS or emergency evacuation—should be selected.

ESCALATORS

Design Factors

Escalators (Exhibit 7-19) have been installed in many transit stations where there are grade separations between the platforms, other areas of the station, or the outside areas. Typically, escalators are used to supplement stairways and, in many cases, the two facilities are located adjacent to one another. When possible, co-location of stairs, escalators, and one end of an elevator is important for pedestrians with visual impairments or service animals, as these pedestrians do not use escalators and guide dogs are trained to avoid escalators.

(a) Denver

(b) Los Angeles

Exhibit 7-19
Escalator Configuration Examples

The capacity of an escalator is dependent upon the entry width and operating speed. In the United States and most other countries, the normal angle of incline of escalators is 30 degrees, and the stair width is either 24 or 40 in. (0.6 or 1.1 m) (at the tread). Operating speed is typically 90 ft/min (27.4 m/min), but a higher speed of 120 ft/min (36.6 m/min) is occasionally used when allowed by code and insurance underwriters. These operating speeds are within the average range of stair-climbing speeds.

Studies have shown that increasing the speed of an escalator from 90 to 120 ft/min (27.4 to 36.6 m/min) can increase the capacity by as much as 12%. An interesting finding is that the practice of walking on a moving escalator does not significantly increase escalator capacity. An escalator's capacity is established at its entrance and a moving pedestrian must occupy two steps at a time, thereby reducing the standing capacity of the escalator.

The size of the queuing area provided at the exiting end of an escalator is an important consideration.

As with stairways, both ends of an escalator require some queuing area if passenger demand exceeds the capacity of the facility. A clear area at the end of an escalator is especially important, as passengers are unable to queue on a moving escalator and will be pushed into the area at the end. The area at the end of an escalator should be wider than the escalator to allow people to quickly pass anyone who has stopped at the end of the escalator, and this area should be free of any queues, such as for another escalator, fare gate, ticket machine, vending machine, or automated teller machine. This clear area should generally be at least 20 ft (6 m) in length.

Escalator Capacity

Escalator manufacturers rate the maximum theoretical capacity of their units based on 100% step utilization. Studies have shown, however, that 100% utilization is never obtained. Escalator steps not being utilized under a heavy demand may be due to any of the following factors:

- Intermittent pedestrian arrival process,
- Pedestrian inability to board quickly,
- Pedestrians carrying baggage or packages, and
- Pedestrians' desire for a more comfortable space.

Because 100% utilization is typically not attainable, nominal design capacity values have been developed (see Exhibit 7-20). These values represent a step utilization of 1 person every other step on a 24-in. (0.6-m) wide escalator and one person per step (or two people every second step) on a 40-in. (1.1-m) wide escalator.

Exhibit 7-20
Nominal Escalator Capacity Values[R6]

	Width at Tread		Incline Speed		Nominal Capacity	
Type	**(in.)**	**(m)**	**(ft/min)**	**(m/min)**	**(p/h)**	**(p/min)**
Single-width	24	0.6	90	27.4	2,040	34
			120	36.6	2,700	45
Double-width	40	1.0	90	27.4	4,080	68
			120	36.6	5,400	90

Evaluation Procedures

Number of Escalators

The procedures to determine the required number of escalators are based on the width and speed of the escalator being considered. The following is a list of steps recommended for determining the required number of escalators:

1. Estimate the directional peak 15-minute pedestrian demand for the escalator.
2. Compute the design pedestrian flow (persons per minute) by dividing the 15-minute demand by 15.
3. Based on the width and speed of the escalator, choose the nominal capacity (pedestrians per minute) from Exhibit 7-20.
4. Compute the required number of escalators by dividing the design pedestrian flow by the nominal capacity of one escalator.

Size of Queuing Area

The possibility that escalators can generate large queues, even at pedestrian demands below nominal capacity, should be considered. Queues may generate when demand exceeds capacity or when pedestrian arrival is intermittent or persons are carrying baggage or luggage. For these situations, an adequate queuing area should be placed at the approach of an escalator based on an average pedestrian space of 5 ft^2 (0.5 m^2) per person. (Where alternative stationary stairs are conveniently available, the maximum wait time for an escalator may be assumed to be 1 minute.) Sufficient space should also be provided at the discharge end of an escalator to avoid conflicts with other traffic streams. The following are steps for computing the required size of a queuing area at the approach to an escalator:

1. Determine the capacity of the escalator from Exhibit 7-20.
2. Compute the maximum demand by determining the maximum number of pedestrians arriving at the approach of the escalator at one time. (Assume pedestrians having to wait more than 1 minute at the escalator will take the stairs, if available.)
3. Determine the number of arriving pedestrians exceeding capacity by subtracting the capacity from the demand.
4. Compute the required queue area by multiplying the number of pedestrians exceeding capacity by 5 ft^2 (0.5 m^2) per pedestrian.

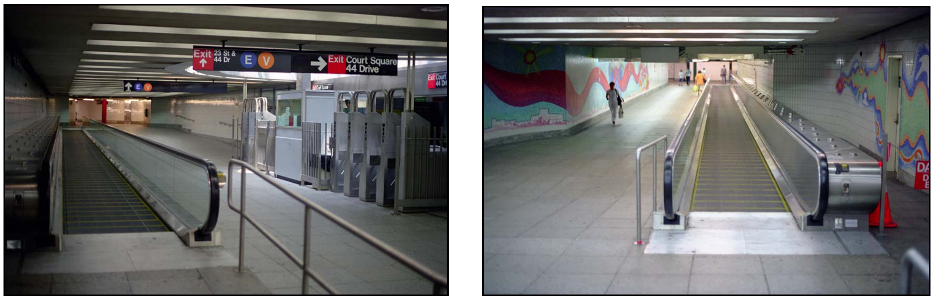
Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 standard allows both stopped and running escalators, equipped to operate in both directions, to be considered as emergency exits. The 2000 NFPA 130 values for stopped escalator capacity and pedestrian travel speed may be found in the preceding section on stairways. Escalators shall not account for more than one-half of the exit capacity, and one escalator shall be considered to be out of service.[R11]

MOVING WALKWAYS

Moving walkways (Exhibit 7-21) have been installed in a number of transit stations and terminals around the world and are very common in larger airports. Moving walkways are normally installed where large numbers of pedestrians traverse medium and longer distances, from approximately 100 to 1,000 ft (30 to 300 m). Individual moving walkways can be constructed in varying lengths, but are rarely more than 400 ft (120 m) in length, with longer distances being covered by a series of moving walkways with a circulation space between each successive walkway.

Exhibit 7-21
Moving Walkway Examples (New York)



Moving walkways normally operate at a speed of 100 ft/min (30 m/min) but some operate at up to 160 ft/min (50 m/min). Thus, most moving walkways operate at less than walking speed. Moving walkways that accelerate pedestrians to a faster speed are under development. Some designs use sequential rubber belts or metal rollers to accelerate pedestrians at the beginning of the moving walkways, then decelerate them at the end of the run. Other designs use metal pallets somewhat like those in escalators and achieve acceleration and deceleration by compressing overlapping pallets or by moving on a non-linear course.

Design Factors

When planning moving walkways, the following factors should be considered:

- The pedestrian volumes moving in each direction. For longer multi-unit moving walkway systems, the volumes may differ in various segments as pedestrians access intermediate destinations.
- Adequate space, measured in corridor width, for moving walkways and a parallel walkway (1) to carry those who cannot or do not wish to use the moving walkway and (2) to serve as an alternate route when a walkway is undergoing maintenance. Similar to escalators, it may not be possible to enter and walk on a moving walkway that is undergoing maintenance if the end plates have been removed.
- The ongoing cost of operating and maintaining the moving walkway.

Moving Walkway Capacity

The capacity of a moving walkway is primarily dependent on its width at its entrance, as this determines the number of people who can enter the walkway. The speed of the walkway only affects the capacity to the extent that it affects the spacing of people as they enter. Walking on a moving walkway increases the pedestrian's travel speed and reduces travel time, but does not affect capacity because it does not affect the rate of entry to the moving walkway. Likewise, systems that accelerate pedestrians to higher speeds do not increase the capacity compared with a standard moving walkway of the same width because the capacity at the entrance is the same as a standard speed unit.

Manufacturers of moving walkways sometimes state theoretical capacities based on square feet of walkway per minute. These theoretical capacities are generally much higher than practical capacities and should not be used in passenger flow analysis. Studies have shown that the practical capacity of a double-width moving walkway is comparable with the capacity of a double-width escalator of equal width, or approximately 90 persons per minute or 5,400 persons per hour.

Evaluation Procedures

The procedures to determine the required number of moving walkways and the queuing areas at each end are similar to the procedure for escalators. If volumes in either direction are expected to approach or exceed the estimated capacity of 90 persons per minute for a double-width moving walkway, field studies at a moving walkway of comparable width and speed are recommended to confirm capacity.

Designing for Emergency Evacuation

The NFPA 130 standard(R11) does not address moving walkways. It is prudent to calculate emergency evacuation flow under the assumption that power is off.

ELEVATORS AND LIFTS

Design Factors

Elevators, lifts, or ramps are required in new or modified grade-separated facilities to meet ADA requirements.

http://www.access-board.gov/adaag/html/adaag.htm

Elevators, lifts, or ramps are required in all new transit or modified transit stations in the United States to meet ADA requirements when level changes are required to access or move within a station. These requirements are defined in the ADA Accessibility Guidelines. Elevators may be provided at one end of a platform or in the center. Separate elevators may be needed between the street and the concourse (mezzanine), and between the concourse and the platforms. Side platform stations generally require at least two elevators, whereas a center platform station may only require one. In the case of especially deep stations, as in New York City (e.g., 168th, 181st, and 191st Streets), Washington, DC (Forest Glen), and Portland, Oregon (Washington Park), elevators are the sole means of passenger access to and from stations, not including emergency stairs. Open lifts are sometimes used in stations to move passengers using mobility aids between levels a few feet apart, in locations where a ramp is not feasible.

On-going elevator maintenance is important for keeping stations consistently ADA accessible.

Good, on-going elevator maintenance is important for maintaining accessibility for mobility-impaired passengers at transit stations. As a cost-saving measure, most transit stations provide only one elevator per platform, or from the concourse level to the street. However, when any of these elevators is out of service, the station is effectively inaccessible to mobility-impaired passengers. Although these passengers can be served during these times by directing them to alternate stations and providing them with paratransit bus service to their destination, it is much less convenient for these passengers and serves to reduce the accessibility and convenience of the transit system as a whole to passengers with disabilities.

Exhibit 7-22 shows a typical elevator location in a transit station. Traffic flow on elevators differs from other vertical pedestrian movers. As opposed to escalators and stairs, which provide constant service, elevators provide on-demand service. Because of its characteristics, determining the capacity of an elevator is similar to determining the capacity of a transit vehicle.

Exhibit 7-22
Elevator Application Examples

(a) Station Access (Portland, Oregon) (b) Station Circulation (Los Angeles)

Elevator Level of Service

The LOS of an elevator system is typically based both on wait time and on the level of crowding. The tolerance level for an acceptable waiting time for elevator service at a transit terminal is around 30 seconds but also depends on the vertical distance traveled and alternate means. Average pedestrian space will be less important, unless inadequate capacity causes excessive crowding or causes people to miss an elevator, increasing their travel time and raising frustration. It is important to consider the maneuverability of wheelchairs in an elevator. This is particularly important in crowded situations or where the person using a wheelchair needs to turn to access the control panel or to exit.

Evaluation Procedures

Waiting Time

In evaluating wait time for an elevator, both the maximum and average wait times can be measured. The maximum wait time with a single elevator is the cycle time for the elevator to depart, make one or more intermediate stops, and return to its starting point ready to return in the initial direction. This represents the time spent by a person who arrived just as the elevator doors were closing but was unable to board. The average waiting time will generally be half of the cycle time. The effect on waiting times of multiple elevators depends on the coordination of their operation. If electronic controls space elevator departures, waiting times will be reduced by a factor of the number of elevators. In practice, the reduction is usually somewhat less, particularly if passengers hold elevator doors.

Elevator Capacity

The capacity of an elevator system depends on the following four factors:

- Entering and exiting patterns of users;
- User characteristics, including luggage, strollers, bicycles, and wheelchairs;
- Elevator travel time; and
- Practical capacity of the elevator cab.

Boarding and alighting times will depend on the door width and whether passengers are carrying baggage or luggage. The number of passengers boarding may also affect boarding rates. Studies that have investigated boarding rates for transit vehicles have found that boarding rates increase as the number of passengers increase due to “peer pressure.” To determine average boarding and alighting times for a particular elevator system, it is recommended that field data be collected.

Elevator travel time will be based on the operating characteristics of the elevator, including the following:

- Distance traveled (height of shaft),
- Elevator speed,
- Elevator acceleration and deceleration rates, and
- Elevator door opening and closing times.

The above factors will remain constant for a particular elevator system. The practical capacity of an elevator in a transit station will be based on the following:

- Presence of heavy winter clothing, and
- Presence of baggage or luggage.

The presence of heavy clothing and baggage or luggage increases the required area per person and, therefore, reduces standing capacity. Although the crush capacity of an elevator is approximately 1.8 ft^2 (0.17 m^2) per person, most people require 3.0 ft^2 (0.28 m^2) or more to feel comfortable in an elevator and this is a suitable design standard. As mentioned above, riders of elevators are more willing to accept less personal space due to the short time period associated with the elevator ride.

Designing for Emergency Evacuation

Elevators are not considered part of an evacuation route, and their capacity should not be included in evacuation design.

RAMPS

Design Factors

Ramps may be provided primarily to serve people with disabilities, but are also useful to passengers with baby carriages, wheeled luggage, or heavy packages. Some persons with disabilities who can negotiate stairs will prefer a ramp and will use it if it is available and convenient. Ramps may also be designed for general passenger use in place of stairs or steps. While ramps generally should not have a slope greater than 1:12 (8.3%), an even more gradual slope (1:20 to 1:16, or 5% to 6.25%) is preferred wherever feasible. The ADA requires level landings at the ends of each ramp, and at the end of each ramp run. In addition, the ADA limits the lengths of individual ramp runs, and the maximum rise of each run.

Used as an alternative to elevators or lifts, ramps have the advantage that they require little maintenance, have no operating cost, and are available to a broader spectrum of passengers who may choose them.

Ramp Level of Service

LOS thresholds have not been established for ramps, but would be comparable with those for walkways.

Evaluation Procedures

In many applications, ramps are considered auxiliary to the main circulation routes in a station, provided to serve only a small portion of a station's total users. In these cases, their capacity will not be critical to the analysis of passenger flow and they need not be evaluated in terms of LOS. Where ramps are used in place of stairs as a primary pedestrian circulation element, they can be treated much like level walkways. Grades of up to 6% have been found to have negligible effect on pedestrians, while a slope of 10% has reduced speeds by about 12%.

Designing for Emergency Evacuation

The NFPA 130 standard specifies ramp capacities and pedestrian travel speeds for use in emergency evacuation design. The 2000 NFPA 130 treats ramps with a grade of 4% or less the same as level walkways, while ramps with a grade over 4% are treated as stairways. The corresponding capacity and pedestrian travel speed values can be found in the previous sections on walkways and stairways.(R11)

FARE CONTROL BARRIERS, GATES, AND TURNSTILES

Design Factors

Different types of fare gates have different capacity characteristics.

Fare gates limit the capacity of a walkway by imposing restricted lateral spacing and by requiring pedestrians to perform an activity that consumes additional time. Because of these restrictions on capacity, fare gates will impact the overall capacity of a pedestrian walkway system within a transit terminal, and therefore will require additional design considerations. Fare gates or turnstiles are typically applied at heavy rail stations to control fare payment. They are applied to a lesser extent at commuter rail and light rail stations, due to the proof-of-payment system associated with most of these systems. Fare gates are required to comply with the ADA Accessibility Guidelines, although turnstiles and some types of gates are not considered part of an accessible route.

http://www.access-board.gov/adaag/html/adaag.htm

Exhibit 7-23 illustrates the placement and operation of fare gate configurations in a transit terminal. There are three different types of fare gates applied in stations:

1. Free admission (a barrier only),
2. Coin- or token-operated, and
3. Automatic ticket reader.

Coin-operated fare gates may have single or double slots to accept change. Automatic fare gates, using magnetic stripe farecards, have been used on newer heavy rail systems with distance-based fares, such as BART in the San Francisco Bay Area and Metro in Washington, DC, and are increasingly being used in other systems such as MTA-New York City Transit. Some agencies—particularly ferry systems—use staff to check and collect tickets before allowing passengers access to the waiting area or vessel. This form of gate is little used for rail transit applications in North America and Western Europe, except during special event situations, such as at sports stadia. Systems using automated fare gates generally also have a channel available next to the station agent's booth to accommodate checking users with non-standard tickets (e.g., visitor passes with scratch-off dates).

Exhibit 7-23
Fare Gate Examples

(a) New York

(b) San Francisco

The effect of fare gates on pedestrian flow will depend on the headway between pedestrians. When a pedestrian reaches a fare gate, there must be sufficient time separation to allow that pedestrian to pass through the fare gate before the next pedestrian arrives. If the times between successive pedestrians are too close, a pedestrian queue will develop.

The capacity of a fare gate is therefore determined by the minimum time required by each pedestrian to pass through. Exhibit 7-24 summarizes observed average headways for different types of fare gates. Although it is recommended that headways be recorded at fare gates that are of a similar design and operation to those under investigation, the values in Exhibit 7-24 may be used if field data are not available, with the lower value representing closer to a minimum headway.

Exhibit 7-24
Observed Average Fare Gate Headways and Capacities(R6)

Type of Entrance	Observed Average Headway (s)	Equivalent Pedestrian Volume (p/min)
Free admission (barrier only)	1.0-1.5	40-60
Ticket collection by staff	1.7-2.4	25-35
Single-slot coin- or token-operated	1.2-2.4	25-50
Double-slot coin-operated	2.5-4.0	15-25
Card reader (various types)	1.5-4.0	25-40
High entrance/exit turnstile	3.0	20
High exit turnstile	2.1	28
Exit gate, 3.0 ft (0.9 m) wide	0.8	75
Exit gate, 4.0 ft (1.2 m) wide	0.6	100
Exit gate, 5.0 ft (1.5 m) wide	0.5	125

Fare Gate Capacity

Fare gates and turnstiles are evaluated based on a design volume-to-capacity (*v/c*) ratio, rather than a design LOS. The selected *v/c* ratio should allow some room for growth in passenger flow.

Evaluation Procedures

Determining the Required Number of Fare Gates

The procedure to determine the required number of fare gates is based on determining the capacity of individual fare gates in either direction (entering and existing) and providing enough capacity to handle peak period conditions and allow for some growth. Special provisions may be made for periodic high volumes such as after a major public event. Consideration should be given to pedestrian characteristics, including provisions for passengers with luggage, bicycles, strollers, wheelchairs, or other mobility aids. The possibility of one or more gates being unavailable due to malfunction or maintenance should be considered. The following is a list of steps recommended for determining the required number of fare gates:

1. Estimate the peak 5- to 15-minute passenger demand.
2. Compute the design pedestrian flow (passengers per minute) by dividing the demand by the number of minutes.
3. Compute the number of gates, turnstiles, or combination required by dividing the passenger flow by the capacity of individual units, or subtracting the capacity of units if more than one type is to be used (always round up or add one extra unit for each direction of flow). One gate should always be provided for reverse flow, even if the reverse flow is relatively minor.

Determining Fare Gate Capacity

When possible, the capacity of a specific fare gate type should be determined through field observations of an identical or similar gate in the same system or a system with a similar fare structure and fare medium. Observations should be made when a fare gate is operating at maximum capacity, as evidenced by a queue at the entry to the gate. As an alternative, an estimated capacity from Exhibit 7-24 can be used. Compute the total capacity of a fare control array by summing the capacity of all the gates in the array. Adjustments should be made as appropriate to reflect special pedestrian characteristics.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 divides fare gates into two categories: (1) fare collection gates that provide barrier-free egress in emergency mode and (2) turnstiles that free wheel in the exit direction in emergency mode. The 2000 NFPA 130 capacity values are 50 persons per minute for the former and 25 persons per minute for the latter.(R11)

TICKET MACHINES

Design Factors

At a transit station, passengers pay their fares at ticket machines or pay booths before they enter the platform area. Exhibit 7-25 illustrates different ticket machine/booth configurations at transit stations. At larger heavy rail stations, several ticket machines are typically provided to handle peak passenger demand for tickets. At light rail stations, at least one ticket machine is provided on each platform, but some redundancy is desirable in case one machine is out of service. Conversely, a ticket machine may not be provided on a light rail or bus rapid transit platform that is used primarily for alighting, especially if ticket machines elsewhere are readily accessible. Staffed ticket booths are used at older heavy rail stations and at many commuter rail stations.

Transit systems are increasingly using either electronic fare media or proof-of-payment systems. Electronic media increase the importance and the complexity of ticket vending machines, with varying effects on the fare control systems.

Ticket Machine Level of Service

Passenger processing times at ticket vending machines vary widely depending on the particular characteristics of the ticket vending machine and the fare structure of the transit system. Passenger processing time at ticket machines increases with complex zone fare systems, which require some deciphering by the passenger at the machine prior to paying the correct fare. Infrequent passengers require more time to purchase fares than regular commuters who have had practice using the machines. Ticket vending machines must be made accessible for persons with disabilities, including Braille writing and other design features.

(a) San Francisco (b) New Jersey

Exhibit 7-25
Ticket Machine Examples

Evaluation Procedures

To identify the required number of ticket machines at a station, pre-testing of the particular machine to be purchased could prove beneficial to approximate an average passenger processing time. In many cases, the number of machines or booths will be restricted by space, personnel, or cost constraints.

SIGNAGE AND PASSENGER COMMUNICATION SYSTEMS

Signage and Information Displays

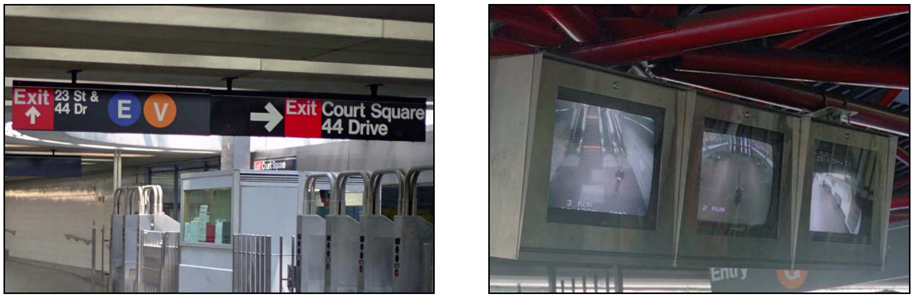
Station signage, illustrated in Exhibit 7-26, provides information to passengers both in the station and on transit vehicles. Signs can direct passengers to loading areas or platforms for various transit services, nearby destinations, and emergency evacuation routes. System maps, schedules, fare information, and neighborhood maps provide information for passengers. While most stations or stops will include at least minimal signage, more complex stations require more extensive wayfinding systems. Signage and information is particularly important to the occasional transit passenger, but reinforces the transit experience and options for all passengers.

Signage should be accessible to persons with disabilities, including Braille signage, and should be placed so that they are accessible to wheelchair users.

Exhibit 7-26
Signage and Communication System Examples

(a) Posted System Information

(b) Real-Time Schedule Information



(c) Wayfinding Information

(d) Video Security Monitors

(e) Emergency Call Box

(f) Elevator Availability Information

Photo locations:
(a) San Diego
(b) Denver
(c) New York
(d) New York
(e) Boston
(f) San Francisco

Public Address Systems

Public address systems may be provided in stations both for public information and for security. A public address system can be activated by on-site personnel or may be connected to a remote central control facility. It may be combined with passenger call boxes allowing passengers to call for information or emergency assistance. Video monitors allow staff to monitor conditions and events in the station and to record them for law enforcement purposes. The presence of video cameras and call boxes also acts as a deterrent to some crimes.

Real-Time Passenger Information Systems

In recent years, new electronic technology has been developed to provide improved traveler information systems. For transit stations, "real-time" passenger communications can assist in managing passenger flows and queues. This can include providing information on bus and train departure times, bus and train berth locations, and out-of-service elevators and other facilities.

PASSENGER AMENITIES

Placement of passenger amenities at bus stops and in stations impacts space required for circulation and waiting areas.

Passenger amenities are those elements provided at a bus stop or transit station to enhance comfort, convenience, and security for the transit patron. Amenities include such items as shelters, benches, vending machines, trash receptacles, lighting, phone booths, art, and landscaping. The effects that particular amenities have on transit ridership is not well known. Amenities at most bus stops or transit stations are placed in response to a human need or a need to address a local condition. Some advantages and disadvantages of various passenger amenities are summarized in Exhibit 7-27. Examples of passenger amenities at transit stops and stations are illustrated in Exhibit 7-28.

Exhibit 7-27
Types of Passenger Amenities at Bus Stops(R15)

Amenity	Advantages	Disadvantages
Shelters	• Provides comfort for waiting passengers • Provides protection from climate (sun, glare, wind, rain, snow) • Help identify the stop/station	• Requires maintenance, trash collection • May be used by graffiti artists
Benches	• Provides comfort for waiting passengers • Help identify the stop/station • Low-cost when compared with installing a shelter	• Requires maintenance • May be used by graffiti artists
Vending Machines	• Provides reading material for waiting passengers	• Increases trash accumulation • May have poor visual appearance • Reduces circulation space • Can be vandalized
Lighting	• Increases visibility • Increases perceptions of comfort and security • Discourages "after hours" use of bus stop facilities by indigents	• Requires maintenance • Can be costly
Trash Receptacles	• Provides place to discard trash • Keeps bus stop and surroundings clean	• May be costly to maintain • May be used by customers of nearby land uses • May have a bad odor • May be removed for security reasons
Telephones	• Convenient for transit patrons • Provides access to transit information and emergency services	• May encourage loitering at bus stop • May encourage illegal activities at bus stop

Exhibit 7-28
Passenger Amenity Examples

(a) Shelter & Bench (Denver)

(b) Telephones (Denver)

(c) Vending Machines (Brisbane, Australia)

(d) Lighting (Cleveland)

(e) Trash Receptacle (Albuquerque)

(f) Art (Los Angeles)

The space needed for passenger waiting at transit stops and stations should account for space taken by shelters, benches, information signs, and other amenities. Amenities at bus stops and transit stations should be placed so that they do not interfere with the landing area for a lift or ramp for people with disabilities and so that their spacing or placement does not constrict movement by wheelchair users.

When shelters are provided at light rail and busway stations, they typically do not cover the entire station platform. The extent of coverage depends on local climate, impacts on surrounding properties, circulation, and passenger waiting patterns. If most passengers wait for trains or buses on one platform and alight on the other platform, then canopies may be provided only on the side of the station where passengers wait, or there may be fewer or smaller canopies on the alighting side of the station.

BICYCLE STORAGE

Bicycle storage may be provided at transit stations where demand exists and space allows. Bike racks provide a simple, relatively low-cost approach and can hold a large number of bicycles in a relatively small space, but the bicycles are subject to potential damage and theft. Enclosed bicycle lockers provide added protection from theft and from weather, but are more costly and require more space. The demand for bicycle spaces will vary greatly by station and may be best assessed by observation and test provision of facilities.

PARK-AND-RIDE FACILITIES

Park-and-ride facilities are sized based on estimated demand.

At selected transit stations, park-and-ride facilities for autos are provided. Generally, park-and-ride facilities are located along the outer portions of a rail line or busway, in the outer portions of central cities, and in the suburbs in metropolitan areas. At many locations, park-and-rides are integrated with bus transfer facilities. Their size can vary from as few as 10 to 20 spaces at minor stations to more than 1,000 spaces at major stations. Most park-and-ride facilities are surface lots, with pedestrian connections to the transit station. Parking structures are used where land is at a premium and where a substantial number of parking spaces are required.

Exhibit 7-29
Park-and-Ride Lot Examples

(a) Cleveland (b) Houston

Surface parking lots around transit stations occupy potentially valuable space that could be used for transit-oriented development. Instead, parking for commuters can be integrated with transit-oriented development. One option is to utilize parking structures in place of surface parking to free additional land for mixed-use development. Parking garages can also contain street-level commercial space to better integrate them with surrounding development. Parking, whether structured or surface, can also be moved 100 to 300 ft (35 to 100 m) from the station if the area between is developed in a pedestrian-friendly manner. In a mixed-use development, the same parking spaces used by commuters during the daytime can also serve residents, shoppers, and diners during the evening and weekend.

The required number of park-and-ride spaces at a transit station typically involves identifying the demand for such parking, and then relating the space demand to the ability to physically provide such a facility within cost constraints. Parking spaces in park-and-ride facilities typically have a low turnover during the day, as most persons parking at transit stations are commuters gone most of the day. In larger urban areas, the regional transportation model will have a mode split component which will help identify park-and-ride demand at transit station locations. This information is particularly applicable for new rail line or busway development. Where the regional model does not have the level of sophistication to provide such demand estimates, then park-and-ride demand estimation through user surveys and an assessment of the ridership sheds for different station areas would be appropriate.

KISS-AND-RIDE FACILITIES

Kiss-and-ride facility capacity is governed by space required for passenger pick-ups.

Kiss-and-rides are dedicated auto loading areas at stations, where transit patrons can be dropped off and picked up by another person in a vehicle. Short-term parking is based on the need to serve vehicles waiting to pick up transit riders, as the drop-off requires no parking maneuver (though curb space is needed to handle the drop-off). As with park-and-ride facilities, the sizing of kiss-and-ride facilities is reflective of the demand and physical constraints of the site. Several rail stations in Toronto use a "carousel" design incorporating an enclosed waiting area.

Exhibit 7-30
Kiss-and-Ride Examples

(a) Denver

(b) Boston

(c) Toronto

CHAPTER 5. REFERENCES

1. Americans with Disabilities Act Access Guidelines for Buildings and Facilities: Architectural Barriers Act Accessibility Guidelines, NPRM Vol. 64 FR 62248, November 18, 1999.
2. Benz, Gregory P. Application of the Time-Space Concept to a Transportation Terminal Waiting and Circulation Area. In *Transportation Research Record 1054*, TRB, National Academy Press, Washington, DC (1986).
3. Benz, Gregory P., *Pedestrian Time-Space Concept: A New Approach to the Planning and Design of Pedestrian Facilities,* Second Edition, Parsons Brinckerhoff, Inc., New York, NY (1992).
4. Boyd, Annabelle and John P. Sullivan, *TCRP Synthesis of Practice 27: Emergency Preparedness for Transit Terrorism,* TRB, National Academy Press, Washington, DC (1997). http://gulliver.trb.org/publications/tcrp/tsyn27.pdf
5. Demetsky, Michael J., Lester A. Hoel, and Mark A. Virkler, *Methodology for the Design of Urban Transportation Interface Facilities,* U.S. Department of Transportation, Program of University Research, Washington, DC (1976).
6. Fruin, John J., *Pedestrian Planning and Design*, Revised Edition, Elevator World, Inc., Mobile, AL (1987).
7. Griffths, John R., Lester A. Hoel, and M. J. Demetsky, *Transit Station Renovation: A Case Study of Planning and Design Procedures,* U.S. Department of Transportation, Research and Special Programs Administration, Washington, DC (1979).
8. *Highway Capacity Manual.* TRB, National Research Council, Washington, DC (2000).
9. Levinson, Herbert S., Samuel Zimmerman, Jennifer Clinger, James Gast, Scott Rutherford, and Eric Bruhn, *TCRP Report 90: Bus Rapid Transit, Volume 2: Implementation Guidelines,* TRB, Washington, DC (2003). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_90v2.pdf
10. Levinson, Herbert and Texas Transportation Institute, *Conceptual Planning and Design: Lockwood Transit Center* (1983).
11. National Fire Protection Association, *NFPA 130 Standard for Fixed Guideway Transit and Passenger Rail Systems,* 2000 Edition, Washington, DC (2000).
12. National Transportation Safety Board, "Highway Accident Summary Report: Bus Collision with Pedestrians, Normandy, Missouri, June 11, 1997," *Report PB98-916201,* NTSB, Washington, DC (1998).
13. Needle, Jerome A. and Renée M. Cobb, J.D., *TCRP Synthesis of Practice 21: Improving Transit Security,* TRB, National Academy Press, Washington, DC (1997). http://gulliver.trb.org/publications/tcrp/tsyn21.pdf
14. *TRB Special Report 209: Highway Capacity Manual,* TRB, National Research Council, Washington, DC (1985).
15. Texas Transportation Institute, "Guidelines for the Location and Design of Bus Stops," *TCRP Report 19,* TRB, National Academy Press, Washington, DC (1996). http://gulliver.trb.org/publications/tcrp/tcrp_rpt_19-a.pdf

This page is intentionally blank.

CHAPTER 6. EXAMPLE PROBLEMS

Example Problem 1

Derived from a problem in the 1985 HCM.(R10,R14)

The Situation

A transit agency plans to construct a suburban transit center.

The Question

What are the "base year" 2000 and "design year" 2015 berth requirements?

The Facts

- The bus lines serving the proposed transit center are identified below. Year 2000 data are based on actual schedules, while year 2015 data are based on a growth forecast of 60% for local bus service and 100% for freeway bus service.
- Bus berths will be assigned according to principal geographical destinations.
- Bus dwell times will be approximately 5 minutes per bus passing through the center and 8 minutes for buses that begin and end trips there.

		Peak Direction Buses		Off-Peak Dir. Buses		Service
Rte. #	**Route Name**	**2000**	**2015**	**2000**	**2015**	**Type**
	LOCAL SERVICE					
42	Holman Crosstown	8	13	0	0	Terminating
68	Brays Bayou Crosstown	4	6	0	0	Terminating
76	Lockwood Crosstown	4	6	4	6	Through
77	MLK Limited	6	10	6	10	Through
	Subtotal Local	*22*	*35*	*10*	*16*	
	EXPRESSWAY SERVICE					
242	Clear Lake Park-and-Ride	3	6	1	2	Through
245	Edgewood Park-and-Ride	3	6	1	2	Through
250	Hobby Park-and-Ride	2	4	1	2	Through
255	Fuqua Park-and-Ride	4	8	1	2	Through
41	Garden Villas Limited	2	4	1	2	Through
147	Sagemont Express	2	4	1	2	Through
	Subtotal Express	*16*	*32*	*6*	*12*	
	TOTAL	**38**	**67**	**16**	**28**	

Comments

- In 2000, 22 local buses and 16 express buses use the transit center in the peak direction, while 10 local buses and 6 express buses will use it in the off-peak direction.
- Bus dwell times are longer than the 3-minute passenger service time needed to fill an empty bus to seated capacity, assuming that exact fares are paid on the bus, to allow for schedule irregularities and (for the terminating routes) driver layover time.

Steps

The table on the next page provides estimated berth requirements for 2000 and 2015. The berths were estimated as follows:

1. The bus routes were grouped by geographic destination in 3 categories.
2. The "capacity" of each type of service was obtained by the equation $c = 60 / t_d$, where t_d was the specified dwell time (clearance time was neglected, as it is short in comparison with the dwell times at the transit center). Thus a 5-minute dwell time could accommodate 12 buses/berth/hour; an 8-minute dwell time, 7.5 buses/berth/hour.

3. The number of inbound berths for the a.m. peak hour was computed by dividing the number of buses by the berth capacity. Thus, for lines 42 and 68, in 2000, 12 buses need 12 / 7.5 or 1.6 berths, rounded up to 2 berths.
4. The bus routes that start at the center need only inbound berths. The other bus routes need an equal number of outbound berths to accommodate p.m. peak hour bus flows and to ensure that each major geographic destination would have its own specified area.

The Results

For the year 2000, the following calculations result:

Route	Service Type	Dwell Time/Bus (min)	Buses/ Berth/ Hour	A.M. Inbound Buses	Inbound Berths	Max. Outbound Berths for P.M.	Total Berths
			LOCAL SERVICE				
42-68	Start	8	7.5	12	2	0	2
76	Through	5	12	4	1	1	2
77	Through	5	12	6	1	1	2
			Subtotal	*22*	*4*	*2*	*6*
			EXPRESSWAY SERVICE				
All	Through	5	12	16	2	2	4
			TOTAL	**38**	**6**	**4**	**10**

For the year 2015, the following calculations result:

Route	Service Type	Dwell Time/Bus (min)	Buses/ Berth/ Hour	A.M. Inbound Buses	Inbound Berths	Max. Outbound Berths for P.M.	Total Berths
			LOCAL SERVICE				
42-68	Start	8	7.5	19	3	0	3
76	Through	5	12	6	1	1	2
77	Through	5	12	10	1	1	2
			Subtotal	*35*	*5*	*2*	*7*
			EXPRESSWAY SERVICE				
All	Through	5	12	32	3	3	6
			TOTAL	**67**	**8**	**5**	**13**

The total berth requirements represent the sum of the inbound and outbound berths. As a result, 10 loading positions are needed for year 2000 conditions, and 13 loading positions are needed for year 2015 conditions. Ideally, 15 loading positions should be provided to account for growth and traffic fluctuations within the peak hour.

Note that 38 inbound buses with a berth capacity of 10 buses/berth/hour would require only 4 inbound loading positions in 2000 if routes were not separated geographically. However, this is *not* advisable when one considers clarity to the riding public, so 6 berths are anticipated based on the grouping shown above.

Example Problem 2

The Situation

A new rail station will be constructed below grade. This three-level station (platform, mezzanine, and surface) will serve a new transit center and an adjacent urban university campus. The initial concept is to connect the single center platform to the mezzanine at two locations: at one end of the platform and halfway down the platform. A pair of double-width (40-in.) escalators with a stairway in between would be located at each platform access point. One elevator between each level would also be provided.

The Question

Based on the estimated demand under typical peak 15-minute conditions and evacuation conditions, how wide should the stairways be?

The Facts

All values reflect design conditions 25 years in the future, rather than conditions when the station first opens.

- For the design year, four-car trains are expected to run at 7 to 8 minute headways (i.e., 8 trains/hour/direction).
- The a.m. peak hour exiting demand is estimated to be 3,200 passengers per hour. The corresponding a.m. peak hour entering demand is estimated to be 500 p/h. The estimated p.m. peak hour demands are 2,900 p/h entering and 500 p/h exiting.
- During the peak 15 minutes of the a.m. peak hour, the average inbound train entering the station will have 700 passengers on board, while the average outbound train will have 300 passengers on board. During the peak 15 minutes of the p.m. peak hour, the average inbound train entering the station will have 200 passengers on board, and the average outbound train will have 500 passengers on board.
- The maximum schedule load of a car is 200 passengers.
- The average peak hour factor currently observed on the system is 0.714.
- The system operates on a proof-of-payment basis; thus, no fare gates are required.
- Sporting events are held at off-campus sites and do not impact peak demand conditions at this station.

Comments

LOS "C" is a reasonable design level for a station under typical daily conditions. The NFPA 130 evacuation standard(R11) is conservative in its assumptions of the number of people that will need to be evacuated. The number of people that should be designed for includes:

- The loads of one train on each track during the peak 15 minutes, assuming each train is running one headway late (i.e., is carrying twice its normal load, but no more than a full [maximum schedule] load); and
- Passengers waiting on the platform to board trains during the peak 15 minutes, assuming their trains are running one headway late.

Outline of Solution

Conditions during both peak hours will be checked to see which controls different elements of the design. Next, the stairways will be sized to accommodate the design conditions during the peak 15 minutes. The resulting width will then be compared with the width required to evacuate the platform within 4 minutes. The larger width will control design.

Steps

Design Periods

Peak-hour volumes should be converted to peak 15-minute volumes by multiplying by the peak hour factor:

$$P_{15} = \frac{P_h}{4(PHF)}$$

For example, the peak-15-minute exiting volume during the a.m. peak hour is:

$$P_{15} = \frac{3{,}200}{4(0.714)} = 1{,}120 \text{ p}$$

The corresponding peak-15-minute entering volume is 175 passengers during the a.m. peak hour. During the p.m. peak-15-minute period, 1,015 passengers will be entering and 175 passengers will be exiting.

The number of people that may need to be evacuated is based on the train loads and passengers waiting to board. During the a.m. peak hour, this number is calculated from the following:

- *Inbound train*: an average train carries 700 people during the peak 15 minutes. A train operating one headway late would have a demand of twice this number, or 1,400 people, but only 800 of those people (the maximum schedule load of a four-car train) would actually have been able to board the train.
- *Outbound train*: an average train carries 300 people during the peak 15 minutes. A train operating one headway late would have a demand of twice this number, or 600 people, which is less than the train's capacity.
- *Waiting on platform*: At an average headway of 7.5 minutes between trains in a given direction, up to half of the entering volume during the peak 15 minutes typically would be present if the trains arrived on schedule. However, the design should assume that the trains are one headway late and, therefore, twice the typical number of waiting passengers should be used. This results in (175)(0.5)(2), or 175 people.

The total number of people to be evacuated during the a.m. peak hour is the sum of these three components, or 1,575 people. During the p.m. peak hour, the corresponding numbers are 400 inbound, 800 outbound, and 1,015 platform, for a total of 2,215 people.

The greatest exiting or entering volumes under typical daily conditions occur during the a.m. peak hour. The greatest number of people that may need to be evacuated occurs during the p.m. peak hour.

Stairway Width

Exhibit 7-7 gives stairway pedestrian flows of 7 to 10 p/ft/min for a design LOS "C." Because the users are commuters, the high end of the range can be used, resulting in the following stairway width:

$$\text{Stairway width} = \frac{1{,}120\text{ p}}{15\text{ min} \times 10\text{ p/ft/m}} = 7.5\text{ ft (90 in.)}$$

As the exiting volume is split between two stairways, each stairway would only need to be about 45 in. wide to serve exiting flows. An additional 30 in. should be provided to accommodate the small number of entering passengers, resulting in a total width of 75 in. for each stair.

Because escalators are being provided to supplement the stairs, the stairs would only be totally used in the event of unscheduled maintenance, power failures, or similar situations. Maximum stair capacity, or LOS "E," could be used:

$$\text{Stairway width} = \frac{1{,}120\text{ p}}{15\text{ min} \times 17\text{ p/ft/m}} = 4.4\text{ ft (53 in.)}$$

Dividing the result by two (because there are two stairways), and adding 30 in. to accommodate the small reverse flow, results in a total width of 57 in., which could be rounded up to the nearest foot (60 in.). Either width is greater than the NFPA minimum for an exit stair (44 in.).

Under emergency evacuation conditions, 2,215 people would need to be evacuated from the platform within 4 minutes. One of the four escalators should be assumed to be out of service. A stopped escalator can serve 1.59 p/in/min in the up direction, according to the NFPA 130 standard;(R11) thus a 40-in. escalator can serve (40 in.)(1.59 p/in./min), or 63 p/min. In 4 minutes, three escalators could serve (4 min)(3 escalators)(63 p/min/escalator), or 756 people, leaving 1,459 people to be served by stairs. The total stairway width required to serve these people in 4 minutes is:

$$\text{Stairway width} = \frac{1{,}459\text{ p}}{4\text{ min} \times 1.59\text{ ped/in./m}} = 229\text{ in. (19.1 ft)}$$

The Results

Two 10-foot stairways would be required. Evacuation needs, in this case, control the stairway size.

Although not addressed in this example problem, the evacuation capacity of the routes from the station's mezzanine level to the surface would also need to be evaluated. Further, the maximum time required for a passenger to reach a point of safety (generally either the surface or a point beyond fire doors) would need to be evaluated. The NFPA 130 standard provides example calculations for these situations.

Example Problem 3

The Situation

A new rail station will be constructed below grade with a mezzanine and a single center platform. The initial concept for the platform level is to connect it to the mezzanine at two locations: at one end of the platform and halfway down the platform. A pair of double-width (40-in.) escalators with a stairway in between would be located at each platform access point. One elevator between each level would also be provided. Each stair will be 10 feet wide.

The Questions

Based on the estimated demand under typical peak 15-minute conditions, how wide should the platform be? What would the capacity of the platform be to handle delayed train conditions?

The Facts

- For the design year, four-car trains are expected to run at 7 to 8 minute headways (i.e., 8 trains/hour/direction). Each car will be 75 feet long and will have a maximum schedule load of 200 persons.
- The a.m. peak hour exiting and entering demands are estimated to be 3,200 passengers per hour. The corresponding a.m. peak hour entering demand is estimated to be 500 p/h. The estimated p.m. peak hour demands are 2,900 p/h entering and 500 p/h exiting.
- During the peak 15 minutes of the a.m. peak hour, the average inbound train entering the station will have 700 passengers on board, while the average outbound train will have 300 passengers on board. During the peak 15 minutes of the p.m. peak hour, the average inbound train entering the station will have 200 passengers on board, and the average outbound train will have 500 passengers on board.
- The average peak hour factor currently observed on the system is 0.714.

Comments

LOS "C" is a reasonable design level for a station under typical daily conditions. The NFPA 130 standard(R11) is conservative in its assumptions of the number of people that will need to be evacuated. The number of people that should be designed for includes:

- The loads of one train on each track during the peak 15 minutes, assuming each train is running one headway late (i.e., is carrying twice its normal load, but no more than a full [maximum schedule] load); and
- Passengers waiting on the platform to board trains during the peak 15 minutes, assuming their trains are running one headway late.

Steps

Design Periods

Peak-hour volumes should be converted to peak 15-minute volumes by multiplying by the peak hour factor:

$$P_{15} = \frac{P_h}{4(PHF)}$$

For example, the peak-15-minute exiting volume during the a.m. peak hour is:

$$P_{15} = \frac{3{,}200}{4(0.714)} = 1{,}120 \text{ p}$$

The corresponding peak-15-minute entering volume is 175 passengers during the a.m. peak hour. During the p.m. peak-15-minute period, 1,015 passengers will be entering and 175 passengers will be exiting.

The number of people that may need to be evacuated is based on the train loads and passengers waiting to board. During the a.m. peak hour, this number is calculated from the following:

- *Inbound train*: an average train carries 700 people during the peak 15 minutes. A train operating one headway late would have a demand of twice this number, or 1,400 people, but only 800 of those people (the maximum schedule load of a four-car train) would have been able to board the train.
- *Outbound train*: an average train carries 300 people during the peak 15 minutes. A train operating one headway late would have a demand of twice this number, or 600 people, which is less than the train's capacity.
- *Waiting on platform*: At an average headway of 7.5 minutes between trains in a given direction, up to half of the entering volume during the peak 15 minutes typically would be present if the trains arrived on schedule. However, the design should assume that the trains are one headway late and, therefore, twice the typical number of waiting passengers should be used. This results in (175)(0.5)(2), or 175 people.

Platform Size

Since arrivals exceed departures at the station in the morning and departures exceed arrivals in the evening, the peak platform condition in the station will be in the p.m. peak period when passengers are queuing on the platform to wait for trains. Therefore, the platform analysis will focus on that period. The steps given in the section on sizing platforms will be followed:

1. *Choose a design pedestrian space.* To achieve LOS "C," at least 7 ft²/p is required for queuing space (from Exhibit 7-8) and at least 15 ft²/p is required for walking space (from Exhibit 7-3).
2. *Adjust as appropriate for passenger characteristics.* No special characteristics (e.g., passengers with luggage) were identified; therefore, no adjustment is made in this case.
3. *Estimate the maximum passenger queuing demand for the platform.* Under typical conditions, with trains running on schedule, up to 507 passengers would be on the platform when trains arrived. (A total of 1,015 people enter the station during the peak p.m. 15 minutes, two trains arrive in each direction during the 15 minutes, and thus one-half of 1,015 people could be present.)
4. *Calculate the required waiting space.* Multiplying 507 passengers by 7 ft²/p results in a required area of 3,549 ft² under typical conditions. At the end of this process, non-typical conditions will be checked to make sure overcrowding will not occur.
5. *Calculate the additional walking space required.* Circulation area is required for arriving passengers to walk to the platform exits. This passenger demand is highly peaked, corresponding to individual train arrivals. During the p.m. peak 15 minutes, approximately 175 passengers will arrive on four trains. Approximately 70% of these passengers (500/700) will arrive on the two

outbound trains, or about (175)(0.7)/2 = 61 passengers per outbound train. At an LOS "C" flow of 15 ft^2/p, and assuming that three-quarters of the passengers from each train would be on the platform simultaneously results in total walking area of (61)(0.75)(15), or 686 ft^2.

6. *Calculate the queue storage space required for exit points.* From Exhibit 7-20, the capacity of a double-width escalator is 68 p/min at a typical incline speed of 90 ft/min. As two up escalators will be provided, the capacity provided (136 p/min) is much greater than the maximum p.m. peak demand (58 p/train); thus no queue should develop. See Example Problem 4 for an example of how to calculate queue storage space.
7. *Consider the additional platform space that will be unused.* A typical rail transit car has multiple doors along its length, minimizing dead areas. However, an underground station with a center platform will have other unused platform space, including elevator shafts, stairs and escalators, benches, and potentially advertising or information displays, trash cans, or pillars. In this case, a total of 550 ft^2 will be assumed to be used by the central stairs and escalators, the elevator shaft, and assorted benches and displays.
8. *Calculate the required buffer zone.* A buffer 1.5 ft wide is required on each side of the platform. Since the platform needs to be 300 ft long to accommodate a four-car train, and buffers are required on both sides of a center platform, this results in a total of 900 ft^2.
9. *Calculate the total platform area.* Adding up the results of steps 4 through 8, and rounding, results in a 5,685 ft^2 platform area for LOS "C" conditions.

Based on the initial design concept, the platform would need to be at least 31 feet wide to accommodate the central stairs (10 ft, from above) and escalators (5 ft each), a 4-ft walkway on either side, and a 1.5-ft buffer zone adjacent to each track. This would result in a total platform area of 9,300 ft^2, which is much more than is required. (The tracks would typically be parallel through the station, to avoid creating gaps between the cars and the platform at the car doors.) The width could be reduced by placing the platform exit and entry escalators and/or the stairs in separate locations along the platform length.

The platform size can also be evaluated for non-typical situations. For example, if there was a disruption in service, how long would it take for the platform to become overcrowded? Based on the initial design concept, a total of (9,300 – 900 – 550 – 686), or 7,164 ft^2 of space is available for queuing passengers, while leaving circulation space available for arriving passengers. A typical minimum design value for passenger waiting areas is 5 ft^2/p, which allows passengers to wait without touching one another. At this level of crowding, 1,432 people could be accommodated on the platform. This is about 40% higher than the peak 15-minute entering demand. At a minimally tolerable crowding level of 3 ft^2/p, about 2,388 people could be accommodated, representing about 80% of the p.m. peak hour entering demand. However, most passengers would find this amount of crowding to be uncomfortable, and it is greater than the design evacuation load of 2,215 people calculated in the previous example problem (note that this design load evacuation load includes 1,400 passengers requiring evacuation from trains). The transit agency should plan to limit platform access under either circumstance to limit the amount of crowding.

The Results

The initial design concept appears to produce a wider platform than required to accommodate either typical or non-typical conditions. Alternative designs could involve spreading out the exit points to narrow the platform; this would also have the benefit of shortening the distance to the nearest platform exit.

Example Problem 4

Derived from a problem in Fruin.(R6)

The Situation

A subway platform on an urban heavy rail line will be modified to install an up direction escalator at the center of a subway platform.

The Question

What is the pedestrian queuing and delay for the proposed installation?

The Facts

- Field counts of passengers discharged by the subway trains show that maximum traffic occurs during a short micro-peak, when two trains arrive within 2 minutes of each other, carrying 225 and 275 passengers, respectively.
- The remaining trains in the peak period are on 4-minute headways.
- The platform is 275 meters long, and 4.6 meters wide.
- Field observations of other subway stations in this city with similar passenger volumes reveal a maximum escalator capacity of 100 p/min (for the assumed 36.6 m/min, 1-meter-wide escalators in this example), as opposed to the nominal capacity of 90 p/min/minute given in Exhibit 7-20.

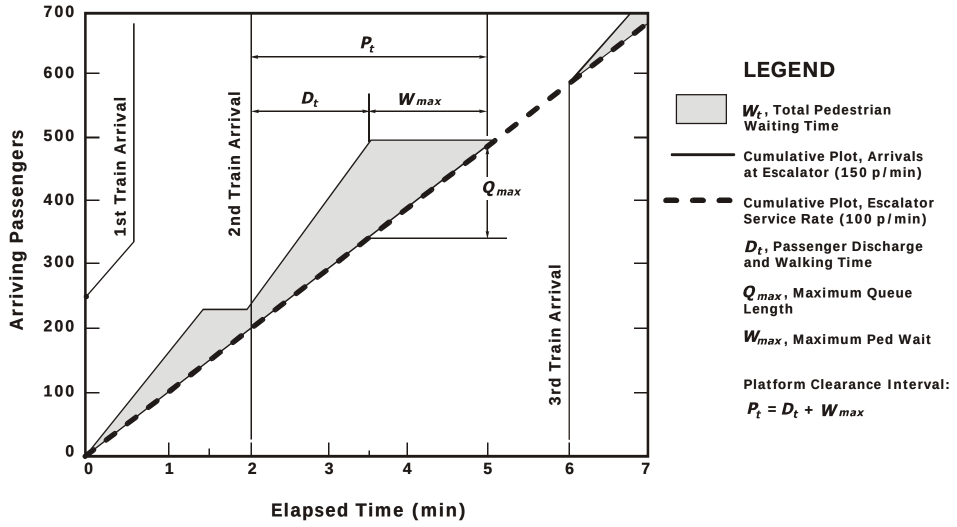
Steps

Construction of the Time Clearance Diagram

1. A graph is constructed (see the figure on the next page), with time, in minutes, as the horizontal axis, and pedestrians as the vertical axis.
2. The escalator capacity of 100 p/min is then drawn (dashed sloped line).
3. The arrival rate at the escalator is a function of the train discharge time and walking time required to reach the escalator. If it is assumed that pedestrians are discharged uniformly along the length of the platform and the escalator is located in the center of the platform, arrival time can be approximately represented on the clearance diagram by determining the time required to walk half the platform length. A commuter walking speed of 91.4 m/min (300 ft/min) is used in this example.

$$\text{Total arrival time} = \frac{\text{1/2 platform length}}{\text{average walking speed}} = \frac{137.5\text{ m}}{91.4\text{ m/min}} = 1.5\text{ min}$$

The two train arrivals, with 225 and 275 passengers, are plotted as solid lines on the diagram.



Maximum Queue Size and Maximum Wait

Assuming that all the passengers will use the escalator and not the stairs, the clearance diagram illustrates a number of significant facts. The shaded area between the pedestrian arrival rate (solid line), and the escalator service rate (dashed line), represents *total waiting time*.

Dividing the waiting time area by the number of arriving passengers gives *average passenger waiting time*. The maximum vertical intercept between these two lines represents *maximum passenger queue length*. The maximum horizontal intercept represents the *clearance interval* of the platform.

The clearance diagram shows that a maximum queue size of 75 persons would be generated by the first train arrival, if all persons seek escalator service. It also shows that 25 persons will still be waiting for the escalator service when the next train arrives.

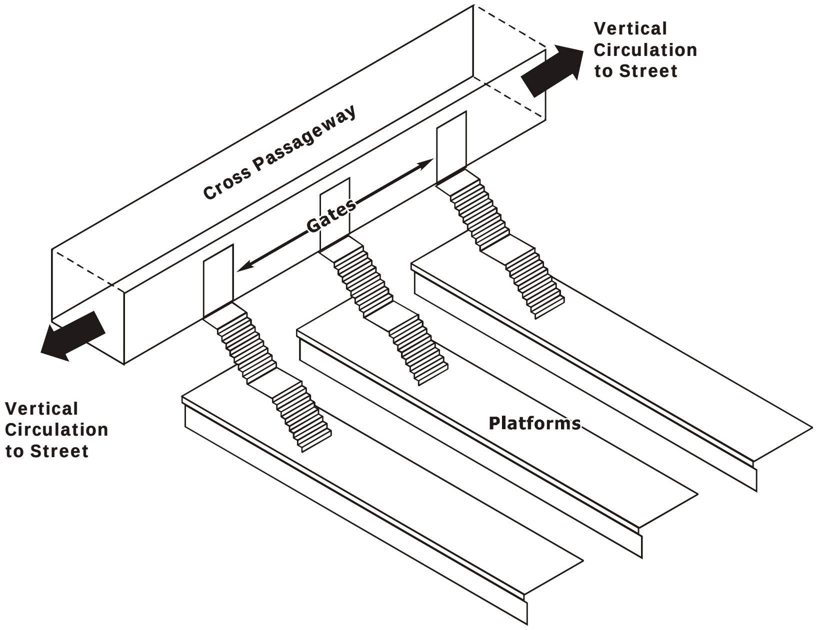
The maximum waiting time for escalator service after the first train arrival is 1 minute. The average passenger waiting time is 15 seconds. After the second train arrival, the maximum waiting and maximum queue size builds up to 1.5 minutes and 150 passengers, respectively. If it is assumed that passengers will divert to the stairs if the maximum escalator wait exceeds 1 minute, a 1-minute-wide horizontal intercept on the graph shows that maximum queue size will not likely get larger than 50 persons. This is about the limit observed for low-rise escalators of this type, where alternative stationary stairs are conveniently available.

Example Problem 5

Derived from a problem in Benz.(R2)

The Situation

A new cross passageway (depicted below) will provide access to and from the ends of platforms at a busy commuter rail terminal that currently has access at one end only. The passageway is essentially a wide corridor that will run perpendicular to and above the platforms, with stairs connecting the passageway to each platform. The cross passageway is connected to the surface at several points.



The Question

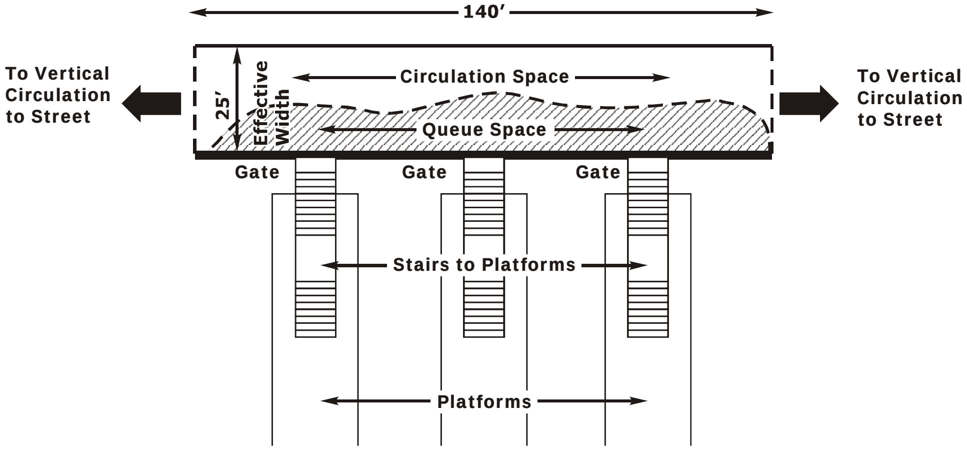
Can the corridor meet the space requirements of both queuing passengers and circulating passengers within a portion of the cross passageway adjacent to a departure gate?

The Facts

- Surveys at the station show that passengers departing on trains typically start to gather in front of a gate about 23 minutes before the train's scheduled departure time and assemble at the following rates:

Time Before Departure (min):	20	15	10	5	1
Departing Passengers (% gathered):	9	26	53	86	100

- The maximum accumulation of passengers outside the gate to the train platform occurs just before the opening of the gate—typically 10 minutes before train departure when 53% of the passengers leaving on the train are present. The accumulation of waiting passengers, if large enough, can easily affect the cross passageway width available to handle longitudinal flow.
- As shown in the figure on the next page, the cross passage way is 140 ft long with an effective width of 25 ft (i.e., the width actually available for passenger activities: the wall-to-wall dimension minus the width occupied by obstructions and columns and the boundary or "cushion" maintained by pedestrians along walls). During the 1 minute before the opening of the departure gate, 194 people will be waiting in the cross passageway. The flow rate of people walking along the corridor during this time is 167 p/min.



Comments

- The problem is to examine whether the corridor can meet the space requirements of both queuing passengers and circulating passengers within a portion of the cross passageway adjacent to a departure gate.
- The analysis period is the 1 minute before the opening of the gate when the maximum accumulation of waiting passengers will occur.

Steps

With a design criterion of LOS "B," the average pedestrian queuing area is 10 ft^2/ped (see Exhibit 7-8). This classification reflects the unordered (random) nature of the queue in this space, the need for some circulation and movement within the queue, and the comfort level expected by commuter rail passengers. The 194 people waiting will require:

$$194 \text{ p} \times 10 \text{ ft}^2/\text{p} = 1{,}940 \text{ ft}^2$$

The shape of the queue has to be estimated in order to determine the portion of the 25-ft-wide cross passageway that the queue will occupy. For this example, the waiting passengers, occupying 1,940 ft^2 are assumed to be evenly distributed along the 140-foot linear dimension of the space. Therefore, the queue is expected to require the following width at the widest point:

$$\frac{1{,}940 \text{ ft}^2}{140 \text{ ft}} = 13.9 \text{ ft}$$

This leaves 11.1 feet available for the flow of the 167 circulating passengers who would walk through the cross passageway during the 1-minute peak queue period. The unit width flow rate available is:

$$\frac{167 \text{ p/min}}{11.1 \text{ ft}} = 15.0 \text{ p/ft/min}$$

The Results

From Exhibit 7-3, this identified pedestrian flow rate equates to LOS "C" to "D." In this level of service range, walking speeds and passing abilities are becoming restricted but are generally considered adequate for peak period conditions. There will be some conflicts between opposing pedestrian traffic streams.

Derived from a study of Town Hall Station in Sydney, NSW, Australia.

Example Problem 6

The Situation

A complex urban rail transit station currently experiences congestion during peak periods and is expected to witness significant ridership growth over the next 20 years. Various improvement and expansion schemes will be developed and tested to increase the capacity of the station and improve passenger comfort and convenience.

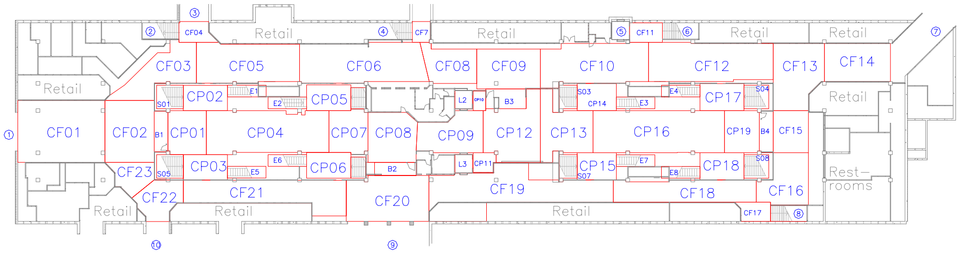
The Question

In order to identify potential improvements within the station, it is desirable to identify congested areas throughout the station, both on the platforms and on vertical circulation elements. Alternate station improvement and expansion schemes would then be laid out and tested in the same manner as the existing configuration.

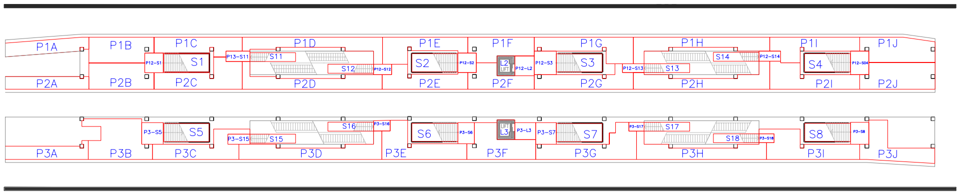
The Facts

- The station has three levels underground: a concourse level and two platform levels that each have two platforms and three tracks. As shown in the following figure, the concourse level includes a paid area surrounded by a free area lined with narrow retail establishments. The second figure shows the upper platform level with vertical circulation passing through to reach the lower platform level. On each level one platform operates as an island serving two tracks and the other serves the third track.
- Because the station is an important transfer point, it experiences significant numbers of transfers, including same-track and cross-platform transfers, and transfers requiring changes between platforms and levels.
- Extensive surveys have been conducted to count the number of people passing through each entrance and using each vertical circulation element. Passenger interviews have been conducted to identify patterns of movement between platforms and the various access points and transfers within the station.

Station Concourse



Upper Platform Level



Approach

The station is subdivided into discrete circulation zones including areas of the concourse and platform levels and each of the vertical circulation elements. Zones and their identifying codes are shown in the concourse and platform plans on the previous page. Extensive spreadsheets are used to assign peak-period pedestrians moving between distinct origin and destination points within the station to routes that either pass through or stay within each zone within the station. Additional spreadsheets organize data on the area of each zone, distinguish between persons walking and standing in each zone, and calculate levels of service in each zone.

Due to the extensive nature of this type of analysis, which is only practical with large spreadsheet models, this example presents the sequence of spreadsheets applied to the task without showing the lengthy formulas, which, due to extensive cross-referencing of tables, are only meaningful in the spreadsheet environment.

Steps

Analysis is conducted on a series of custom spreadsheets as follows:

Pedestrian Volumes by Origin and Destination

The station has a total of 16 possible origins and destinations, comprising six platforms and ten external access/egress points. A pedestrian volume worksheet presents existing or future forecast volumes between any combination of the 16 origin/destination (O/D) points and any other, including those who transfer from platform to platform and pedestrians who enter the free area of the concourse, but do not enter the station. Allowance is also made for those who may transfer to a different train on the same platform or enter and leave the concourse by the same door, as a person might do when visiting one of the shops on the concourse.

The data is input into the model in the form of a.m. and p.m. peak 5-minute origin-destination matrices.

Routing Assignment

This worksheet includes an assignment by percent of people traveling between each of the 16 origins and destinations (256 combinations) to any of the 171 elements or zones (resulting in 43,776 assignment cells). Due to a change in direction of two escalators from the morning to the evening and different use of ticket gates at one entrance, different assignments are needed for each period. Additional modified routing assignment tables are required to analyze any proposed physical changes to the station.

Walk Volumes

This worksheet calculates the pedestrian volumes passing through each zone by multiplying the origin and destination volumes with the percentage assignment for each zone.

Walk Time

This worksheet includes the approximate time in seconds to walk through each analysis zone. Different walk times through a zone, representing different paths, can be associated to each origin and destination pair. The three typical choices are (1) the full length of the zone, (2) half the length, either as an average for people who end their walk in the zone or cut through it diagonally, or (3) a cross measurement that may be used for particular routes across some zones. Walk time is calculated based on distance in feet or meters divided by an assumed walking speed of 4.0 ft/s (1.2 m/s).

Dwell Percent

This worksheet indicates the percent of pedestrians passing through a particular zone that dwell within that zone, either to wait for a train, to purchase a ticket, to make a purchase, or for other purposes. No dwell time is assumed on stairs, escalators, or fare control barriers but may be applied to the zones approaching these elements.

Dwell Time

This worksheet includes an average time in seconds that pedestrians who dwell in a zone spend there. On platforms it is related to train headways. On a system with very frequent service where people do not time their arrivals, this will generally be half the average headway. On a system with less frequent service where passengers time their arrivals to a train schedule, it will generally be less than half of the average headway. Appropriate times are also assigned for ticketing, browsing, or other dwell activities based on observations. A function based on volumes through circulation elements (turnstiles, stairs, escalators) representing crowding at the approach to these circulation elements may be added to this worksheet. The dwell time for the zones prior to the circulation elements, at the base of escalators and stairs, is based on a function related to the capacity of the element. When the circulation element tends toward capacity, the dwell times in the prior zones are increased by the formula.

Time-Space Demand

The demand for walk time-space is calculated for each analysis zone by multiplying pedestrian volumes in each zone by the walk time required and by an assumed design standard of 1.4 m^2 per person. The demand for dwell time-space is calculated by multiplying pedestrian volumes in each zone by the dwell percent, the average dwell time, and an assumed dwell space of 0.65 m^2 per person. The two are totaled for a combined time-space demand in each zone.

Level of Service

The operating condition of each zone is assessed by levels of service. Design capacity for all elements is considered to be the break point between LOS "C" and "D." In order to calculate an LOS from a combination of walking and standing, the time-space demand is converted into a volume-to-*design* capacity ratio for each zone or element that is proportional to the LOS standards, as shown in the following table.

	Volume-to-Design Capacity Ratios	
Level of Service	**for Walk/Standing Zones**	**for Escalators/Fare Controls**
LOS A	< 0.4	< 0.6
LOS B	0.4 – 0.6	0.6 – 0.8
LOS C	0.6 – 1.0	0.8 – 1.0
LOS D	1.0 – 1.5	1.0 – 1.1
LOS E	1.5 – 2.8	1.1 – 1.2
LOS F	2.8 +	1.2 +

NOTE: Ratios have no units and may be applied with any units of measure.

The Results

The product of this analysis is an LOS for each platform or mezzanine zone and each stairway, and a volume-to-capacity ratio for each fare control array and escalator. To provide a spatial representation of passenger congestion, station plans can be colored based on the rating for each zone using a geographic information system or other graphic software. By using a suitable range of colors to represent free-flow to congested conditions, the relative congestion of areas throughout the station can be observed.

APPENDIX A: EXHIBITS IN METRIC UNITS

Exhibit 7-1m
Pedestrian Speed on Walkways[(R6)]

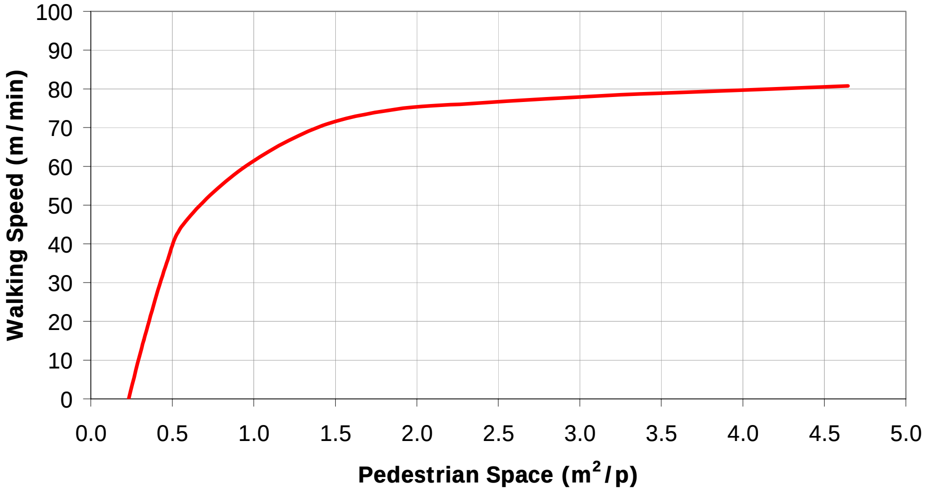


Exhibit 7-2m
Pedestrian Flow on Walkways by Unit Width and Space[(R6)]

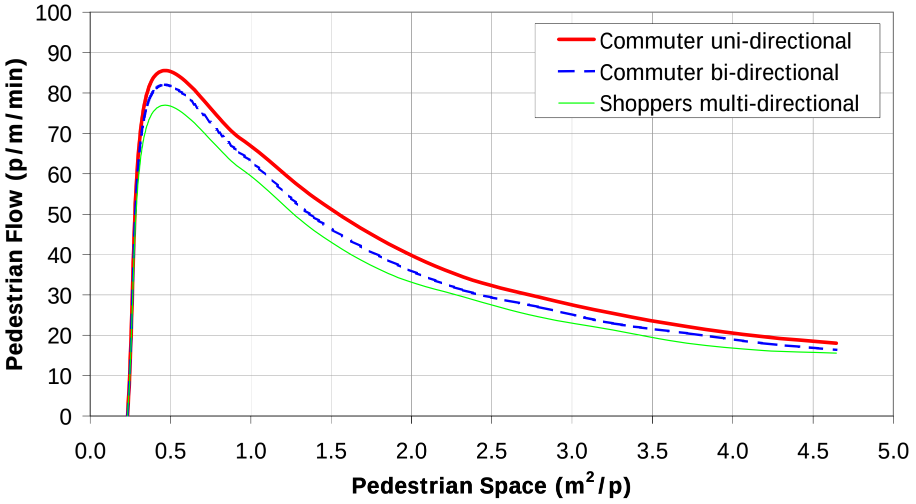


Exhibit 7-5m
Pedestrian Ascent Speed on Stairs[(R6)]

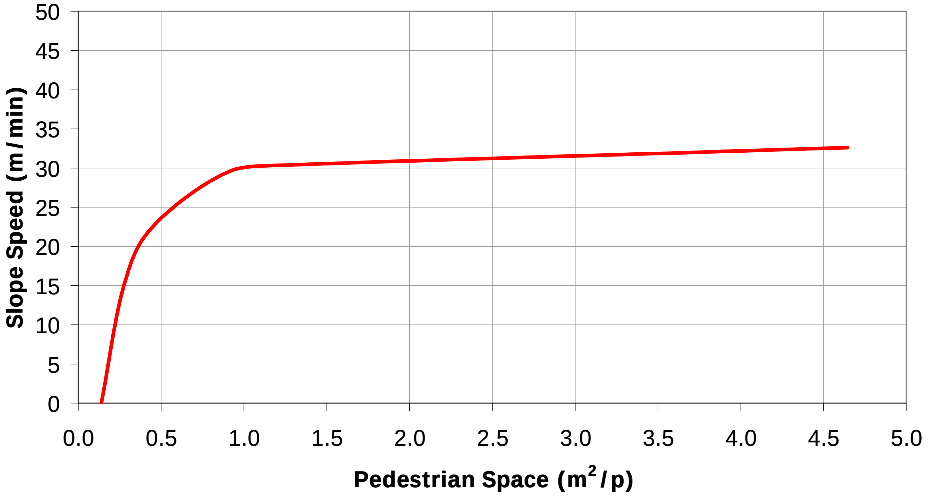
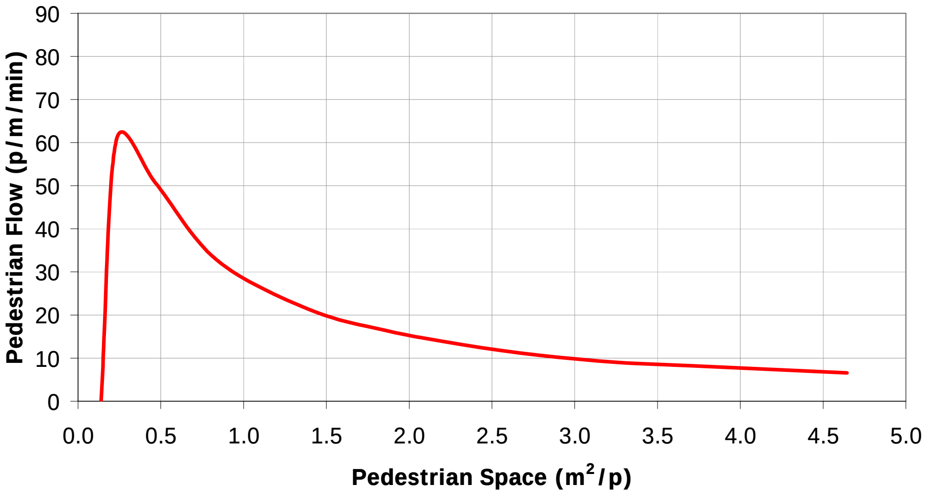


Exhibit 7-6m
Pedestrian Flow Volumes on Stairs(R6)



PART 8
GLOSSARY

This part of the manual presents definitions for the various transit terms discussed and referenced in the manual. Other important terms related to transit planning and operations are included so that this glossary can serve as a readily accessible and easily updated resource for transit applications beyond the evaluation of transit capacity and quality of service. As a result, this glossary includes local definitions and local terminology, even when these may be inconsistent with formal usage in the manual.

Many systems have their own specific, historically derived, terminology: a motorman and guard on one system can be an operator and conductor on another. Modal definitions can be confusing. What is clearly light rail by definition may be termed streetcar, semi-metro, or rapid transit in a specific city. It is recommended that in these cases local usage should prevail.

AADT—accessibility, transit

A

AADT — annual average daily traffic; see *traffic, annual average daily.*

AAR — Association of American Railroads; see *organizations, Association of American Railroads.*

AASHTO — American Association of State Highway and Transportation Officials; see *organizations, American Association of State Highway and Transportation Officials.*

AAWDT — annual average weekday traffic; see *traffic, annual average weekday.*

ABS — automatic block signal; see *control system, automatic block signal.*

AC — alternating current.

ADA — Americans with Disabilities Act of 1990; see *legislation, Americans with Disabilities Act of 1990.*

ADB — advanced design bus; see *bus, advanced design* and *ATTB.*

ADT — average daily traffic; see *traffic, average daily.*

ATTB — Advanced Technology Transit Bus.

AFC — automatic fare collection; *see fare collection system, automatic.*

AGT — automated guideway transit; automated guided transit; see *transit system, automated guideway.*

ALRT — advanced light rail transit, see *transit system, light rail.*

APC— automatic passenger counter.

APM — automated people-mover, see *people-mover.*

APTA — American Public Transportation Association; see *organizations, American Public Transportation Association.*

APTS — Advanced Public Transportation Systems.

ATC system — automatic train control system.

ATIS — Advanced Traveler Information Systems.

ATO — automatic train operation.

ATP — automatic train protection.

ATS — automatic train supervision; automatic train stop system.

ATU — Amalgamated Transit Union; see *union, transit.*

AVL — automatic vehicle location system.

AW0, AW1, AW2, AW3 — see c*ar, weight designations.*

absolute block — see *block, absolute.*

absolute permissive block — see *block, absolute permissive.*

acceleration — increase in velocity per unit time; in transit, usually measured in feet per second squared (meters per second squared) or, in the United States, sometimes in miles per hour per second.

access, limited (controlled access) — in transportation, to have entry and exit limited to predetermined points, as with rail rapid transit or freeways.

accessibility — **1.** A measure of the ability or ease of all people to travel among various origins and destinations. **2.** In transportation modeling and planning, the sum of the travel times from one zone to all other zones in a region, weighted by the relative attractiveness of the destination zones involved. **3.** In traffic assignment, a measure of the relative access of an area or zone to population, employment opportunities, community services, and utilities.

accessibility, persons with disabilities (full accessibility) — the extent to which facilities are free of barriers and usable by persons with disabilities, including wheelchair users.

accessibility, station — a measure of the ability of all people within a defined area to get to a specific transit station.

accessibility, transit — **1.** A measure of the availability to all people of travel to and from various origins and destinations by transit. **2.** A measure of the ability of all people to get to and from the nearest transit stop or station and their actual origin or destination. **3.** In common usage, often used to mean the ability of persons with disabilities to use transit.

accessible station — see *station, accessible.*

accessible vehicle — see *vehicle, accessible.*

accessible transit system — see *transit system, accessible.*

accessible transportation facilities — transportation facilities that are barrier-free, allowing their use by all travelers, including, elderly, transportation disadvantaged, and persons with disabilities.

access mode — see *mode, access.*

access time — see *time, access.*

active vehicle — see *vehicle, active.*

activity center — see *major activity center.*

act — see *legislation.*

add fare — **1.** an additional fare to upgrade an existing ticket. **2**. an additional fare paid on exit from a distance based fare system when there are insufficient funds remaining on a stored value ticket, see also *fare, differential*.

adult cash fare — see *fare, adult cash.*

advanced design bus — see *bus, advanced design.*

Advanced Public Transportation Systems — collection of technologies to increase efficiency of public transportation systems and offer users greater access to information on system operation.

Advanced Railroad Grade Crossing — National ITS Architecture Market Package that manages highway traffic at *highway-rail intersections* where operational requirements demand advanced features (e.g., where rail speeds are greater than 80 mph or 128 km/h). It includes all capabilities from the *Standard Railroad Grade Crossing Market Package* and augments these with additional safety features to mitigate the risks associated with higher rail speeds.

Advanced Traveler Information Systems — technologies that provide travelers and transportation professionals with the information they need to make decisions, from daily individual travel decisions to larger-scale decisions that affect the entire system, such as those concerning incident management.

advisory committee — see *organizations, citizen advisory committee.*

aerial lift — ropeways on which passengers are transported in cabins or on chairs and that circulate in one direction between terminals without reversing the travel path.

aerial structure — in transportation, any structure other than a culvert that carries a roadway or track or other guideway above an earth or water surface; see also *guideway, elevated.*

aerial tramway — ropeways on which passengers are transported in cable-supported carriers and are not in contact with the ground or snow surface, and in which the carrier(s) reciprocate between terminals. Also called a *reversible tramway.*

agencies, federal — see *U.S. Government.*

agency, regional planning — see *organizations, regional planning agency.*

agency, transit — see *transit district.*

air brake — see *brake, air;* and *brake, automatic air.*

air distance — see *distance, air.*

alight — to get off or out of a transportation vehicle.

alignment — in transportation, the horizontal and vertical layout of a roadway, railroad, transit route, or other facility as it would appear in plan and profile. The alignment is usually described on the plans by the use of technical data, such as grades, coordinates, bearings, and horizontal and vertical curves, see also *roadbed* and *formation.*

all-or-nothing trip assignment — see *trip assignment, all-or-nothing.*

all-stop station — see *station, all-stop.*

alternate fuel — alternatives to conventional diesel fuel for urban transit buses, intended to reduce pollution, includes methanol, propane, CNG (compressed natural gas), LNG (liquefied natural gas), hydrogen (for fuel cells) and biomass derived fuels. All carry premium costs that trend in larger or more cost-conscious operators toward "clean diesel" solutions. See also *buses, hybrid.*

alternating-current motor — see *motor, alternating-current.*

alternative fuel — see *fuel, alternative.*

Amalgamated Transit Union — see *union, transit.*

amenity, passenger — see *passenger amenity.*

American Association of State Highway and Transportation Officials — see *organizations, American Association of State Highway and Transportation Officials.*

American Public Transit Association — see *organizations, American Public Transportation Association.*

American Public Transportation Association — see *organizations, American Public Transportation Association.*

a.m. peak — see *peak.*

Amtrak — see *U.S. Government, National Railroad Passenger Corporation.*

annual average daily traffic — see *traffic, annual average daily.*

annual average weekday traffic — see *traffic, annual average weekday.*

area, auto-free — see *auto-free zone.*

area, auto-restricted — see *auto-restricted zone.*

area, coverage — in transit operations, the geographical area that a transit system is considered to serve, normally based on acceptable walking distances (e.g., ¼ mile, 0.4 km) from loading points. For suburban rail transit that depends on automobile access (park-and-ride or kiss-and-ride), coverage may extend several miles (kilometers). Coverage is usually computed for *transit-supportive areas.* See also *area, service.*

area, fare paid — **1.** An area that a passenger may enter only after having paid a fare or with proper credentials. **2.** The area in a station that is set off by barriers, gates, or other structures to permit ready access to transit only by those who have paid fares or secured passes before entering.

area, free — a portion of a transportation facility that people are permitted to enter without the payment of a fare.

area, fringe — the portion of a municipality immediately outside the central business district or the portion of an urban area outside of a central city or cities (urban fringe) that is characterized by a variety of business, industrial, service, and some residential activity.

area, loading — see *loading area.*

area, service — **1.** The jurisdiction in which the transit property operates. **2.** The geographic region in which a transit system provides service or that a transit system is required to serve. See also *area, coverage.*

area, transit-supportive — an area with sufficient population and/or employment density to warrant at least hourly fixed-route transit service.

area, urbanized (UA) — as defined by the Bureau of the Census, a population concentration of at least 50,000 inhabitants, generally consisting of a central city and the surrounding, closely settled, contiguous territory *(suburbs).* The boundary is based primarily on a population density of at least 1,000 people/mi^2 (370 people/km^2) but also includes some less densely settled areas, as well as such areas as industrial parks and railroad yards, if they are within areas of dense urban development. The boundaries of UAs, the specific criteria used to determine UAs, or both may change in subsequent censuses. It should be noted that some publications abbreviate urbanized area *UZA.*

area occupancy — in station and other facility design and in pedestrian movement, the area provided per person.

arterial roadway — a signalized street that primarily serves through traffic and secondarily provides access to abutting properties; signal spacing is typically 2 miles (3 km) or less.

arterial service — see *service, arterial.*

articulated bus or articulated trolleybus — an extra-long, high-capacity bus or trolleybus that has the rear body section or sections flexibly but permanently connected to the forward section. The arrangement allows the vehicle to bend in curves and yet have no interior barrier to movement between the two parts. The *puller* type features a powered center axle while the *pusher* type features a powered rear axle. Articulated buses with powered center and rear axles exist but are not common. Typically, an articulated bus is 54-60 ft (16-18 m) long with a passenger seating capacity of 60 to 80 and a total capacity of 100 to 140.

articulated rail vehicle (articulated car) — **1.** An extra-long rail vehicle with two or more bodies connected by joint mechanisms that allow bending in curves yet provide a continuous interior Typically, the vehicle is 55-100 ft (17-33 m) long. It is common on light rail but is also found on several heavy rail systems. **2.** Rapid transit cars with separate bodies that share a common center truck.

aspect, signal — see *signal aspect.*

assignment, traffic or trip — see *trip assignment.*

Association of American Railroads — see *organizations, Association of American Railroads.*

attendant — the individual assigned to particular duties or functions in the operation of a ropeway. Also called a *conductor*.

attraction, trip — see *trip attraction*.

attributes, service — see *service attributes.*

authority, transit — see *transit district.*

automated guideway transit — see *transit system, automated guideway.*

automated people-mover — see *people-mover.*

automatic block signal — see *signal, automatic block.*

automatic block signal control system — see *control system, automatic block signal.*

automatic coupler — see *coupler, automatic.*

automatic fare collection — see *fare collection system, automatic.*

automatic passenger counter (APC) — an automated system that counts the number of passengers boarding and alighting a transit vehicle. The information may used for later data analysis, or for real-time activities, such as providing signal priority only to buses that are at least half full.

automatic signal — see *signal, automatic.*

automatic train control system (ATC system) — **1**. A system for automatically controlling train movement, enforcing train safety, and directing train operations by computers; see also *automatic train operation, automatic train protection,* and *automatic train supervision.* **2.** A trackside system working in conjunction with equipment installed on the train, arranged so that its operation will automatically result in the application of the brakes to stop or control a train's speed at designated restrictions, should the operator not respond. The system usually works in conjunction with cab signals (more correctly called *automatic train stop*).

automatic train operation (ATO) — the subsystem within automatic train control that performs such functions as speed control, programmed stopping, and (sometimes) door operation.

automatic train protection (ATP) — the subsystem within automatic train control that provides fail-safe protection against collisions, and sometimes against excessive speed or other hazardous conditions.

automatic train stop system (ATS) — a system that works in conjunction with equipment installed on the electric rail car or locomotive to apply the brakes at designated restrictions or on a dispatcher's signal, should the operator not respond properly.

automatic train supervision (ATS) — the subsystem within automatic train control that monitors trains, adjusts the performance of individual trains to maintain schedules, and provides data for adjusting service to minimize the inconveniences otherwise caused by irregularities. May also be used for systems that merely display train status and rely on staff intervention for any corrective action.

automatic vehicle location system (AVL) — a system that determines the location of vehicles carrying special electronic equipment that communicates a signal back to a central control facility. AVLs are used for detecting irregularity in service and are often combined with a computer-aided dispatch system.

automobile equivalent unit (AEU) — measure of a vessel's capacity to transport vehicles that reflects the amount of space used by each vehicle type. Vehicle types are assigned a size in AEUs based on the space they occupy compared with a standard automobile.

automobile or auto occupancy — see *vehicle occupancy.*

availability, transit system — see *transit system availability.*

average daily traffic — see *traffic, average daily.*

average fare — see *fare, average.*

average speed — see *velocity, effective.*

average trip length — passenger miles divided by unlinked passenger trips. Can be computed for pedestrian trips and vehicle trips, based on special surveys.

B

barn — older term for streetcar storage building (also known as a *carhouse*), or for buses (*garage*), infrequently applied for light and heavy rail vehicles (alternates: *yard, depot, shop, maintenance and storage facility*.)

barrier-free — containing no obstacles that would prevent use by persons with disabilities or any other person.

barrier-free fare collection system — see *fare collection system, self-service barrier free.*

base fare — see *fare, base.*

base headway — see *headway, base.*

base period (off-peak period) — in transit, the time of day during which vehicle requirements and schedules are not influenced by peak-period passenger volume demands (e.g., between morning and afternoon peak periods). At this time, transit riding is fairly constant and usually moderate in volume when compared with peak-period travel. See also *off peak.*

base-period fleet — in transit, the number of transit units (vehicles or trains) required to maintain base-period schedules.

base-period service — see *service, base-period.*

basic fare — see *fare, base.*

basic operating unit — in rail rapid transit, the smallest number of rapid transit vehicles that can operate independently in revenue service, usually one to three (exceptionally more) cars.

battery bus — see *bus, electric.*

bay, bus — see *bus bay.*

beacon — short-range roadside transceiver for communicating between vehicles and the traffic management infrastructure. Common transmission technologies include microwave and infrared.

belt, passenger — see *moving walkway.*

berth, bus — see *bus bay.*

berth, ferry — see *ferry berth.*

berth, train — see *train berth.*

bicable system — an *aerial ropeway* that uses track cable(s) to support the carriers and separate haul rope(s) to control motion of the carriers (see also *monocable system*).

bicycle-friendly — characterized by features and elements that make bicycling safe and convenient. A bicycle-friendly environment at a transit stop might include bicycle parking that is well-lit, sheltered, secure, and easily accessed.

bicycle locker — a lockable, enclosed container used for storing a bicycle. Typically provided at major transit stops and stations and rented on a monthly basis.

bicycle rack — **1.** A fixed post or framework to which bicycles may be secured and locked, typically provided on a first-come, first-served basis. **2.** A device mounted to a transit vehicle that allows bicycles to be transported outside the passenger compartment. Typically provided on a first-come, first-served basis; many transit operators require that passengers obtain a permit to use them.

bidirectional car — see *car, bidirectional.*

bidirectional transit unit — see *double-ended transit unit.*

bi-level car — see *car, bi-level.*

blister — see *bus bay.*

block — **1.** A section of track or guideway of defined limits on which the movement of trains is governed by block signals, cab signals, or both; also known as a *signal block.* **2.** A section of track of defined length, the occupancy of which is regulated by fixed signal(s), telephone or radio orders, or timetables; also known as a *block section. **3.*** The daily operating schedule of a transit unit (vehicle or train) between pull-out and pull-in, including scheduled and deadhead service. A block may consist of a number of runs.

block, absolute — a signal block that no train may enter while the block is occupied by another train.

block, absolute permissive — a signal system for a single track or guideway that prevents simultaneous opposing train movements between sidings but permits following movements at a safe distance.

block, signal — a standard railroad signal system that uses a fixed signal at the entrance of a block to govern the separation of trains entering the block; see also *block.*

block control system, dynamic — see *control system, moving block.*

block control system, fixed — see *control system, fixed block.*

block control system, manual — see *control system, manual block.*

block control system, moving — see *control system, moving block.*

block indicator — a device, generally located near a turnout switch, that is used to indicate the presence of a train in the block or blocks leading to that switch.

block section — see *block.*

block signal — see *signal, block.*

block signal control — see *control system, block signal;* and *control system, automatic block signal.*

board — to go on to or into a transportation vehicle.

bollard — an upright fixed block (usually concrete) used to prevent the unauthorized or unintended entry of vehicles into an area.

brake, air — a brake in which the mechanism is actuated by manipulation of air pressure. The term is often used to describe brakes that employ air under pressure above brake atmospheric, in contrast to vacuum brakes, which employ pressure below atmospheric.

brake, blended — see *brake, dynamic.*

brake, continuous (trainlined brake) — a system of brakes interconnected among rail cars so that the brakes on all cars in the train can be operated simultaneously from the locomotive or from any car in a multiple-unit train.

brake, disc — a brake used primarily on rail passenger cars that uses brake shoes clamped by calipers against flat steel discs.

brake, dynamic (electric brake, electrodynamic brake, motor brake) — a system of electrical braking in which the traction motors, used as generators, retard the vehicle by converting its kinetic energy into electrical energy. This energy is absorbed by resistors. See also *brake, regenerative.* Dynamic brakes may be used to control train speed and to brake a train to a low speed, after which air brakes are blended in to bring the train to a full stop.

brake, electric or electrodynamic — **1.** alternate to air brake for some streetcars and light rail vehicles — most notably immediately post-war PCC cars. **2.** braking through electric motors, see *brake, dynamic.*

brake, electromagnetic — see *brake, track.*

brake, electropneumatic (pneumatic brake) — an automatic air brake that has electrically controlled valves to expedite applying and releasing the brakes.

brake, friction (mechanical brake) — a brake that presses brake shoes against the running wheel tread or pads against inboard or outboard disc surfaces.

brake, hydraulic — hydraulically operated brake typical of automotive practice, used on small buses and vans and entering use on some rail vehicles as alternate to air brake.

brake, magnetic — see *brake, track.*

brake, mechanical — see *brake, friction.*

brake, motor — see *brake, dynamic.*

brake, pneumatic — see *brake, electropneumatic.*

brake, regenerative — a form of dynamic brake in which the electrical energy generated by braking is returned to the power supply line instead of being dissipated in resistors. In rare cases the traction sub-stations can return this power to the electric utility or burn it in resistors, then the line is always receptive, eliminating on-board resistors.

brake, service — **l.** The primary train brake system. **2.** The braking rate used for normal deceleration requirements, in contrast to emergency braking, which may provide greater retardation. Typically 0.13*g*, 3.0 mph/s, or 1.3 m/s^2, a level beyond which standing passengers become uncomfortable or may loose their balance.

brake, slip-slide control — an electronic control used on most current rail vehicles to sense and correct wheel slip or slide by modulating braking or reducing acceleration.

brake, track (electromagnetic brake, magnetic brake) — a brake that consists of electromagnets suspended above the track rail between the two wheels on both sides of a truck. When applied, the brakes are attracted onto the steel rails, exerting braking force through friction. The brakes are difficult to apply gradually and so are reserved for emergencies (often from battery power) and are always supplementary to another braking system. This type of brake is used on most light rail vehicles and streetcars and on some heavy rail cars (modulated electromagnetic track brakes are used on the Vancouver SkyTrain.)

brake, trainlined — see *brake, continuous.*

brake shoe — the non-rotating portion of a tread or disc brake assembly. The shoe is pressed against the tread, disc, or drum when the brake is applied.

braking, closed loop — braking under continuous modulation by means of feedback from the train control system.

braking, emergency (emergency application) — in rail operations, applying the brakes to stop in the minimum distance possible for the equipment, usually at a higher retardation rate than that obtained with a maximum service brake application. Once the brake application is initiated, it often cannot be released until the train has stopped or a predetermined time has passed.

braking, full service — see *braking, maximum service.*

braking, maximum service (full service braking) — in rail operations, a non-emergency brake application that obtains the maximum brake rate that is normally regarded as comfortable for passengers and consistent with the design of the primary brake system.

braking, open-loop — unmodulated braking without feedback control from the train control system.

braking, programmed — automatically controlled braking that causes a train to stop or reduce its speed to a predetermined level at a designated point within a specified range of deviation.

braking rate — see *deceleration.*

braking, service (service application) — in rail operations, retardation produced by the primary train braking system at the maximum rate of retardation regarded as comfortable for repeated use in service stopping. See *brake, service* for rates.

broad gauge — see *gauge, broad.*

Broadcast Traveler Information — National ITS Architecture Market Package that provides the user with a basic set of ATIS services. It involves the collection of traffic conditions, advisories, general public transportation, toll and parking information, incident information, and air quality and weather information, and the dissemination of this information over a wide area through existing infrastructures and low-cost user equipment (e.g., FM subcarrier, cellular data broadcast).

bulb — see *bus bulb.*

bull wheel — a terminal sheave that deflects the haul rope 150 degrees or more. When under power, the sheave is referred to as a drive sheave (or drive bull wheel). When acting as a movable tensioning device, it is referred to as a tension sheave (or tension bull wheel). When it is acting simply as a fixed return for the haul rope, it is referred to as a fixed return sheave (or fixed return bull wheel).

bunching — with transit units, a situation that occurs when passenger demand is high and dwell times at stops are longer than scheduled. Headways become shorter than scheduled, and platoons of transit units (vehicles or trains) develop, with longer intervals between platoons. The same effect (one transit unit caught by the following) can also be caused by lack of protection from general road traffic congestion or by traffic signal timing. Bunching can become cumulative and can result in delay to passengers and unused capacity.

bus — a self-propelled, rubber-tired road vehicle designed to carry a substantial number of passengers (at least 16, various legal definitions may differ slightly as to minimum capacity), commonly operated on streets and highways. A bus has enough headroom to allow passengers to stand upright after entering. Propulsion may be by internal combustion engine, electric motors or hybrid; see also *alternate fuels*. Smaller capacity road transit vehicles, often without full headroom, are termed vans.

bus, advanced design (ADB) — a prototype bus, originally introduced in the mid-1970s, that incorporates new styling and design features specified by the then Urban Mass Transportation Administration.

bus, articulated — see *articulated bus or articulated trolleybus.*

bus, battery — see *bus, electric.*

bus, commuter — see *service, commuter.*

bus, cruiser — name for highway coaches used in transit service (probably a contraction of Scenicruiser or Americruiser), high floor over luggage compartments with depressed aisle, usually with single, swing front door.

bus, double-decker — a high-capacity bus that has two levels of seating, one over the other, connected by one or two stairways. Total bus height is usually 13-14.5 ft (4.0-4.4 m), and typical passenger seating capacity ranges from 60 to 80 people.

bus, dual-mode — **1.** A bus designed to operate both on city streets and on rails or other types of guideway; also known as a *dual-control bus.* **2.** Sometimes used to refer to a trolleybus with a diesel or gasoline engine that can operate away from overhead wires; also known as a *dual-powered bus.*

bus, electric (battery bus) — a bus that is propelled by electric motors mounted on the vehicle. The power source, usually a battery or battery pack, is located in the vehicle or on a trailer.

bus, express — see *service, express bus.*

bus, hybrid — a bus combining two power sources, usually a small diesel, gas, or Sterling engine and batteries. The engine drives an electrical generator at constant speed, optimizing efficiency and minimizing pollution. When maximum power is required the generator plus batteries feed the traction motor(s), often hub type. At other times the generator and regenerative braking power charges the batteries. Combinations can include fuel cells and/or flywheels.

bus, intercity (over-the-road coach) — a large bus with luggage space, used primarily for transportation between cities. It usually has reclining seats and restroom facilities.

bus, limited stop — see *service, limited stop.*

bus, local — see *service, local bus.*

bus, low-floor — a bus without steps at entrances and exit. The low floor may extend throughout the bus or may use a ramp or steps to access the raised rear portion over a conventional axle and drive train. Wheelchair access is provided by a retracting ramp.

bus, motor (motor coach) — a bus that has a self-contained source of motive power, usually a diesel engine.

bus, New Look — generally refers to a bus model manufactured by General Motors in the United States and Canada between 1959 and 1983. New Look buses are characterized by large slanting windows, often with an additional row of small windows to allow standing passengers to see out. Also similar designs from other makers. Colloquial term: *fishbowl.*

bus, owl — see *run, owl.*

bus, replica streetcar — see *bus, trolley replica.*

bus, school — **1.** A vehicle operated by a public or private school or by a private contractor for the purpose of transporting children (through grade 12) to and from school or to and from other school-sponsored activities. The vehicle is externally identifiable as a school bus, typically by color (yellow) and lettering that identifies the school or school district served by the vehicle. This definition includes vehicles designed and built as school buses as well as other vehicles, such as vans and station wagons. See also *service, school bus.* **2.** A vehicle designed and built as a school bus, typically with body-on-chassis construction. Such a vehicle may be used for other purposes than school bus service (e.g., military or church service.)

bus, small — bus that is less than 20 ft (6 m) long.

bus, standard urban (transit coach, urban transit bus) — a bus for use in frequent-stop service with front and (usually) center doors, normally with a rear-mounted engine and low-back seating. Typically 35-40 ft (10-12 m) long.

bus, subscription — see *service, subscription bus.*

bus, suburban transit (suburban coach) — a bus with front doors only, normally with high-backed seats, reading lights, and without luggage compartments or restroom facilities for use in longer-distance service with relatively few stops.

bus, trolley — see *trolleybus.*

bus, trolley replica — a bus with an exterior (and usually an interior) designed to look like a vintage streetcar.

bus, urban transit — see *bus, standard urban.*

bus bay — **1.** A branch from or widening of a road that permits buses to stop, without obstructing traffic, while laying over or while passengers board and alight; also known as a *blister, duckout, turnout, pullout, pull-off* or *lay-by.* As reentry of the bus into the traffic stream can be difficult, many transit agencies discourage their construction. **2.** A specially designed or designated location at a transit stop, station, terminal, or transfer center at which a bus stops to allow passengers to board and alight; also known as a *bus dock* or *bus berth.* **3.** A lane for parking or storing buses in a garage facility, often for maintenance purposes.

bus bay, angle — a bus bay design similar to an angled parking space that requires buses to back up to exit; allows more buses to stop in a given linear space. Typically used when buses will occupy the berth for a long period of time (for example, at an intercity bus terminal).

bus bay, drive-through (pull-through) — a bus bay design providing several adjacent loading islands, between which buses drive through, stop, and then exit. Allows bus stops to be located in a compact area. Sometimes used at intermodal transfer centers, as all buses can wait with their front destination signs facing the direction passengers will arrive from (e.g., from a rail station exit).

bus bay, linear — a bus bay design where buses stop directly behind each other; requires the bus in front to leave its bus bay before the bus behind it can exit. Often used when buses will use the bus bay only for a short time (e.g., at an on-street bus stop). Also called *on-line bus stop*.

bus bay, sawtooth — a bus bay design where the curb is indented in a sawtooth pattern, allowing buses to enter and exit bus bays independently of other buses. Often used at transit centers.

bus berth — see *bus bay* and *loading area.*

bus bulb — an extension of the sidewalk into the roadway for passenger loading without the bus pulling into the curb, gives priority to buses and eases reentry into traffic, often landscaped and fitted with bus shelter and other passenger amenities. Also called *bus bulge*, *curb bulge*, and *curb extension*.

bus dock or turnout — see *bus bay.*

bus gate — **1.** A bus priority signal control for intersection approaches. Signals located upstream from the intersection stop traffic in regular lanes while the bus lane remains open, allowing buses to proceed to any lane at the intersection signal ahead of other traffic. **2.** In some areas, a crossing gate on highway ramps that opens only for buses. **3.** A bus-only passageway between suburban sub-divisions, controlled by a gate, or a pit that is too wide for automobiles to pass — examples in Calgary, also known as a *vehicle trap*.

business district — see *central business district* and *outlying business district.*

bus lane — see *lane, bus.*

bus mile (bus kilometer) — one bus operated for 1 mile (kilometer.)

bus-only street — see *street, bus-only.*

bus platoon — several buses operating together as a convoy, with each bus following the operating characteristics of the one in front.

buspool — group of people who share the use and cost of a special bus transportation service between designated origins and destinations on a regular basis; for example, daily trips to work.

bus priority lane — see *lane, bus.*

bus priority system — a system of traffic controls in which buses are given special treatment over general vehicular traffic (e.g., bus priority lanes, preemption of traffic signals, or adjustment of green times for buses.)

bus priority system, metered freeway — a means of giving buses preferential access to enter a freeway by restraining the entrance of other vehicles through the use of ramp metering; see also *freeway, metered.*

bus rapid transit — see *transit system, bus rapid.*

bus run — see *run, bus.*

bus shelter — see *transit shelter.*

bus stop — see *stop, transit.*

bus turnout — see *bus bay.*

busway — a special roadway designed for exclusive use by buses. It may be constructed at, above, or below grade and may be located in separate rights-of-way or within highway corridors. Variations include grade-separated, at-grade, and median busways. Sometimes called a *transitway.*

bypass, queue — see *queue jumper.*

bypass lane — see *queue jumper.*

C

CBD — central business district.

CNG — Compressed natural gas.

CTC — Centralized traffic control; see *control system, centralized traffic.*

CUTA — Canadian Urban Transit Association; see *organizations, Canadian Urban Transit Association.*

cab — **1.** The space or compartment in a locomotive or a powered rail car containing the operating controls and providing shelter and seats for the engine crew or motor operator **2.** A taxicab.

cab car — see *car, cab.*

cab signal — see *control system, cab signal.*

cabin — an enclosed or semi-enclosed compartment for transporting passengers. Most often used on aerial tramways and detachable-grip aerial lifts.

cable — wire rope consisting of several strands twisted together.

cable, track — a wire rope or strand used to support a carrier or carriers on a bicable system.

cable car — see *car, cable.*

cable-hauled automated people-mover — see *people-mover.*

cableway — a *ropeway* similar to an *aerial tramway,* but having the added ability to raise and lower a load during transport. Generally only used for freight movement.

call, road — see *road call.*

cam controller — a device to regulate direction, accelerating, running, and braking of an electric vehicle with switched resistor control. Cams on a rotating shaft open or close spring-loaded contacts that make or break electric circuits between the power supply and the traction motors.

Canadian Urban Transit Association — see *organizations, Canadian Urban Transit Association.*

capacity, achievable — the maximum number of passengers that can be transported over a given section of a transit line in one direction during a given time period, factored down to reflect the uneven passenger demand during the peak hour, uneven vehicle occupancy and, for rail, the uneven loading of cars within a train. Usually the maximum capacity with unlimited vehicles, if constrained by number of vehicles this must be clearly stated.

capacity, crush (crush load) — the maximum feasible passenger capacity of a vehicle, that is, the capacity at which one more passenger cannot enter without causing serious discomfort to the others. Note that the crush load specification for some rail transit vehicles does not relate to an achievable passenger loading level but is an artificial figure representing the additional weight for which the car structure is designed or for which the propulsion and braking system will meet minimum performance criteria.

capacity, design — **1.** for transit lines, a synonym for *person capacity*. **2.** for transit vehicles, a synonym for *scheduled design load.* **3.** For highways, the maximum number of vehicles that can pass over a given section of a lane or roadway in one or both directions during a given time period under prevailing environmental (e.g., weather and light), roadway, and traffic conditions.

capacity, fleet (rolling stock capacity) — **1.** the total number of passenger spaces in all vehicles of a transit fleet. **2.** Maximum system or line capacity when the entire fleet, less maintenance spares, are deployed, *not in common use.*

capacity, line — the maximum number of passenger spaces that can be moved past a fixed point in one direction per unit of time (usually 1 hour) without station stops or dwells; see also *capacity, achievable* and *capacity, design*. (Real operating conditions will reduce this capacity. Except for busways without stops, this is an academic measure that should be avoided.)

capacity, normal vehicle — see *capacity, vehicle.*

capacity, person — the maximum number of persons that can be carried past a given location during a given time period under specified operating conditions without unreasonable delay, hazard, or restriction. Usually measured in terms of persons per hour.

capacity, productive — a measure of efficiency or performance. The product of passenger capacity along a transit line and speed.

capacity, rolling stock — see *capacity, fleet.*

capacity, seating (seated capacity) — the number of passenger seats in a vehicle.

capacity, standing — the number of standing passengers that can be accommodated in a vehicle under specified comfort standards, expressed in area per standee.

capacity, theoretical line — see *capacity, line.*

capacity, vehicle — **1.** The maximum number of passengers that the vehicle is designed to accommodate comfortably, seated and standing; may sometimes refer to number of seats only. Also known as *normal vehicle capacity* or *total vehicle capacity.* **2.** The maximum number of vehicles that can be accommodated in a given time by a transit facility.

capital cost — nonrecurring or infrequently recurring costs of long-term assets, such as land, guideways, stations, buildings, and vehicles. These costs often include related expenses: for example, depreciation and property taxes. See also *operating costs.*

captive (transit) rider — see *rider, captive transit.*

car — **1.** A vehicle running on rails, for example, streetcar, light rail car, rapid transit car, railroad car. **2.** An automobile.

car, articulated — see *articulated rail vehicle.*

car, bidirectional (double-ended) (DE) — a powered rail car that has controls at both ends and symmetrically designed sides and ends for operation in either direction.

car, bi-level — a rail car that has two levels for passenger accommodation. The upper level may extend through the entire length of the car or only over a part of it. In this latter case the car has three different levels, two in the middle and an intermediate level over the trucks at each end, hence the term *tri-level* is occasionally seen. Bi-level cars include double-deck and gallery cars.

car, cab — **1.** A rail car with a driving cab. **2.** A passenger-carrying car used in push-pull service and fitted with a cab at one end, to be used to operate the train when the locomotive is pushing; see also *car, commuter rail.*

car, cable — **1.** An individually controlled rail passenger vehicle operating in mixed street traffic and propelled by gripping a continuously moving endless cable located in an underground slot between the rails. The cable (which can haul many cable cars simultaneously) is powered by a large stationary motor at a central location. **2.** A term sometimes applied to *aerial tramways.*

car, commuter rail — a passenger rail car designed for commuter rail services, usually with more seats than a conventional long-distance rail passenger car. The car may be hauled by a locomotive, have a self-contained internal combustion engine, or be electrically propelled by power from a third rail or overhead wire. See also *car, cab.*

car, diesel multiple-unit — see *car, multiple-unit.*

car, diesel rail — see *car, rail diesel.*

car, double-deck — a bi-level rail car with a second level that covers the full width of the car but may or may not extend the full length.

car, electric multiple-unit — see *car, multiple-unit.*

car, electric rail — an electric rail car powered by current from an overhead wire or third rail..

car, gallery — a bi-level rail car that has seating and access aisles on a second level along each side of an open well. Tickets of passengers on the second level can be inspected or collected from the lower level. Now unique to Chicago and Montreal.

car, light rail (LRV, light rail vehicle) — a streetcar or rail vehicle similar to a streetcar, often articulated, operating on light rail systems with substantial amounts of segregated track and higher speeds than traditional *on-street* streetcar operation. Designs available with folding steps, capable of boarding and discharging passengers at either track or car-floor level, as in San Francisco and Hannover. See also *car, streetcar.*

car, light rail vehicle, low-floor — a light rail vehicle with low floor for level boarding and exiting. Floor height is 10-14 in. (250-350 mm), requiring a platform or raised curb at this height. Wheelchair access is provided directly or by a hinged or removable bridge plate, or by an electrically operated retractable plate. Partial low-floor light rail vehicles have internal steps to access high-floor area(s) over trucks and (rarely) any articulations. In this way conventional trucks and propulsion equipment can be used.

car, motor — see *car, rail motor.*

car, multiple-unit (MU) — a powered rail car arranged either for independent operation or for simultaneous operation with other similar cars, when connected to form a train of such cars. It may be designated as *DMU (diesel multiple-unit)* or *EMU (electric multiple-unit)*, depending on the source of power.

car, PCC (PCC, Presidents' Conference Committee car) — a streetcar first produced in 1935. Its performance and efficiency were significantly improved over those of any streetcar previously built. The PCC car, characterized by lightweight construction, smooth and rapid acceleration and deceleration, and soft ride, became the standard for U.S. streetcars for many years. About 5,500 cars were manufactured in North America, 16,000 in Europe, and many using PCC features in Russia, as recently as 1997. See *organizations, Presidents' Conference Committee.*

car, powered — see *car, rail motor.*

car, rail diesel (RDC, diesel rail car) — a self-powered rail car, usually with two diesel engines capable of multiple-unit operation. (DMU)

car, rail motor (motor car, powered car, self-powered car, self-propelled car) — a rail car that is propelled by an electric motor or internal combustion engine located on the car itself, see *car, electric rail* and *car, rail diesel.*

car, rail rapid transit (rapid transit car, subway car, heavy rail car) — bidirectional rail car for rapid transit systems, usually powered, multiple unit equipped, and with a control cab at one or both ends. Characterized by multiple double doors per side, designed for fast boarding and alighting from high-level platforms.

car, self-propelled or self-powered — see *car, rail motor.*

car, single-unit (SU) — a powered rail car, equipped with a control cab at one or both ends, that operates alone.

car, streetcar — an electrically powered rail car, with width and turning radius suitable for operating on city streets and equipped with lower skirt and safety devices to protect pedestrian falling under car; see also *car, light rail.*

car, track — a self-propelled rail car (e.g., burro crane, highway rail car, detector car, weed burner, tie tamper) that is used in maintenance service and that may or may not operate signals or shunt track circuits.

car, trailer — **l.** An unpowered rail car operated in trains with powered cars (rapid transit) or towed by locomotives (regional rail). **2.** In some rail rapid transit systems, a trailer may be powered; however, it does not have operator control and thus can only be operated in consists with cars that do.

car, trolley — **1.** A local term for a streetcar. **2.** Recently, also a local term for a bus with a body simulating that of an old streetcar (see *streetcar, replica*).

car, unidirectional — a rail car (usually light rail or streetcar) that has doors on one side and an operating cab at only one end so that it must be turned around by separate means (loop tracks or wyes) at terminals.

car, urban rail — a light rail, rail rapid transit, or commuter rail car.

car, weight designations — AW0, empty weight, AW1, weight with seated passenger load, AW2, weight with average peak-hour passenger load, AW3, crush loaded weight. Passengers are usually assumed to weigh an average of 155 lb (70 kg). Peak-hour passenger load is normally based on 0.4 p/ft^2 (4 passengers/m^2) of floor space in North America, 0.4-0.5 p/ft^2 (4-5 p/m^2) in Europe and 0.5-0.6 p/ft^2 (5-6 p/m^2) in Asia, after discounting space used for cabs, stairwells and seated passengers at 0.2/ft^2 (2/m^2). Crush loads are 0.6, 0.6-0.7, and 0.8 p/ft^2 (6, 6-7 and 8 p/m^2) respectively. Caution: some systems and manufacturers use different designations, some systems report loading in excess of 0.8 p/ft^2 (8 p/m^2).

car equivalence, passenger — see *passenger car equivalence.*

carhouse — see *barn.*

car operator — see *operator, train.*

carpool — an arrangement in which two or more people share the use, cost, or both of traveling in privately owned automobiles between fixed points on a regular basis; see also *vanpool.*

carpool, casual — an informal carpool where commuters gather at a location to be picked up at random by motorists who do not have sufficient passengers to use an HOV facility (U.S. West Coast usage). See also *slug.*

carpool lane — see *lane, carpool;* and *lane, exclusive carpool.*

carrier — 1. A person or company in the business of transporting passengers or goods. **2.** The structural and mechanical assemblage in or on which the passengers of a ropeway system are transported. Unless qualified, the carrier includes the carriage or grip, hanger, and cabin or chair.

carrier, common — in urban transportation, a company or agency certified by a regulatory body to carry all passengers who fulfill the contract (e.g., pay the required fare). The service is open to the public.

catamaran — commonly used type of ferry vessel. Water jet propulsion combines relatively good fuel economy with speed and passenger comfort.

catenary system — that form of electric overhead contact system (OCS) in which the overhead contact wire is supported from one or more longitudinal wires or cables *(messengers),* either directly by hangers *(simple catenary)* or by hangers in combination with auxiliary conductors and clamps *(compound catenary).* Attachment of the contact wire to the messenger is made at frequent and uniform intervals to produce a contact surface nearly parallel to the top of the running rails.

center, major activity — see *major activity center.*

center, modal interchange — see *transit center.*

center platform — see *platform, center.*

central business district (CBD) — defined by the Bureau of the Census, an area of high land valuation characterized by a high concentration of retail businesses, service businesses, offices, hotels, and theaters, as well as by a high traffic flow. A CBD follows census tract boundaries; that is, it consists of one or more whole census tracts. CBDs are identified only in central cities of *MSA*s and other cities with populations of 50,000 or more. See also *outlying business district.*

central city — as defined by the Bureau of the Census, the largest city, or one of the largest cities, in a metropolitan statistical area or urbanized area. The criteria for designating a central city vary with the type of area and the particular census.

centralized traffic control system — see *control system, centralized traffic.*

chair — an open or semi-open seat used on an aerial lift.

check — in transit operations, a record of **1.** the passenger volume on all transit units that pass a specific location or time point (also known as a *passenger riding count or check)*, **2.** the actual time the unit passes it (also known as a *schedule check)*, **3.** the number of passengers who board and alight at each stop on a route or line (also known as an *on-and-off count or check),* or any combination of these items. The checker may ride the transit unit (an *on-board* or *ride check),* follow it in another vehicle, or check the transit units from a particular location (a *point* or *corner check).*

choice rider — see *rider, choice.*

chopper — solid-state electronic device that controls electric current flow to traction motors by rapidly turning the power on and off, resulting in gradual vehicle acceleration at reduced current use. Replaced less efficient switched resistor controls from 1960s. Now replaced with more advanced power conversion units (PCU) feeding three phase alternating current motors, which may themselves contain a "chopper," usually to control regenerative braking.

circuit, track — see *track circuit.*

circulator service — see *service, circulator.*

city, central — see *central city.*

city transit service — see *service, city transit.*

civil speed limit — in rail operations, the maximum speed authorized for each section of track, as determined primarily by the alignment, profile, and structure.

clearance time — see *time, clearance.*

clock headway— see *headway, clock.*

close-in time — see *time, close-in.*

close-up — in rail transit operations the process where a train approaching a station will close-up to the train berthed in the station to the minimum distance permitted by the signaling or train control system. This is usually the critical line condition that, combined with the dwell at the maximum load section station, establishes the minimum headway.

closed-loop braking — see *braking, closed-loop.*

coach, motor — see *bus, motor.*

coach, over-the-road — see *bus, intercity.*

coach, suburban — see *bus, suburban transit.*

coach, transit — see *bus, standard urban.*

coach, trolley — see *trolleybus.*

coasting (freewheeling) — of a vehicle, running without influence of either the propulsion or braking systems, that is, with tractive and braking forces at zero. Use of coasting on rail transit sometimes increased outside peak periods to reduce energy consumption. Desirable feature of automatic train operation.

coefficient, riding frequency or habit — see *riding frequency coefficient.*

coefficient, utilization — see definition of *load factor.*

coefficient of directness — **1.** The ratio of the length (measured in units of either distance or time) of a transit trip between two points and the length of the most direct highway route between the two points. **2.** The ratio of the length (measured in units of either distance or time) of a trip between two points by one mode and the length of the trip by another mode.

coefficient of variation — the standard deviation divided by the mean. Usually expressed as a percentage.

cog railway (rack railway, mountain railway) — a rail transportation mode with auxiliary or full traction provided by a geared wheel in the middle of a powered axle that is engaged with a rack (toothed bar) installed along the track center. This system used to overcome steep gradients. Similar *Fell system* uses adhesion grip on center rail without gear teeth.

collector, current — see *current collector.*

command and control system (C&C) — in rail systems, any means of adjusting and maintaining prescribed headways; effecting starting and stopping, merging, and switching; and controlling other such functions. It is usually considered to include transit unit (car or train) protection, transit unit operation, and line supervision to ensure safe movement of the transit unit within the system. Preferred usage is *train control system.* See also *control system.*

common carrier — see *carrier, common.*

commission — **1.** Eastern Canadian term for transit agency — particularly in Ontario. **2.** To prepare new transit vehicles or other hardware for revenue service.

communication based control system — see *control system, moving block.*

commute — regular travel between home and a fixed location (e.g., work, school). The term is often applied only to travel in the direction of the main flow of traffic, to distinguish from reverse commute.

commute, reverse — a commute in the direction opposite to the main flow of traffic, for example, from the central city to a suburb during the morning peak. Increasingly common with growth in suburban employment. Valuable to operator as provides additional passengers and revenue at little or no marginal cost.

commute ticket — in rail systems, a ticket sold at a reduced rate for a fixed or unlimited number of trips in a designated area during a specified time period.

commuter — a person who travels regularly between home and a fixed location (e.g., work, school.)

commuter bus — see *service, commuter.*

commuter lane — see *lane, high-occupancy vehicle.*

commuter rail — see *transit system, commuter rail.*

commuter rail car — see *car, commuter rail.*

commuter service — see *service, commuter.*

compound catenary — see *catenary system.*

concession — in transit, the right to operate a transit service for a given number of years. May or may not include: public contribution to capital and operating costs; regulation of service standards and fares charged; design or construction of any facilities.

conductor — **1.** In rail transit operations, the operating employee who may control the doors on rail transit vehicles, or who may have fare-collecting duties, or both. Also called a *guard* on some systems. **2.** In railroad operations, the operating employee in charge of the train and train crew. **3.** In some bus operations, an operating employee (other than the bus driver) who collects fares and may control doors. 4. The individual assigned to particular duties or functions in the operation of a ropeway.

confidence level — a statement of assurance of the accuracy of a statistical statement, e.g., if it is asserted that a population parameter is indeed within the computed confidence interval at confidence level α, this means that the risk of error is $1-\alpha$. For example, a 95% confidence level has a risk of 5%.

confidence limit — a boundary of the confidence interval, usually referred to as lower and upper confidence limits.

connectivity — the ability of a public transportation network to provide service to the maximum number of origin-and-destination trip pairs through the optimal integration of routes, schedules, fare structures, information systems, and modal transfer facilities.

consist — in rail systems, the makeup or composition (number and specific identity) of individual units of a train. Pronounced with the first syllable emphasized.

contact rail — see *rail, third.*

contact shoe, overhead — see *overhead contact shoe.*

contact wire (trolley wire) — an overhead electric conductor that supplies power to electric rail vehicles and trolleybuses.

continuous brake — see *brake, continuous.*

continuous inductive train control system — see *control system, continuous train.*

continuous train control system — see *control system, continuous train.*

continuous welded rail — see *rail, continuous welded.*

contraflow — movement in a direction opposite to the normal flow of traffic. The term usually refers to flow opposite to the heavier flow of traffic. See also *commute, reverse.*

contraflow lane — see *lane, contraflow.*

control, deadman — see *deadman control.*

control, quality — see *quality control.*

control device, grade crossing traffic — see *grade crossing traffic control device.*

controlled access — see *access, limited.*

controlled access right-of-way — see *right-of-way, limited.*

controller, cam — see *cam controller.*

controls, passenger — see *passenger controls.*

control system, automatic block signal (ABS) — a system of governing train separation in which the signals are controlled by the trains themselves. The presence or absence of a train in a block is determined by a track circuit. If the circuitry fails, a restrictive signal is displayed.

control system, automatic train — see *automatic train control system.*

control system, block signal — a standard railroad signal system that uses a fixed signal at the entrance of a block to govern the separation of trains entering the block.

control system, cab signal — in rail systems, a signal located in the cab, indicating a condition affecting the movement of a train and used in conjunction with interlocking signals and in conjunction with or in lieu of block signals. Can indicate status of next signal(s) or show designated maximum speed.

control system, centralized traffic (CTC) — in rail systems, a traffic control system in which signals and switches are controlled from a remotely located (centralized traffic control) panel.

control system, communication based — see *control system, moving block.*

control system, fixed block — an automatic train control system that records the presence of a train (or a part of it) in each track section (block) and activates the signals on the line to indicate the block is occupied. In some cases, a following train is prevented from entering the block by a forced emergency stop, see *automatic train stop*.

control system, manual block — a system of manually governing train movement in a block or a series of consecutive blocks by means of signals, train orders, telephone, or radio.

control system, manual train — system in which train movement is controlled by the operator (motorman) or engineer.

control system, moving block — an automatic train control system that spaces trains according to their location and relative velocity, and stopping performance, plus a safety distance. Often includes automatic train operation. Moving-block signaling systems are also called transmission or communication based systems. The latter is becoming the preferred term.

control system, multiple-unit — a system that controls the operation of two or more rail motor cars in a train through the simultaneous control of the train by one operator.

control system, overlay — A train control system, usually software controlled, that is overlaid on top of a conventionally fixed block control system. Permits closer headway of trains equipped for the overlay while providing operation and safe separation of non-equipped trains.

control system, traffic — see *control system, centralized traffic.*

control system, transmission based — see *control system, moving block.*

controlling dwell — the dwell, usually at the busiest station on a rail transit line, that, added to the minimum separation time of the train control system for the applicable speed, sets the closest headway possible. Can also apply to a bus line.

conventional rail transport — transportation systems that consist of steel-wheeled trains running on duo-rail tracks. Trains may be self-propelled or hauled by locomotive, with diesel or electric propulsion.

conveyor, passenger or pedestrian — see *moving walkway.*

cordon count — in planning, a count of vehicles and people across a designated (cordon) line to determine **1.** the total flow (people and vehicles by mode and time period) into and out of the study area and **2.** the accumulation (people and vehicles) within the cordon area by time of day.

cordon line — in planning, an imaginary line circumscribing a specific geographic study area.

corner check — see *check.*

corridor — in planning, a broad geographical band that follows a general directional flow or connects major sources of trips. It may contain a number of streets and highways and transit lines and routes.

cost recovery ratio — the ratio of total revenues to total costs; the inverse of operating ratio. It is often used for evaluation of alternative plans. Usually total direct operating and maintenance costs are used although outside the United States; many agencies include annualized capital costs and/or depreciation in the calculation. *Farebox recovery ratio* is the ratio of operating revenue to operating costs.

costs — see *capital costs* and *operating costs.*

count — **1.** In transportation, a process that tallies a particular movement of people or vehicles past a given point during a stated time period. It may be a directional or a two-way value and is also known as a *traffic count* **2.** In transportation, a volume of people or vehicles.

count, cordon — see *cordon count.*

count, on-and-off — see *check.*

count, passenger — see *passenger count.*

count, passenger riding — see *check.*

count, traffic — see *traffic count.*

coupler — a device for connecting one rail vehicle to another. The mechanism is usually placed in a standard location at both ends of all rail cars and locomotives.

coupler, automatic — **1.** A coupler that operates automatically. It may also be capable of uncoupling automatically. May have to take place on tangent track although some designs have automatic centering and can be used on curves. **2.** An automatic connector that joins electric or pneumatic train lines together between rail cars.

coverage area — see *area, coverage.*

critical line condition — in rail transit operations the factor that constrains headway. This is usually the close-in at the maximum load section station or the terminal turnback process, occasionally at junctions.

crossing, grade (railroad grade crossing) — a crossing or intersection of highways, railroad tracks, other guideways, or pedestrian walks, or combinations of these at the same level or grade.

crossing, highway/railroad — a place, at grade or grade separated, where highway traffic crosses railroad tracks.

crossing, railway — see *crossing, track.*

crossing, track (railway crossing) — an assembly of rails and frogs that allows crossing of two tracks at grade.

crossing control device, grade — see *grade crossing traffic control device.*

crossover — **1.** In rail systems, a track with two switches that connects two parallel tracks. **2.** Pedestrian or vehicular links (at grade or grade separated) across a transportation facility.

crosstie (railroad tie, tie) — the transverse member of the track structure to which the rails are fastened. Its function is to provide proper gauge and to cushion, distribute, and transmit the stresses of traffic through the ballast to the roadbed; normally wood or concrete; can be metal or plastic. Also known as a *sleeper*.

crosstown service — see *service, crosstown.*

cruise speed or velocity — see *velocity, cruise.*

cruiser — see *bus, cruiser.*

crush load — see *capacity, crush.*

curb bulb — see *bus bulb.*

curb extension — see *bus bulb.*

current collector — the mechanical component on an electric rail car that makes contact with the conductor that distributes the electric current; see also *overhead contact shoe, pantograph, third-rail shoe,* and *trolley pole.*

customer satisfaction survey — see *survey, customer satisfaction*.

cut-and-cover — a method of construction that consists of excavating the terrain from ground level, placing a structure in the excavation, and then filling over the structure.

cutting — see *run cutting.*

D

DC — **1.** District of Columbia. **2.** direct current.

DE — double ended, rail or streetcar with driving positions at both ends.

DHV — design hourly volume.

DMU — diesel multiple-unit car; see *car, multiple-unit.*

DOT — department of transportation; see *organizations, department of transportation;* and *U.S. Government, Department of Transportation.*

DPM — downtown people mover; see *people mover, downtown.*

day pass or daypass — ticket for unlimited travel for one day, usually to end of service the following day, may be for one or more zones of travel, may be restricted in morning peak period, may be good for one adult, one concession rider or for a family or similar group. Can be valid through a weekend. Often contains "scratch" panels for user to designate day and month of use.

deadhead — an unproductive or non-revenue move without passengers aboard, often to and from a garage, or from one route to another. (Some agencies carry passengers on these runs and still use the term deadhead.)

deadman control — a pedal, handle, or other form of switch, or combination thereof, that the operator must keep in a depressed or twisted position while a rail vehicle (or train) is moving. If the control is released, the power is cut off and the brakes are applied.

deceleration, retardation, braking rate — decrease in velocity per unit time; in transit practice, often measured in ft/s^2 (m/s^2) or, in the United States, mph/s.

deck, vessel — a platform in a vessel that accommodates passengers and/or autos.

default value — a design value that is based on experience or on studied conclusions and that is used as a substitute value when an actual value is not available.

defensible space — a concept in architecture and urban design that precludes designs resulting in dark alleys, corners, or spaces where visibility and openness to other people is severely limited.

delay, re-entry — the time required for a suitable gap in traffic to occur to allow a bus to re-enter the street from an off-line stop; a component of clearance time. Re-entry delay is influenced by the traffic volume in the curb lane and upstream traffic signals.

delay time — see *time, delay.*

demand — **1.** The quantity (of transportation) desired. **2.** In an economic sense, a schedule of the quantities (of travel) consumed at various levels of price or levels of service offered (by the transportation system.)

demand, effective — the number of people or vehicles prepared to travel in a given situation, at a given price.

demand jitney service — see *service, jitney.*

Demand Response Transit Operations — National ITS Architecture Market Package that performs automatic driver assignment and monitoring as well as vehicle routing and scheduling for demand-responsive transit services.

demand-responsive transportation system — see *transportation system, demand-responsive.*

denial, service — see *service denial*.

density, pedestrian — average number of pedestrians per unit of area within a walkway or queuing area; expressed as pedestrians per square foot or meter.

density, population — average number of people per unit area; typically expressed as persons per square mile or square kilometer.

density, train — see *train density.*

department of transportation — see *organizations, department of transportation;* and *U.S. Government, Department of Transportation.*

departments, U.S. — see *U.S. Government.*

dependent, transit — see *transit dependent.*

depot — see *garage, terminal, carhouse* and *barn.*

derail — **1.** To run off the track. **2.** A track safety device designed to guide a rail car off the rails at a selected location to prevent collisions or other accidents, commonly used on spurs or sidings to prevent unattended rolling cars from fouling the main line; also known as a *derailer.*

derailment — an instance of the wheels of a rail vehicle coming off the track.

deropement — the term used when a rope or cable leaves its operating position relative to the groove of a sheave, carriage wheel, or saddle.

design capacity — see *capacity, design.*

design hourly volume (DHV) — the amount of traffic a transportation facility is designed to carry in 1 hr.

desire line — a straight line on a map that connects the origin and destination of a trip (theoretically, the ideal or most desirable route) and may indicate by its width or density the volume of trips between that origin and destination.

destination — **1.** The point at which a trip terminates. **2.** In planning, the zone in which a trip ends.

destination sign or blind — a sign on a transit unit (vehicle or train) indicating the route and/or route number or letter, direction, destination of the unit, or any combination thereof. Destination signs are most commonly located on the front of the transit unit but may also be located on the back, side, or both. Includes roll signs printed on cloth or plastic and electronic signs, most usually dot matrix. See also *head sign*.

detachable-grip lift — a ropeway system on which carriers circulate around the system alternately attaching to and detaching from a moving haul rope. The ropeway system may be *monocable* or *bicable*.

deviation, point — see *point deviation.*

device, grade crossing traffic control — see *grade crossing traffic control device.*

device, signal-actuating — see *pedestrian signal-actuating device* and *vehicle signal-actuating device.*

device, traffic control — see *traffic control device.*

dial-a-bus or dial-a-ride — see *transportation system, dial-a-ride.*

diamond lane — see *lane, diamond.*

diesel-electric locomotive — see *locomotive, diesel-electric.*

diesel multiple-unit car (DMU) — see *car, multiple-unit.*

diesel rail car — see *car, rail diesel.*

differential fare — see *fare, differential.*

direct current (DC) — fixed polarity electrical distribution system universally used for heavy rail, light rail and trolleybuses. For a given load at the voltages used, there are lower losses and longer distances possible between feeder points and sub-stations than with alternating current (AC).

direct current motor — see *motor, direct current.*

directional route miles — see *route miles.*

directional split — the proportional distribution between opposite flows of traffic on two-way facilities.

directness, coefficient of — see *coefficient of directness.*

disability, public transportation — see definition of *persons with disabilities.*

disadvantaged, transportation — see *transportation disadvantaged.*

disc brake — see *brake, disc.*

discharge — in transit operations, to let passengers exit the vehicle.

disembark — to transfer from a vessel to shore.

disincentive — something that discourages people from acting in a certain way. For example, high parking fees or tolls are disincentives to automobile use.

dispatcher — **1.** In bus operations, the individual who assigns buses to runs, makes up work assignments to fill runs, directs the operators at the start of their assignments, and in some cases, maintains a constant awareness of status of the operation, via radio, telephone, or other means. **2.** In rail operations, an operating person whose function it is to dispatch transit units (cars or trains), monitor their operation, and intervene in the event of disruption of schedule or when any change in service or routing is required. **3.** In demand-responsive transportation, the person who assigns the vehicles to customers and notifies the appropriate drivers and who may schedule and route vehicles and monitor their operation.

dispatching — **1.** In rail operations, the process of starting a transit unit (car or train) into service from a terminal, yard, or transfer track. **2.** In demand-responsive transportation systems, the process of relaying service instructions to drivers. The procedure may include vehicle scheduling, routing, and monitoring, and it can be manual or partly or fully automated. **3.** The relaying of service instructions to vehicle drivers or operators.

distance, air — straight-line measure of walking distance between two points that does not consider the availability, connectivity, or condition of pathways between the two points; used in planning-level calculation of service coverage. Compare with *distance, walk.*

distance, linked trip — see *trip distance, linked.*

distance, maximum walking — the maximum distance that people will walk to transit; affected by grade, pedestrian environment, and pedestrian characteristics.

distance, total travel — see *trip distance, linked.*

distance, walk —measure of walking distance between two points following continuous pathways or sidewalks. Compare with *distance, air.*

distribution, flow — see *trip assignment.*

distribution, trip — see *trip distribution.*

district, central business — see *central business district.*

district, outlying business — see *outlying business district.*

diversity, loading — a measure of the unevenness of the passenger loading of transit vehicles in time (e.g., between buses or trains on the same route) or location (e.g., between cars of a train). See also *peak hour factor.*

dock — **1.** Facility defined as a multiple number of berths providing access to vessels. **2.** The process of "parking" a vessel and tying it into its berth.

door, double-stream — a door on a transit vehicle with sufficient width (generally 3.75-4.5 ft or 1.14-1.37 m) to permit two passengers to board and/or alight simultaneously. A handrail may or may not be provided to separate the two passenger streams.

door, single-stream — a door on a transit vehicle that allows passenger flow in only one direction at a time.

district, transit — see *transit district.*

door-to-door service — see *service, door-to-door.*

double — see *extra section.*

double-deck car — see *car, double-deck.*

double-decker bus — see *bus, double-decker.*

double-ended car — see *car, bidirectional.*

double-ended transit unit (bidirectional transit unit) — rail car or train with an operating cab at each end.

downtown people mover — see *people mover, downtown.*

draft — the depth of a vessel's keel below the water line.

driving wheels — wheels that are powered by a motor or engine and that provide the tractive effort, through contact with the running surface, that propels the vehicle.

dual control or mode — see *transit system, dual-mode;* and *bus, dual-mode.*

dual-mode bus — see *bus, dual-mode.*

dual-mode light rail — see *transit system, light rail, dual-mode.*

dual-mode transit system — see *transit system, dual-mode.*

dual-mode vehicle — see *vehicle, dual-mode.*

dual-powered bus — see *bus, dual-mode.*

dual-powered locomotive — see *locomotive, dual-powered.*

dual-power propulsion system — see *propulsion system, dual-power.*

dwell time — see *time, dwell.*

dynamic block control system — see *control system, moving block.*

dynamic brake — see *brake, dynamic.*

Dynamic Ridesharing — National ITS Architecture Market Package that enhances the Interactive Traveler Information package by adding an infrastructure providing dynamic ridesharing/ride matching capability.

Dynamic Route Guidance — National ITS Architecture Market Package that offers the user advanced route planning and guidance which is responsive to current conditions.

dynamic routing — in demand-responsive transportation systems, the process of constantly modifying vehicle routes to accommodate service requests received after the vehicle began operations, as distinguished from predetermined routes assigned to a vehicle.

E

EMU — electric multiple-unit car; see *car, multiple-unit.*

EPA — Environmental Protection Agency; see *U.S. Government, Environmental Protection Agency.*

edge treatment — A standardized surface feature or a physical barrier built in or applied to the walking surface to warn visually impaired people of hazards along the path of travel.

effective demand — see *demand, effective.*

effectiveness — **1.** In transportation, the correspondence of provided service to intended output or objectives, particularly the character and location of service; in other words, producing the intended result (doing the right things). **2.** In transit, the degree to which the desired level of service is being provided to meet stated goals and objectives; for example, the percentage of a given service area population that is within the desired ¼ mile (400 meters) of a transit stop.

effectiveness, measure of — see *performance indicator.*

effective operating speed — see *speed, overall trip.*

effective velocity — see *velocity, effective.*

egress time — see *time, egress.*

el — abbreviation for elevated (railway), mainly east coast; see *transit system, rail rapid.*

elasticity — the percentage change in demand for service for each 1% change in the price or amount of that service.

electric brake — see *brake, dynamic.*

electric bus — see *bus, electric.*

electric locomotive — see *locomotive, electric.*

electric motor — see *motor.*

electric multiple-unit car — see *car, multiple-unit.*

electric rail car — see *car, electric rail.*

Electric Railway Presidents' Conference Committee — see *organizations, Presidents' Conference Committee.*

electric sub-station — transformers, breakers (and rectifiers) to convert supply from electric utility to direct current supply for rapid transit, streetcar or trolleybus systems.

electric trolleybus — see *trolleybus.*

electrification (railway electrification) — in rail systems, a term used to describe the installation of overhead wire or third-rail power distribution facilities to enable operation of electrically powered transit vehicles.

electrodynamic brake — see *brake, dynamic.*

electromagnetic brake — see *brake, track.*

electropneumatic brake — see *brake, electropneumatic.*

elevated, the — see *transit system, rail rapid.*

elevated guideway — see *guideway, elevated.*

elevated-on-fill guideway — see *guideway, elevated-on fill.*

elevator — a mechanical device for moving people vertically between different levels of a building or transit station.

elevator, inclined — see *inclined elevator.*

embark — **1.** To transfer from shore to a vessel. **2.** To board a vessel.

emergency application or braking — see *braking, emergency.*

En-Route Transit Information — National ITS Program User Service that provides information to travelers using public transportation after they begin their trips.

end, head — see *head end.*

end, trip — see *trip end.*

end wall — see *station end wall.*

engine, gas turbine — an internal combustion engine in which the hot compressed gases of combustion drive a turbine.

engine, internal combustion (ICE) — an engine in which the power is developed through the expansive force of fuel that is fired or discharged within a closed chamber or cylinder.

equity — in transportation, a normative measure of fairness among transportation users.

equivalence, passenger car — see *passenger car equivalence.*

escalator — a device providing a continuous series of pallets or treads for standing pedestrians, transporting pedestrians both vertically and horizontally.

exact fare — see *fare, exact.*

excess time — see *time, excess.*

exclusive bus lane — see *lane, exclusive transit.*

exclusive carpool lane — see *lane, exclusive carpool.*

exclusive right-of-way—
farecard reader

exclusive right-of-way — see *right-of-way, exclusive.*

exclusive transit facilities — transportation system infrastructure elements that are set aside for the use of transit vehicles only. Examples include some freeway ramps, queue jumpers, bus lanes, off-street bus loading or unloading areas, and separated and fully controlled rights-of-way.

exclusive transit lane — see *lane, exclusive transit.*

exclusive transit right-of-way — see *right-of-way, exclusive transit.*

express bus — see *service, express bus.*

express service — see *service, express.*

expressway — a divided arterial highway for through traffic. An expressway has full or partial control of access and generally has grade separations at major intersections.

extra section (double) (overload) (duplicate *Br*.**)** — a second bus added to accompany a regularly scheduled bus to handle passenger overloads.

F

FHWA — Federal Highway Administration; see *U.S. Government, Federal Highway Administration*.

FRA — Federal Railroad Administration; see *U.S. Government, Federal Railroad Administration*.

FTA — Federal Transit Administration; see *U.S. Government, Federal Transit Administration*.

facilities, accessible transportation — see *accessible transportation facilities.*

facilities, exclusive transit — see *exclusive transit facilities.*

facility, intermodal transfer — see *transit center.*

factor, K — see *K factor.*

factor, load — see *load factor.*

factor, peak hour — see *peak hour factor.*

factor, travel time — see *travel time factor.*

fail-safe — incorporating a feature that ensures that malfunctions that affect safety will cause the system to revert to a state that is safe.

far-side stop — see *stop, far-side.*

fare — **1.** The required payment for a ride on a public transportation vehicle. It may be paid by any acceptable means, for example, cash, token, ticket, transfer, farecard, voucher, or pass or user fee. **2.** A passenger who pays a fare.

fare, adult cash — basic full fare paid by one adult for one ride, may exclude transfer and zone charges.

fare, average — the arithmetic average of all fares paid by all revenue passengers, including those who received special or reduced fares. It is usually derived by or generally equivalent to dividing total fare revenue by total origin-to-destination trips, although it may be based on unlinked trips.

fare, base (basic fare, regular fare, full fare) — the price (with no discounts) charged to an adult for regular local service or, for systems with zone pricing, a one-zone fare with no discounts, that is, what it costs an adult paying a single cash fare to take a one-zone ride. On systems with time-based fares it is normally the peak period fare,

fare, concession — British and Canadian term for a reduced fare for various classes or passengers: children, students, seniors. A single concession fare reduces the complexity of having multiple fares for different classes of passengers into two, full and concession.

fare, exact — a transit operations policy that precludes the making of change for passengers. A passenger must therefore have the correct change for the fare or else overpay it. Almost universal on North American transit except where ticket kiosks or ticket vending machines make change.

fare, flat — method of travel pricing that uses a single fare for the entire service area regardless of the trip's distance, time of day, area of travel, or other characteristics.

fare, graduated — a fare that is proportional to the distance traveled (also known as mileage fare) or to the length of time that a passenger may ride on a service.

fare, mileage — see *fare, graduated.*

fare, off-peak or peak — see *fare, time-of-day.*

fare, peak period surcharge — see *fare, time-of-day.*

fare, pre-paid — any fare not paid on-board a transit vehicle (e.g., a transit pass, a ticket purchased at a machine prior to boarding a vehicle, or a fare paid prior to entering a fare-paid area).

fare, reduced — a special fare for children, students, senior citizens, or others that is less than the regular fare.

fare, regular — see *fare, base.*

fare, single-coin— a fare that can be paid with a single coin (e.g., a quarter) or token.

fare, time-of-day — a fare that varies by time of day. It is usually higher during peak travel periods (peak fare) and lower during non-peak travel periods (off-peak fare).

fare, zone (zoned fare) — a method of transit pricing that is based on the geographical partitioning of the service area. The price is determined by the location and number of zones traversed. Zone fares are frequently used as a method of charging graduated or distance-based fares but may also be used to provide for differential fares for certain markets.

farebox — a device that accepts coins, bills, tickets, tokens, or other fare media given by passengers as payment for rides.

farebox, registering — a farebox that counts the money and fare media processed and records fare information.

farebox recovery ratio — see *fare recovery ratio.*

farebox revenue — see *revenue, farebox.*

farecard — see *magnetic farecard.*

farecard reader — a device that determines the value stored in a farecard when the farecard is inserted. A farecard reader may also be used for appropriately altering the value stored in a farecard when used in conjunction with a passenger turnstile, gate or registering farebox.

fare collection system — the procedures and devices used to collect fares and to accumulate and account for fares paid.

fare collection system, automatic (AFC) — the controls and equipment that automatically admit passengers on insertion of the correct fare in an acceptable form, which may be coins, tokens, tickets, or farecards (magnetically encoded or smart card). On systems with distance based fares stored value farecards must be inserted again on exit, at which point an additional fare may be subtracted. The system may include special equipment for transporting and counting revenues.

fare collection system, proof of payment, self-service, barrier-free, open — various names for an open fare collection system that has no turnstiles or fare gates. *Proof of payment is the preferred name.* It requires that the passenger display proof of payment (e.g., validated ticket, prepaid pass, valid transfer) while on board the transit vehicle or in other designated *fare paid* areas. Enforced through random checking by specific transit employees, security staff or police with the power to collect premium "on-board" fares (more common in Europe) or issue tickets or citations, typically resulting in revenue loss below 2-3%. Widely used in Europe and on North American light rail systems, the system combines flexibility and low cost with the fewest impediments to passengers with disabilities. Often combined with "self-service" ticket vending machines. Erroneously called an "honor" system, a name that applies only to systems without enforcement.

fare recovery ratio (farebox recovery ratio) — the ratio of fare revenue to direct operating expenses; see also *operating ratio.*

fare-registering fare gate (turnstile) — a fare gate that records the fares paid.

fare structure — the system set up to determine how much is to be paid by various categories of passengers using the system in any given circumstance.

fare gate — a device that unlocks to allow a passenger to enter the paid area after a pass, smart card, farecard, or the correct amount of money or tokens has been inserted into it.

federal agencies — see *U.S. Government.*

Federal Highway Administration — see *U.S. Government, Federal Highway Administration.*

Federal Railroad Administration — see *U.S. Government, Federal Railroad Administration.*

Federal Transit Act of 1964 — see *legislation, Federal Transit Act of 1964.*

Federal Transit Administration — see *U.S. Government, Federal Transit Administration.*

feeder service — see *service, feeder.*

ferry — a vessel that carries passengers, vehicles, and/or goods over a body of water, usually for short distances and with frequent, regular service. A ferry is generally a conventional shallow-draft boat, but hydrofoils, catamarans, and hovercraft are also used. Often such vessels are double-ended with a pilot house at each end for control purposes so that the vessel need not be turned around for the next trip.

ferry, urban — Ferries that have at least one terminal within an urbanized area, excluding international, rural, rural interstate, island, and urban park ferries.

ferry berth — a platform extending from a shore over water and supported by piles or pillars, used to secure and provide access to vessels.

ferry passenger loading platform — see *platform, ferry.*

few-to-few service — see *service, few-to-few.*

few-to-many service — see *service, few-to-many.*

first-track miles or kilometers — see *right–of-way miles.*

fishbowl — see, *bus, New Look.*

fixed-block control system — see *control system, fixed-block.*

fixed-grip lift — ropeway system on which carriers remain attached to a haul rope. The ropeway system may be either continuous or intermittently circulating, and either *monocable* or *bicable.*

fixed guideway transit system — see *transit system, fixed guideway.*

fixed route — *see transportation system, fixed route.*

fixed signal — see *signal, fixed.*

flag stop service — see *service, flag stop.*

flange, wheel — see *wheel flange.*

flat fare — see *fare, flat.*

fleet, (rolling stock) — the vehicles in a transit system. Usually, "fleet" refers to highway vehicles and "rolling stock" to rail vehicles.

fleet, base-period — see *base-period fleet.*

fleet capacity — see *capacity, fleet.*

flotsam — floating refuse or debris.

flow, passenger — see *passenger flow.*

flow distribution — see *trip assignment.*

flow rate (rate of flow) — in transportation, the number of units (passengers or vehicles) passing a point on a transportation facility during some period of time, usually counted or recomputed in units per hour. For example, if 8 buses pass a point in the first half hour and 15 in the second, the volume for the hour is 23. However, the flow rate for the first half hour is 16 buses/h, and for the second half hour the flow rate is 30 buses/h. See also *volume.*

flying junction — see *junction, flying.*

force, tractive — see *tractive effort.*

forecasting — in planning, the process of determining the future conditions, magnitudes, and patterns within the urban area, such as future population, demographic characteristics, travel demand.

free area — see *area, free.*

free transfer — see *transfer, free.*

freeway — a divided highway for through traffic that has full access control and grade separations at all intersections. In some countries, it is also known as a motorway.

freeway, metered — a freeway to which access is controlled by entrance ramp signals that use fixed-time signal settings or are regulated by a computerized surveillance system. This procedure is used to prevent freeway congestion. See also *bus priority system, metered freeway.*

freewheeling — see *coasting.*

frequency, service — see *service frequency.*

frequency coefficient, riding — see *riding frequency coefficient.*

frequency distribution, trip length — see *trip length frequency distribution.*

friction brake — see *brake, friction.*

fringe, urban — see *urban fringe.*

fringe area — see *area, fringe.*

frog — a track component used at the intersection of two running rails to provide support and guidance for the wheels. It allows wheels on each rail to cross the other rail. Also applied to similar overhead components on electric rail or trolleybus systems. On streetcar systems the flangeway at the frog can be ramped up. Cars run on their flanges substantially reducing track noise.

fuel, alternative — a non-petroleum fuel with lower pollution that traditional diesel; includes alcohol fuels, mineral fuels, methanol, propane, hydrogen, compressed and liquefied natural gas.

full accessibility — see *accessibility, persons with disabilities.*

full service braking — see *braking, maximum service.*

funicular railway — a passenger transportation mode consisting of a pair of rail vehicles (or short trains) permanently attached to two ends of the same cable, counterbalancing each other. It may have a single track with a turnout or a double track. In the former case, wheels on one side of the car(s) will have double flanges, on the other side, no flanges. This system is used to overcome steep gradients. See also *ropeway, inclined plane*, and *inclined elevator.*

funitel —a form of detachable-grip *aerial lift* that uses two track cables to support the carrier, rather than the usual one, in order to provide greater stability during windy conditions. The name was coined from the words funicular and télépherique, the French-Swiss name for *gondolas.*

furniture, street — see *street furniture.*

G

GIS — Geographic Information System.

GPS — Global Positioning System.

GRT — group rapid transit; see *transit system, group rapid.*

GTO — Gate turn off thyristor, used in chopper controls for electric rail cars and trolleybuses.

gallery car — see *car, gallery.*

gangway — a walking surface which spans any two marine facilities or vessels. Gangways are not fixed and their slope depends on the relative position of the facilities they are spanning.

garage — in bus systems, the location in which buses are stored and serviced and where operators report for work and receive supplies and assignments. Also sometimes known as a *depot* or *barn.*

gas turbine engine — see *engine, gas turbine.*

gate, bus — see *bus gate.*

gather service — see *service, many-to-one.*

gauge, broad (wide gauge) — a rail track gauge greater than standard, wide gauge is slightly greater, broad gauge is substantially greater.

gauge, narrow — rail track gauge that is less than standard, commonly 3 ft 3.4 in. or 1,000 mm (meter gauge), or 3 ft 6 in. or 1,067 mm (Cape gauge).

gauge, standard — a rail track gauge that is 4 ft 8.5 in. (1,435 mm) wide.

gauge, track — the distance between the inside faces of the two rails of a track measured 5/8 in. (16 mm) below the top of the rails and perpendicular to the gauge line.

gauge, wide — see *gauge, broad.*

gauntlet track — a track configuration where the four rails are interlaced without switches. Used as an alternative to single-track sections where insufficient space exists for double tracks, saving capital and maintenance costs, as well as potential operating problems due to frozen or clogged switch points.

gear, running — see *running gear.*

generation, trip — see *trip generation.*

generator, trip — see *trip generator.*

Geographic Information System (GIS) — a computerized database management system in which geographic databases are related to one another via a common set of location coordinates. GIS can provide a spatial, interactive visual representation of transit operations and allows users to make queries and selections of database records based on geographic proximity and attributes such as bus stop activity levels and demographic data.

Global Positioning System (GPS) — A system that determines the real-time position of vehicles using communications with a satellite. Also, refers more specifically to a government-owned system of 24 Earth-orbiting satellites that transmit data to ground-based receivers and provides extremely accurate latitude/longitude ground positions.

gondola — **1.** A cabin used on an aerial lift. **2.** Name popularly used to describe a continuously circulating aerial lift using cabins.

government, U.S. — see *U.S. Government.*

governor — **1.** A device that keeps a transit vehicle from exceeding a set (maximum) speed. **2.** A device that holds the rotational speed of an engine approximately constant regardless of the load or prevents it from exceeding a predetermined value.

grade — or gradient, rise in elevation within a specified distance. As an example, a 1% grade is a 1 ft (m) rise in elevation in 100 ft (m) of horizontal distance, in Britain expressed as 1/100 or 1 in 100, and in Europe 10°/1000.

grade crossing — see *crossing, grade.*

grade crossing protection signal — see *signal, grade crossing protection.*

grade crossing traffic control device — any form of protective or warning device installed at a railroad or transit guideway grade crossing for the protection of highway or street traffic.

grade separation — a vertical separation of intersecting facilities (road, rail, etc.) by the provision of crossing structures.

graduated fare — see *fare, graduated.*

grid network — see *network, grid.*

grips, detachable — grips that are attached and detached from the moving haul rope at station(s) or terminal(s) during normal operation.

grips, fixed — grips that remain continuously attached to the haul rope during normal operation.

group, low mobility — see *transportation disadvantaged.*

group rapid transit — see *transit system, group rapid.*

group riders — see *riders, group.*

guided busway — see *busway, guided.*

guideway — in transit systems, a track or other riding surface (including supporting structure) that supports and physically guides transit vehicles specially designed to travel exclusively on it.

guideway, elevated — a grade-separated guideway on a structure that provides overhead clearance for vehicles at ground level; see also *aerial structure.*

guideway, elevated-on-fill — a grade-separated guideway above the prevailing surface of the terrain that is supported by an embankment instead of by a structure.

guideway, open cut — a guideway below the prevailing surface of the terrain in a trench like excavation (cut or cutting).

H

HCM — Highway Capacity Manual.

HEP — head end power, see *locomotive, passenger*.

HOV — high-occupancy vehicle; see *vehicle, high-occupancy.*

HOV lane — high-occupancy-vehicle lane; see *lane, high-occupancy-vehicle*.

HOV Lane Management — National ITS Architecture Market Package that manages HOV lanes by coordinating freeway ramp meters and connector signals with HOV lane usage signals. Preferential treatment is given to HOV lanes using special bypasses, reserved lanes, and exclusive rights-of-way that may vary by time of day.

HRI — Highway-Rail Intersection.

habit coefficient, riding — see r*iding frequency coefficient*.

handicapped — see *persons with disabilities*.

hanger — structural element connecting a cabin, chair, or other passenger-carrying device to the ropeway track cable carriage or haul rope grip.

haul rope — a wire rope used on a ropeway that provides motion to carriers and is powered by the drive sheave.

head end — the beginning or forward portion of any train.

head sign — a sign indicating the destination of the transit unit (vehicle or train), usually located above the windshield.

headway — the time interval between the passing of the front ends of successive transit units (vehicles or trains) moving along the same lane or track (or other guideway) in the same direction, usually expressed in minutes; see also *service frequency.*

headway, base — the scheduled headway between transit unit (vehicle or train) trips, between peak periods.

headway, clock — the scheduled headway between transit unit (vehicle or train) trips, based on even times, i.e., 60, 30, 20, 15, 10 and 7½ minutes.

headway, interference — headway that is so close that one vehicle or train interferes with or delays the next.

headway, non-interference — headway such that in normal operations one train does not delay another.

headway, policy — **1.** Headway prescribed by reasons other than matching capacity to demand. **2.** The maximum permissible headway as established by the transit agency or (often) the policy board, usually for off-peak, low-demand periods.

headway adherence — the consistency or evenness of the scheduled interval between transit vehicles. A reliability measure based on the coefficient of variation of headways of transit vehicles serving a particular route arriving at a stop.

headway management — a technique for managing the operation of transit units (vehicles or trains) that focuses on maintaining a certain spacing between units on the same line, instead of on adhering to a timetable. For example, if units become bunched, corrective measures might include delaying the units at the rear of the bunch to provide regular headways and hence load distribution, even at the expense of reducing timetable adherence.

heavy rail — see *transit system, rail rapid.*

high-occupancy vehicle — see *vehicle, high-occupancy.*

high-occupancy-vehicle lane — see *lane, high-occupancy-vehicle.*

high platform — see *platform, high.*

high voltage — see *voltage, high.*

highway, street, or road — **1.** General terms denoting a public way for purposes of vehicular travel, including the entire area within the right-of-way. The recommended usages are as follows: in urban areas, highway or street; in rural areas, street or road. **2.** Street, in common general usage, refers to the vehicular travel way, as distinguished from the sidewalk (the pedestrian travel way).

Highway Capacity Manual — A standard reference used to calculate the capacity and quality of service of roadway facilities.

Highway-Rail Intersection (HRI) — National ITS Program User Service that integrates ITS technology into already existing HRI warning systems to enhance their safety effectiveness and operational efficiency. At railroad grade crossings, HRI technologies located both in-vehicle and along the roadside ensure that train movements are coordinated with traffic signals and that drivers are alerted to approaching trains.

highway/RR crossing — see *crossing, highway/railroad.*

home-based trip — see *trip, home-based.*

honor system — type of fare collection system without controls or checks, once common only in the Soviet Union and Eastern Europe but now rapidly disappearing. Often incorrectly used to describe enforced proof of payment fare collection system, see *fare collection system, open*, *proof of payment*, *self-service*, and *barrier-free*.

hot, running — see *running hot.*

hour(s), rush — see *peak.*

hours of service — **1.** The number of hours during the day between the start and end of service on a transit route, also known as the service span. **2.** For calculating transit level of service, the number of hours during a day when service is provided at least hourly on a transit route.

hub (timed transfer focal point) — transit center or interchange for connections or transfers between modes and/or routes. Connections are usually timed in clock-headway pulses and allow convenient transfer between local routes and to express routes. The express routes can connect to the city center and to other hubs, thus offering better suburb-to-suburb trips than possible with a radial route system. Hubs are best located at activity centers such as shopping malls, suburban town centers and campuses.

hub-and-spoke — type of route structure based on timed connections that increases connectivity and productivity, see *hub.*

hub miles (hub kilometers) — actual logged miles (kilometers) of vehicle operation, usually read from a hubometer or odometer.

hull — the frame or body of a vessel, exclusive of masts, engines, or superstructures.

I

ICE — internal combustion engine; see *engine, internal combustion.*

ISTEA — Intermodal Surface Transportation Efficiency Act of 1991.

ITE — Institute of Transportation Engineers; see *organizations, Institute of Transportation Engineers.*

ITS — Intelligent Transportation Systems.

ITS America — Intelligent Transportation Society of America. A non-profit, public/private scientific and educational corporation that works to advance a national program for safer, more economical, more energy efficient, and environmentally sound highway travel in the United States. Federal advisory committee used by the U.S. Department of Transportation.

ITS Data Mart — National ITS Architecture Market Package that provides a focused archive that houses data collected and owned by a single entity (e.g., agency). This focused archive typically includes data covering a single transportation mode and one jurisdiction that is collected from an operational data store and archived for future use.

ITS Data Warehouse — National ITS Architecture Market Package that includes all the data collection and management capabilities provided by the *ITS Data Mart*, and adds the functionality and interface definitions that allow collection of data from multiple agencies and data sources spanning across modal and jurisdictional boundaries.

impedance — **l.** In transportation generally, any condition that restricts or discourages travel, or a measure of that condition. **2.** In transportation modeling, any such condition explicitly accounted for within the model. Time and costs are the factors usually considered, but others may also be examined.

inbound trip — see *trip, inbound.*

inclined elevator —an elevator capable of both horizontal and vertical movement along a fixed path. Differs from *inclined planes* in that only one cabin is used and no attendant is needed to operate it.

inclined plane (incline, inclined railway) — a special type of rail vehicle permanently attached to and hauled by a cable, used for steep gradients, operating on one or two tracks. When two counter-balanced vehicles operate on railway-type tracks, it is also known as a *funicular railway.*

index — a performance measure developed by weighting two or more other performance measures.

indication, signal — see *signal indication.*

indicator, block — see *block indicator.*

indicator, performance — see *performance indicator*

induced demand or traffic — see *traffic, induced.*

induction loop sensor — see *loop detector.*

induction motor — see *motor, induction.*

information, service or user — see *user information.*

information services — see *Railroad Research Information Service, Transportation Research Information Services,* and *Urban Mass Transportation Research Information Service.*

infrastructure — **l.** In transit systems, all the fixed components of the transit system, such as rights-of-way, tracks, signal equipment, stations, park-and-ride lots, bus stops, maintenance facilities. **2.** In transportation planning, all the relevant elements of the environment in which a transportation system operates.

inspector (road supervisor, route supervisor, street supervisor, road foreman) — a transit employee who evaluates performance, enforces safety and work rules, and attempts to solve problems; an inspector may be mobile (covering several districts in a radio-equipped vehicle) or fixed (assigned to a post at a designated intersection).

Institute of Transportation Engineers — see *organizations, Institute of Transportation Engineers.*

insulated rail joint — see *rail joint, insulated.*

Intelligent Transportation Systems (ITS) — electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system.

integration, intermodal — see *intermodal integration.*

Interactive Traveler Information — National ITS Architecture Market Package that provides tailored information in response to a traveler request. The traveler can obtain current information regarding traffic conditions, transit services, ride share/ride match, parking management, and pricing information.

interchange — **1.** facility for passenger transfers or connection between routes or modes, see *hub*. **2.** The system of interconnecting ramps between two or more intersecting travel ways (highways, transit guideways, etc.) that are grade separated.

interchange center, modal — see *transit center.*

intercity bus — see *bus, intercity.*

intercity transportation — **1.** Transportation between cities. **2.** Transportation service provided between cities by certificated carriers, usually on a fixed route with a fixed schedule.

interface, transportation — see *transportation interface.*

interline — **1.** interchange of passengers between one or more bus lines, rail transit lines, or railroads. **2.** transfer of transit vehicles or trains between routes during a day to improve staff or vehicle assignment efficiency.

interlocking — in rail systems, an arrangement of switch, lock, and signal devices that is located where rail tracks cross, join, separate, and so on. The devices are interconnected in such a way that their movements must succeed each other in a predetermined order, thereby preventing opposing or conflicting train movements.

interlocking limit — the track length between the most remote opposing home signals of an interlocking.

interlocking, solid-state — an interlocking with logic based on computers rather than traditional relays or, now obsolete, mechanical locks.

intermodal — **1.** The ability to connect, and make connections between, modes of transportation. **2.** Those issues or activities which involve or affect more than one mode of transportation, including transportation connections, choices, cooperation and coordination of various modes.

intermodal integration — service coordination between two or more different transportation modes. This arrangement may include joint (transfer) stations, coordinated scheduling, joint fares, and combined public information activities.

intermodal transfer facility — see *transit center.*

intermodalism — seamless integration of multiple travel modes.

internal combustion engine — see *engine, internal combustion.*

International Union of Public Transport — see *organizations, International Union of Public Transport.*

interrupted flow — transit vehicles moving along a roadway or track and having to make service stops at regular intervals.

intersection — the point at which two or more roadways meet or cross.

intersection, point of — see *point of intersection.*

interurban — see *transit system, interurban.*

iron maiden — full height tri-part turnstile with interlocking metal bars, impervious to fraud or vandalism, used mainly on older East Coast rapid transit systems, mainly for exiting station platforms, also on Toronto subway for unattended, token actuated, entrances.

island platform — see *center platform.*

island, loading or pedestrian — see *loading island.*

J

jaywalk — to illegally cross a street in the middle of the block or against a pedestrian signal.

jerk — time rate of change of acceleration or deceleration of a vehicle, measured in ft/s^3 (m/s^3).

jitney — A transit mode comprising passenger cars or vans operating on fixed routes (sometimes with minor deviations) as demand warrants without fixed schedules or fixed stops. See also *transportation system, jitney; service, jitney;* and *público.*

journey, linked — see *trip, linked.*

journey time — see *time, journey.*

jumper, queue — see *queue jumper.*

junction — **1.** In transit operations, a location at which transit routes or lines converge or diverge. **2.** In traffic engineering, an intersection.

junction, flying — a grade-separated rail junction, allowing merging and diverging movements to be made without conflict and with minimal impact on capacity.

K

K&M — see *pendulum suspension.*

K&R — kiss and ride.

K factor — in vehicle operations, the ratio of the minimum operating separation between two vehicles to the maximum emergency stopping distance. Normally, the factor is greater than 1 to provide a margin of safety.

kilometer— for all terms containing "kilometer" see equivalent term with "mile."

kiosk — in the transportation context, an interactive computer center for traffic- or travel-related information. Usually located in shopping malls, hotels, airports, businesses, and transit terminals, kiosks provide pre-recorded and real-time information using text, sound, graphics, and video clips.

kiss-and-ride (kiss 'n' ride, K&R) — An access mode to transit whereby passengers (usually commuters) are driven to a transit stop and left to board a transit unit and then met after their return trip. Transit stations, usually rail, often provide a designated area for dropping off and picking up such passengers.

knot — nautical unit of speed; equivalent to 1 nautical mile (1.15 miles or 1.852 kilometers) per hour.

L

“L” — abbreviation for elevated (railway), mainly Chicago, see *transit system, rail rapid.*

LIM — linear induction motor; see *motor, linear induction.*

LNG — Liquefied Natural Gas.

LOS — level of service.

LRT — light rail transit; see *transit system, light rail.*

LRV — light rail vehicle; see *car, light rail.*

lane, bus (bus priority lane, preferential bus lane, priority bus lane) — a highway or street lane reserved primarily for buses, either all day or during specified periods. It may be used by other traffic under certain circumstances, such as making a right or left turn, or by taxis, motorcycles, or carpools that meet specific requirements described in the traffic laws of the specific jurisdiction.

lane, bypass — see *queue jumper.*

lane, carpool — a highway or street lane intended primarily for carpools, vanpools, and other high-occupancy vehicles, including buses, either all day or during specified periods. It may be used by other traffic under certain circumstances, such as while making a right turn. Minimum occupancy is contentious, many requirements for a minimum of three passengers have been reduced to two through political pressure or legal action.

lane, contraflow — a highway or street lane on which vehicles operate in a direction opposite to what would be the normal flow of traffic in that lane. Such lanes may be permanently designated contraflow lanes, or, more usually, they may be used as contraflow lanes only during certain hours of the day. Frequently, the use of a contraflow lane is restricted to public transit and (possibly) other specially designated vehicles.

lane, diamond — a high-occupancy-vehicle lane physically marked by diamonds painted on the pavement and often indicated by diamond-shaped signs as well. Often used synonymously with high-occupancy-vehicle lane.

lane, exclusive carpool — a highway or street lane reserved for carpools and vanpools.

lane, exclusive transit (reserved transit lane) — a highway or street lane reserved for buses, light rail vehicles, or both.

lane, high-occupancy-vehicle (HOV lane) — a highway or street lane reserved for the use of high-occupancy vehicles (HOVs), see *lane, carpool.*

lane, priority — a highway or street lane reserved (generally during specified hours) for one or more specified categories of vehicles, for example, buses, carpools, vanpools.

lane, ramp meter bypass — a form of preferential treatment in which a bypass lane on metered freeway on-ramps is provided for the exclusive use of high-occupancy vehicles.

lane, reserved transit — see *lane, exclusive transit.*

lane, reversible — a highway or street lane on which the direction of traffic flow can be changed to use maximum roadway capacity during peak-period demands.

lane, reversible bus — a highway or street lane that is reserved for the exclusive use of buses and other high-occupancy vehicles and that can be operated in alternate directions during the two peak-hour periods. It may be the center lane in an arterial street that is used for left-turning traffic in off-peak hours. Usually, bus operators who use this facility are required to have special training and a permit, and the buses may be subject to access or operation controls or both. See *lane, contraflow.*

lay-by — **l.** In rail systems, a side track. **2.** In bus systems, see *bus bay.*

layover, vehicle — see *time, layover.*

layover time — see *time, layover.*

layover zone — a designated stopover location for a transit vehicle at or near the end of the route or line or at a turnback point.

legislation, Americans with Disabilities Act of 1990 (ADA) — federal civil rights law which ensures people with disabilities equal opportunity to fully participate in society, the ability to live independently, and the ability to be economically sufficient.

legislation, Federal Transit Act of 1964 — federal legislation enacted in 1964 that established the federal mass transportation program. Formerly known as the Urban Mass Transportation Act of 1964. Repealed in 1994 and reenacted as chapter 53 of title 49, United States Code.

legislation, Intermodal Surface Transportation Efficiency Act (ISTEA) — signed into federal law on December 18, 1991, it provided authorizations for highways, highway safety and mass transit for 6 years and served as the basis of federal surface transportation programs. Renewed and amended in 1998 for 6 years as TEA-21, see *legislation, TEA-21.*

legislation, National Environmental Policy Act of 1969 (NEPA) — a comprehensive federal law requiring an analysis of the environmental impacts of federal actions, such as the approval of grants, and the preparation of an environmental impact statement for every major federal action that significantly affects the quality of the human environment.

legislation, TEA-21 — 1998 Transportation Efficiency Act for the 21st Century, provides authorizations for highways, highway safety, and mass transit for 6 years and is the basis of federal surface transportation programs, replaces ISTEA.

legislation, Title 49 United States Code, Chapter 53–Mass Transportation — federal legislation establishing the federal mass transportation program. Formerly known as the Federal Transit Act of 1964, and before that, the Urban Mass Transportation Act of 1964.

legislation, Title 49 United States Code, Chapter 53–Mass Transportation, Section 5335 — the section of the United States Code that authorizes the Secretary of Transportation to request and receive statistical information about the financing and operations of public mass transportation systems eligible for Section 5307 grants on the basis of a uniform system of accounts and records. This information is compiled in the

National Transit Database. Formerly Section 15 of the Federal Transit Act of 1964.

legislation, Urban Mass Transportation Act of 1964 — see *legislation, Federal Transit Act of 1964.*

level of service (LOS) — **1.** A designated range of values for a particular service measure (e.g., "A" through "F" or "1" through "8"), based on users' perceptions (see *quality of service*) of the aspect of transportation performance being measured. **2.** The amount of transit service provided.

levitation, magnetic — see *magnetic levitation.*

lift, wheelchair — see *wheelchair lift.*

light rail — see *transit system, light rail;* and *transit system, light rail rapid.*

light rail car — see *car, light rail.*

light rail, dual-mode— see *transit system, light rail, dual-mode.*

light rail rapid transit — see *transit system, light rail rapid.*

light rail transit — see *transit system, light rail.*

light rail vehicle — see *car, light rail.*

limit, civil speed — see *civil speed limit.*

limited access — see *access, limited.*

limited service — see *service, limited.*

limited-stop service — see *service, limited-stop.*

limits, interlocking — see *interlocking limits.*

limits, yard — see *yard limits.*

line — **1.** A transportation company (e.g., a bus line). **2.** A transit service operated over a specified route or combination of routes. **3.** An active (in-use) railroad track or AGT guideway. **4.** In network coding, a route and its service level, including mode designation (type of service), line number, headway, and sequence of transfer points (nodes). These factors describe the line's route as an ordered set.

line, cordon — see *cordon line.*

line, desire — see *desire line.*

line, main — the principal roadway, rail tracks, or other type of transportation right-of-way over which all or most of the traffic moves.

line speed — see *speed, line.*

linear electric motor — see *motor, linear electric.*

linear induction motor — see *motor, linear induction.*

line capacity — see *capacity, line;* and *capacity, theoretical line.*

line-clear — in rail transit, operation such that trains do not have to stop or slow down due to the train ahead but receive a succession of green signals. See also *headway, non-interference.*

line haul — see *service, line haul.*

line miles (line kilometers, miles or kilometers of directional roadway) — the sum of the actual physical length (measured in only one direction) of all streets, highways, or rights-of-way traversed by a transportation system (including exclusive rights-of-way and specially controlled facilities), regardless of the number of routes or vehicles that pass over any of the sections; see also *route miles.*

line volume — see *passenger volume.*

link — in planning, a section of a transportation system network defined by intersection points (nodes) at each end; that is, a link connects two nodes. It may be one way or two way.

linked journey or trip or passenger trip — see *trip, linked.*

linked trip distance — see *trip distance, linked.*

linked trip time — see *time, linked trip.*

link load — in planning, the assigned volume of traffic on a link; see also *link volume.*

link volume — in planning, the total number of highway vehicles or transit passengers assigned to a network link.

load, crush — see *capacity, crush.*

load, link — see *link load.*

load, passenger — see *passenger load.*

load, scheduled design — the maximum number of people that agency policy calls for being on-board a transit vehicle at a given time. It can be expressed as an average load over a half-hour, hour, or other time period, or as a value not to be exceeded more than a certain percentage of time (or at all). Service is scheduled to ensure that sufficient vehicles are operated that passenger loads do not exceed the limits set by the agency policy.

load factor — **1.** The ratio of used capacity to offered capacity of equipment or a facility during a specified time period. It is usually expressed as a percentage of seats occupied at a given point or (in continuous form) passenger miles (km) divided by seat miles (km). For rail services, the load factor is sometimes expressed as passenger miles (km) per train mile (km) to account for the ability to couple rail cars together to achieve efficiency. **2.** The ratio of passengers actually carried versus the total passenger capacity of a vehicle; also known as a *utilization coefficient.*

load point, maximum — see *maximum load point.*

load section, maximum — see *maximum load section.*

load shedding — **1.** reducing the amount of conventional transit service at peak hours by encouraging the use of paratransit operations to carry some of the peak-period passengers. **2.** disconnecting part of electric traction network at time of power shortage or sub-station failure. Available power will then be rotated from section to section of line to move all trains into a station, or to keep part of the line operating normally.

loading, link — see *link loading.*

loading area — a curbside space where a single bus can stop load and unload passengers. Bus stops include one or more loading areas. See also *bus bay* and *stop, transit.*

loading island — **1.** A pedestrian refuge within the right-of-way and traffic lanes of a highway or street. It is provided at designated transit stops for the protection of passengers from traffic while they wait for and board or alight from transit vehicles; also known as a *pedestrian* or *boarding island.* **2.** A protected spot for the loading and unloading of passengers. It may be located within a rail transit or bus station. **3.** On streetcar and light rail systems, a passenger loading platform in the middle of the street, level with the street or more usually raised to curb height, often protected with a *bollard* facing traffic, also known as a *safety island.*

local bus or service — see *service, local bus.*

local train — see *train, local.*

location referencing — technology that more precisely identifies locations of vehicles, locations, and travelers. Used with GPS and AVL technologies.

location, vehicle — see *automatic vehicle location system.*

locomotive — a powered rail vehicle used for towing rail cars. It does not carry passengers and is usually powered by electric motors or diesel engines.

locomotive, diesel-electric — a locomotive that uses one or more diesel engines to drive electric generators that in turn supply electric motors geared to the driving axles. By far the dominant type of locomotive in North America.

locomotive, dual-powered — a locomotive that is capable of both diesel and electric operation, generally specific to services entering New York City (Grand Central Terminal) where diesel operation is limited.

locomotive, electric — a locomotive in which the propulsion is effected by electric motors mounted on the vehicle. The electric power comes from an external source, usually overhead catenary.

locomotive, passenger — a locomotive commonly used for hauling passenger trains and generally designed to operate at higher speeds and lower tractive effort than a freight locomotive of equal power. Usually equipped with head end power that, through power take-off from the existing generator, a separate generator, or power conversion unit(s), provides heat, light, and air conditioning power for the passenger cars.

loop — **1.** A transit route or guideway layout that is of a closed continuous form, such as a circle. **2.** A terminal track layout or bus driveway that reverses the direction of a vehicle without the vehicle itself reversing.

loop detectors — a loop of wire embedded in the roadbed that carries a small electric current used to sense a passing vehicle and to yield information about the presence of the vehicle. Loop detectors are also used to actuate traffic signals and detect roadway incidents.

low-floor bus — see *bus, low-floor.*

low-floor light rail vehicle — see *car, light rail vehicle, low-floor.*

low-floor streetcar — see *car, light rail vehicle, low-floor.*

low mobility group — see *transportation disadvantaged.*

low platform — see *platform, low.*

low voltage — see *voltage, low.*

M

MAC — major activity center.

MAC system — major activity center system; see *transit system, major activity center.*

MAGLEV — magnetic levitation.

MG set — see *motor-generator.*

MLP — maximum load point.

MLS — maximum load section.

MSA — metropolitan statistical area.

MU — multiple unit; see *car, multiple-unit.*

MUTCD — *Manual on Uniform Traffic Control Devices.*

magnetic brake — see *brake, track.*

magnetic farecard — a card containing a magnetic tape strip or other electronic means of indicating the value purchased. The card is usually obtained from a vending machine and must be inserted into a farecard reader to gain access to the paid area of the transit system. In systems with fares by distance the card must also be inserted into a farecard reader to exit the paid area, see also *smart card* and *fare collection system, automatic.*

magnetic levitation (MAGLEV) — support technology that keeps a vehicle vertically separated from its track or riding surface by magnetic force, either attractive or repulsive. After interest in the 1970s and 1980s this technology has been discredited for urban transit use and is essentially moribund.

main line — see *line, main.*

maintenance — the upkeep of vehicles, plant, machinery, and equipment. It may be scheduled, planned, progressive, or periodic on the basis of pre-established intervals of time, hours, or mileage, and employ preprinted checklists *(preventive maintenance),* or it may be unscheduled or corrective, in which case it is generally not interval based.

major activity center (MAC, activity center) — a geographical area characterized by a large transient population and heavy traffic volumes and densities; for example, central business district, major air terminal, large university, large shopping center, industrial park, sports arena.

major activity center transit system — see *transit system, major activity center.*

mall, transit — see *street, transit.*

management, headway — see *headway management.*

management, transportation system — see *transportation system management.*

manual block control system — see *control system, manual block.*

Manual on Uniform Traffic Control Devices — standard reference published by the U.S. Department of Transportation guiding the usage of traffic and on-street light rail control devices.

manual train control — see *control system, manual train.*

many-to-few service — see *service, many-to-few.*

many-to-many service — see *service, many-to-many.*

many-to-one service — see *service, many-to-one.*

market — **1.** The potential or actual consumers (or both) of a (transportation) product or service. A general market denotes the entire population of a designated geographical area, whereas a specialized market denotes particular groups, such as the elderly, persons with disabilities, or students. **2.** The extent of demand for a transportation commodity or service.

Market Package — the building blocks of the National ITS Architecture. Derived from the User Services, the Market Packages provide a finer-grained breakdown tailored to fit—separately or in combination—real-world transportation problems and needs.

market share — the percentage of a (transportation) market realized by or available to a particular (transportation) provider.

married pair — two semi-permanently coupled rail cars (A car and B car) that share some mechanical and electrical equipment and must be operated together as a unit.

mass transit, mass transportation — urban public transport by bus, rail, or other conveyance, either publicly or privately owned, providing general or special service to the public on a regular and continuing basis (not including school bus, charter, or sightseeing service). The term has developed a negative connotation and its use is discouraged in favor of urban transport, transit, public transit, public transport or public transportation.

maximum load point (MLP) — see *maximum load section*.

maximum load section (MLS) — the section of a transit line or route that carries the highest total number of passengers for that line or route and direction. *Maximum load point* is commonly but inaccurately used in place of this term.

maximum service braking — see *braking, maximum service.*

maximum theoretical velocity — see *velocity, maximum theoretical.*

measure of effectiveness — see *performance measure* and *service measure, transit.*

mechanical brake — see *brake, friction.*

median (median strip) — the portion of a divided highway or guideway that separates the opposing flows of traffic.

messenger — see definition of *catenary system.*

metered freeway — see *freeway, metered.*

metered freeway bus priority system — see *bus priority system, metered freeway.*

metering, ramp — see *ramp metering.*

metro— short for metropolitan railway, the most common international term for subway, heavy rail, rail rapid transit, increasingly used in North America, see *transit system, rail rapid.*

metropolitan railway — see *transit system, rail rapid.*

micro-peaking — short peak periods and surges within the 15-minute or hourly peak. For stations and stops, micro-peaking is likely to occur just after a transit vehicle arrives and discharges passengers; may result in increased crowding for a short duration.

mid-block stop — see *stop, mid-block.*

midibus — a bus with a passenger capacity of approximately 20-30 people.

mileage fare — see *fare, graduated.*

miles of route or roadway — see *route miles.*

miles of travel, vehicle — see *vehicle miles of travel.*

mini-high platform — see *platform, mini-high.*

minibus — a small bus, typically capable of carrying 20 passengers or fewer. It is most often used for making short trips, demand-responsive transportation, community services or bus pools.

missed trip — see *trip, missed.*

mixed mode street — see *street, mixed mode.*

mixed or mixed-flow traffic — see *traffic, mixed.*

mixed traffic operations — the operation of transit vehicles on nonexclusive rights-of-way with non-transit vehicles.

mobility — the ability to satisfy the demand to move a person or good.

modal interchange center — see *transit center.*

modal split (mode split) — **1.** The proportion of total person trips that uses each of various specified modes of transportation. **2.** The process of separating total person trips into the modes of travel used; see also *urban transportation modeling system* and *model, sequential.*

mode — **1.** A transport category characterized by specific right-of-way, technological and operational features, **2.** A particular form of travel, for example, walking, traveling by automobile, traveling by bus, traveling by train.

mode, access — a feeder mode to the principal mode of transportation; for example, walking, kiss and ride, park and ride.

mode, dual — see *transit system, dual-mode.*

mode, transit — a category of transit systems characterized by common characteristics of technology, right-of-way, and type of operation. Examples of different transit modes are regular bus service, express bus service, light rail transit, rail rapid transit, and commuter rail.

model — **l.** A mathematical or conceptual presentation of relationships and actions within a system. It is used for analysis of the system or its evaluation under various conditions; examples include land use, economic, socioeconomic, transportation. **2.** A mathematical description of a real-life situation that uses data on past and present conditions to make a projection about the future.

mode split — see *modal split.*

monocable system — a ropeway system that uses a single haul rope to both support and control motion of the carriers.

monorail — see *transit system, monorail.*

monthly pass — see *pass, monthly.*

mooring — a secure object to which a vessel may be tied.

motor (electric motor) — a machine that transforms electrical energy into mechanical energy (torque).

motor, alternating-current — an electric motor (asynchronous, synchronous, induction, etc.) that operates on alternating current, generally three phase. The dominant motor type on modern electric transit vehicles from the mid-1990s.

motor, direct current — an electric motor (shunt, compound, etc.) that operates on direct current.

motor, electric — see *motor.*

motor, induction — an asynchronous alternating-current rotary motor that converts alternating-current electric power, delivered to the primary winding (usually the stator) and carried as induced current by the secondary winding (usually the rotor), into mechanical power.

motor, linear induction (LIM), single-sided linear induction, linear electric — an electric motor that produces mechanical force through linear, instead of rotary, motion, used to propel vehicles along a track or other guideway. The vehicle borne motor creates a "moving" magnetic field that is translated into linear motion via an inert steel guideway reaction rail, often laminated and aluminum covered. Used on the ALRT and AGT systems in Vancouver, Toronto (Scarborough), Detroit, New York JFK Airport, and Kuala Lumpur.

motor, series-wound — a motor in which the field circuit is connected in series with the armature circuit, often called a *traction motor.*

motor, shunt — a type of rotary electric motor in which the field coils are connected in parallel with the motor armature.

motor, synchronous — a synchronous machine that transforms electrical power from any alternating-current system into mechanical power. The average speed of normal operation is equal to the frequency of the power system to which it is connected.

motor, traction — an electric motor, usually direct current and series wound, that propels a vehicle by exerting its torque through the wheels; see also *motor, series-wound.*

motor brake — see *brake, dynamic.*

motor bus — see *bus, motor.*

motor car, rail — see *car, rail motor.*

motor coach — see *bus, motor.*

motor-generator (MG set) — an electrical motor, usually at line voltage, mechanically coupled to a direct current generator to provide low voltage (*12, 24 or 32 volts, sometimes higher)* supply for rail transit cars and trolleybuses. Now replaced with solid-state DC-DC converters.

motor operator or motorman — see *operator, train.*

move, reverse — see *reverse move.*

mover, people — see *people mover.*

moving block control system — see *control system, moving block.*

moving ramp — see *ramp, moving.*

moving sidewalk — see *moving walkway.*

moving walkway (moving sidewalk, passenger or pedestrian conveyor, passenger belt, travelator) — a fixed, level or gently inclined (up to 12°) conveyor device (usually a flexible belt) on which pedestrians may stand or walk while being transported; see also *ramp, moving.*

Multi-modal Coordination — National ITS Architecture Market Package that establishes two-way communications between multiple transit and traffic agencies to improve service coordination. Intermodal coordination between transit agencies can increase traveler convenience at transfer points and also improve operating efficiency. Coordination between traffic and transit management is intended to improve on-time performance of the transit system to the extent that this can be accommodated without degrading overall performance of the traffic network.

multimodal —the availability of transportation options using different modes within a system or corridor.

multimodal transit agency — a transit agency operating more than one mode of service.

multiple-unit car — see *car, multiple-unit.*

multiple-unit control system — see *control system, multiple-unit.*

N

NCHRP — National Cooperative Highway Research Program.

NCTRP — National Cooperative Transit Research and Development Program.

NEPA — National Environmental Policy Act; see *legislation, National Environmental Policy Act of 1969.*

NFPA — NFPA 130 — National Fire Prevention Association 130. Standards for fire and life safety on fixed guideway transit systems. Adopted into law in Canada and the United States, and, in part or whole, in some other jurisdictions. Even where not adopted the standards are generally applied in designing new fixed guideway systems worldwide. Older rail transit systems are not required to retrofit to these standards, first issued in 1983. Separate standards issued in 1998 for automated guideway transit. Available from NFPA, Batterymarch Park, Quincy, MA 02269 USA.

NPTS — Nationwide Personal Transportation Study.

NTD — see *National Transit Database.*

NTSB — National Transportation Safety Board; see *U.S. Government, National Transportation Safety Board.*

narrow gauge — see *gauge, narrow.*

National Cooperative Highway Research Program (NCHRP) — a program established by the American Association of State Highway Officials (now American Association of State Highway and Transportation Officials) to provide a mechanism for a national coordinated program of cooperative research employing modern scientific techniques. The NCHRP is administered by the Transportation Research Board.

National Environmental Policy Act of 1969 — see *legislation, National Environmental Policy Act of 1969.*

National ITS Architecture — a common framework for ITS interoperability. The National ITS Architecture comprises the logical architecture and physical architecture that satisfy a defined set of User Services. The National ITS Architecture is maintained by the U.S. DOT and is available on the DOT web site at http://www.its.dot.gov/.

National Railroad Passenger Corporation — see *U.S. Government, National Railroad Passenger Corporation*

National Transit Database (NTD) — a database compiled by the Federal Transit Administration of operating and financial statistics for over 600 transit agencies in the United States (those systems eligible for grants under Title 49 United States Code, Chapter 53–Mass Transportation, Section 5307.) Formerly known as Section 15 of the Federal Transit Act.

National Transportation Safety Board — see *U.S. Government, National Transportation Safety Board.*

Nationwide Personal Transportation Study (NPTS) — the NPTS, conducted periodically by the Bureau of the Census, has been the primary source of national data on travel patterns and frequency, transit use for all purposes, and the characteristics of transit users versus all travelers.

near-side stop — see *stop, near-side.*

network — **l.** In planning, a system of links and nodes that describes a transportation system. **2.** In highway engineering, the configuration of highways that constitutes the total system. **3.** In transit operations, a system of transit lines or routes, usually designed for coordinated operation.

network, grid — **1.** In planning, an imaginary network of evenly spaced horizontal and vertical bars or lines that divides a study area into small geographic zones. **2.** In transit operations, a service pattern in which two sets of parallel routes intersect each other at right angles.

network, radial — in transit operations, a service pattern in which most routes converge into and diverge from a central hub or activity center (e.g., central business district), like the spokes of a wheel. The hub may serve as a major transfer point.

New Look bus — see *bus, New Look, fishbowl.*

node — in planning, a point that represents an intersection of two or more links, highways, or transit lines or routes or a zone centroid; used in trip assignment.

non-fixed route — see *transportation system, non-fixed route.*

non-home-based trip — see *trip, non-home-based.*

non transportation revenue — see *revenue, non transportation.*

normal vehicle capacity — see *capacity, vehicle.*

not-in-service time — see *time, deadhead.*

O

OBD — outlying business district.

OCS — overhead contact system.

O-D study — origin-destination study.

occupancy, area — see *area occupancy.*

occupancy, vehicle — see *vehicle occupancy.*

off-line — not in the main flow of traffic or not on the main line of traffic, for example, off-line station.

off-line station — see *station, off-line.*

off peak — the periods of time outside the peak periods; see also *base period.*

off-peak fare — see *fare, time-of-day.*

off-peak period — see *base period.*

off-street terminal — see *terminal, off-street.*

on-and-off check or count — see *check.*

on-board check — see *check.*

one-to-many service — see *service, one-to-many.*

one-way trip — see *trip.*

one-zone ride — a transit ride within the limits of one fare zone.

on-line — in the main flow of traffic.

on-line station — see *station, on-line.*

on-time performance — the proportion of the time that a transit system adheres to its published schedule times within stated tolerances; for example, a transit unit (vehicle or train) arriving, passing, or leaving a predetermined point (time point) along its route or line within a time period that is no more than x minutes earlier and no more than y minutes later than a published schedule time. (Values of 0 minutes for x and 5 minutes for y are the most common. On frequent rail services the headway can be used for x, with greater values indicating that the late train interferes with (delays) the following one.)

open cut guideway — see *guideway, open cut.*

open-loop braking — see *braking, open-loop.*

open fare system — see *fare collection system, proof of payment, self-service, barrier-free, open.*

operating costs — the sum of all recurring costs (e.g., labor, fuel) that can be associated with the operation and maintenance of the system during the period under consideration. Operating costs usually exclude such fixed costs as depreciation on plant and equipment, interest paid for loans on capital equipment, and property taxes on capital items. See also *capital costs.*

operating employees (operating personnel) — **l.** Employees whose major function is operating the service, such as station employees, bus drivers, train operators, and conductors. **2.** In rail operations, those employees that have direct and supervisory responsibility for the movement of transit units (cars or trains), embodying both on-board and wayside duties.

operating expenses — the total of all expenses associated with operation of an individual mode by a given operator. In the United States, total operating expense is reported on line 14 of Form 301 for a single mode system, and is derived from Form 310 for a multimodal system. Operating expenses include distributions of "joint expenses" to individual modes, and exclude "reconciling items" such as interest expenses and depreciation. Do not confuse with "vehicle operations expense."

operating margin — **1.** the amount of time that a train can run behind schedule without interfering with following trains. **2.** imprecise reference to operating ratio.

operating ratio — the ratio of operating expenses to operating revenue; the inverse of cost recovery ratio. It is used as a measure of financial efficiency. See also *fare recovery ratio.*

operating revenue, total — see *revenue, total operating.*

operating speed — see *speed, running;* and *speed, schedule.*

operating speed, effective — see *speed, overall trip.*

operating time — see *time, operating.*

operating unit — see *basic operating unit.*

operation — see *operator* and *property.*

operation, automatic train — see *automatic train operation.*

operation, train — see *train operation.*

operational characteristic — any characteristic of transit service operation, i.e., this route is frequently overcrowded.

operations, mixed traffic — see *mixed traffic operations.*

operator — **1.** An employee of a transit system whose workday is spent in the operation of a transit unit (vehicle or train), such as a bus driver or train operator. Such an employee may also be known as a *platform operator.* **2.** The organization that runs a transportation system on a day-to-day basis. also known as an *operation, property, agency* or *system;* see also *property.*

operator, car — see *operator, train.*

operator, motor — see *operator, train.*

operator, rapid transit — see *operator, train.*

operator, streetcar — see *operator, train.*

operator, train (motor operator, engineer) — the operating employee who controls the movement of a rail transit unit (vehicle or train.) Specific titles are also used, such as *car operator, rapid transit operator, streetcar operator.*

order, slow — see *slow order.*

orders — authorization to move a train, as given by a train dispatcher either in writing or orally.

organizations — see also *U.S. Government* and *union, transit.*

organizations, American Association of State Highway and Transportation Officials (AASHTO) — membership includes state and territorial highway and transportation departments and agencies and the U.S. Department of Transportation. Its goal is to develop and improve methods of administration, design, construction, operation, and maintenance of a nationwide integrated transportation system. It studies transportation problems, advises Congress on legislation, and develops standards and policies.

organizations, American Public Transportation Association (APTA) — a non-profit international industry association made up of transit systems and other organizations and institutions connected to or concerned with the transit industry. It performs a variety of services for the industry, and its objectives include promotion of transit interests, information exchange, research, and policy development. Known as the American Public Transit Association prior to 2000.

organizations, Association of American Railroads (AAR) — an industry association made up of individual railroads in the United States, Canada, and Mexico. It performs a variety of technical services for the railroads, and its purposes include the promotion of railroad interests and the standardization and coordination of operating and mechanical activities within the railroad industry.

organizations, Canadian Urban Transit Association (CUTA) — an industry association made up of individual transit operators and suppliers in Canada.

organizations, department of transportation (DOT) — a municipal, county, state, or federal agency responsible for transportation; see also *U.S. Government, Department of Transportation.*

organizations, Institute of Transportation Engineers (ITE) — a society of professionals in transportation and traffic engineering. It promotes education, research, the development of public awareness, and the exchange of professional information in these areas with the goal of contributing individually and collectively toward meeting human needs for mobility and safety.

organizations, International Union of Public Transport (UITP) — an association that pools information and experience of urban and interurban transportation undertakings for joint study and research and promotes technical and economic development.

organizations, Presidents' Conference Committee (PCC, Electric Railway Presidents' Conference Committee) — a group of leading streetcar producers and operators who, between 1930 and 1935, sponsored the development of the PCC car. This car had performance characteristics superior to any previous model of streetcar and became the standard of U.S. streetcars for many years. See also *car, PCC.*

organizations, Public Utilities Commission (PUC, Public Service Commission, PSC) — a state agency whose responsibilities include regulation of for-hire (public and private) carriers of passengers and goods within a state. Other jurisdictions (e.g., a city) may also have a PUC or PSC that regulates for-hire carriers within that jurisdiction.

organizations, regional planning agency (RPA) — a non-profit, quasi-public organization whose policy board is composed of member municipal government representatives. It makes recommendations related to land use, the environment, human resources, housing, and transportation for a specific region.

organizations, Transportation Research Board — a unit of the National Research Council, operating under the corporate authority of the private and nonprofit National Academy of Sciences. The purpose of TRB is to advance knowledge concerning the nature and performance of transportation systems by stimulating research and disseminating the information derived therefrom. Its affiliates and participants include transportation professionals in government, academia, and industry.

origin — **1.** The point at which a trip begins. **2.** In planning, the zone in which a trip begins.

origin-destination service — see *service, origin-to-destination.*

origin-destination study (O-D study) — a study of the origins and destinations of the trips of vehicles or travelers. It may also include trip purposes and frequencies.

out-of-service (not in service) — a transit vehicle or facility that is not available for transporting passengers.

outbound trip — see *trip, outbound.*

outlying business district (OBD) — the portion of an urban area that is normally separated from the central business district and fringe area but that supports considerable business activity and has its own traffic circulation, superimposed on some through traffic.

overall travel time — see *time, linked trip.*

overall trip speed — see *speed, overall trip.*

overhead — colloquial abbreviation for overhead contact system in electric traction, see *OCS.*

overhead contact shoe (contact shoe, trolley shoe) — a metal bar, usually with graphite insert, for collecting current from an overhead conductor along which it slides. It is held in place by a trolley pole, pantograph or bow.

overhead contact system (OCS) — the overhead electric supply system for rail and trolleybus systems, including contact wire, catenary, messenger wires, supporting masts, span wires and bracket arms.

overload — see *extra section.*

overload factor — a safety factor applied in designing a vehicle staging lot. The factor is obtained by dividing the vessel vehicle carrying capacity into the staging lot capacity. Allows for storage for more vehicles than can be accommodated on the vessel.

overspeed governor — see *governor.*

over-the-road coach — see *bus, intercity.*

owl bus or run — see *run, owl.*

owl service — see *service, owl.*

P

P&R — park and ride.

PCC — Presidents' Conference Committee; see *organizations, Presidents' Conference Committee;* and *car, PCC.*

PCC car — Presidents' Conference Committee car; see *car, PCC.*

PCE — passenger car equivalence.

PRT — personal rapid transit; see *transit system, personal rapid,* and *transit system, automated guideway transit.*

PSC — Public Service Commission; see *organizations, Public Utilities Commission.*

PUC — Public Utilities Commission; see *organizations, Public Utilities Commission.*

paid area — see *area, paid.*

paid area transfer — see *transfer, paid area.*

paid miles — see *revenue vehicle miles.*

paid transfer — see *transfer, paid.*

pair, married — see *married pair.*

pantograph — a device for collecting current from an overhead conductor, characterized by a hinged vertical arm operated by springs or compressed air and a wide, horizontal contact surface that glides along the wire. Older versions usually consist of two parallel, hinged, double-diamond frames.

paratransit — forms of transportation services that are more flexible and personalized than conventional fixed-route, fixed-schedule service but not including such exclusory services as charter bus trips. The vehicles are usually low- or medium-capacity highway vehicles, and the service offered is adjustable in various degrees to individual users' desires. Its categories are public, which is available to any user who pays a pre-determined fare (e.g., taxi, jitney, dial-a-ride), and semi-public, which is available only to people of a certain group, such as the elderly, employees of a company, or residents of a neighborhood (e.g., vanpools, subscription buses). See also *transit system, demand-responsive.*

paratransit, complementary — paratransit service provided within a certain distance of fixed-route transit service to accommodate disabled passengers unable to use the fixed-route service. Required by the Americans with Disabilities Act.

park-and-ride (park 'n' ride, P&R) — an access mode to transit in which patrons drive private automobiles or ride bicycles to a transit station, stop, or carpool/vanpool waiting area and park the vehicle in the area provided for that purpose (park-and-ride lot, park-and-pool lot, commuter parking lot, bicycle rack or locker). They then ride the transit system or take a car or vanpool to their destinations.

parking facility — an area, which may be enclosed or open, attended or unattended, in which automobiles may be left, with or without payment of a fee, while the occupants of the automobiles are using other facilities or services.

parking turnover — the ratio of the total number of parked vehicles accommodated during a given period in a specified area to the total number of parking spaces in that area.

pass — **1.** A means of transit prepayment, usually a card, that a transit passenger displays to the operator, conductor, or fare inspector or processes through automatic fare collection equipment instead of paying a cash fare. Passes are usually sold by the week or month. In some areas, to encourage tourism, they are also sold for shorter periods, sometimes with restricted hours for their use. **2.** A means, usually a card, of granting free access to a transit system. This type of pass is issued to employees, visiting dignitaries, police, and so on. Employee passes usually carry some form of identification. See also *daypass.*

pass, monthly — a pass valid for unlimited riding within certain designated zones for a 1-month period, or sometimes for a 30-day period from purchase or initial use.

passenger — a person who rides a transportation vehicle, excluding the operator or other crew members of that transportation vehicle; see also *customer.*

passenger, revenue — a passenger who pays (or has prepaid) a fare.

passenger, transfer — a passenger who changes from one route or line to another route or line.

passenger amenity — an object or facility (such as a shelter, telephone, or information display) intended to enhance passenger comfort or transit usability.

passenger belt — see *moving walkway.*

passenger car equivalence (PCE) — the representation of larger vehicles, such as buses, as equal to a quantity of automobiles (passenger cars) for use in level of service and capacity analyses.

passenger controls — **1.** a system of railings, booths, turnstiles, fare gates and other fixtures for collecting fares and otherwise directing the movement of passengers. The controls may also be used to maintain the distinction between fare-paid and unpaid people. **2.** on proof-of-payment fare collection systems, the process of checking and enforcing fare payment.

passenger conveyor — see *moving walkway.*

passenger count — a count of the passengers on a vehicle or who use a particular facility.

passenger environment survey — see *survey, passenger environment.*

passenger flow (passenger traffic) — the number of passengers who pass a given location in a specified direction during a given period.

passenger load — the number of passengers on a transit unit (vehicle or train) at a specified point.

passenger locomotive — see *locomotive, passenger.*

passenger mile (passenger kilometer) — the transportation of one passenger a distance of 1 mile (km)

passenger miles (passenger kilometers) — the total number of passengers carried by a transit system for a unit of time multiplied by the number of miles (kilometers) they travel. The ratio of passenger miles (kilometers) and seat or place miles (kilometers) provides a measure of efficiency.

passenger miles per train mile (passenger kilometers per train kilometer) — the number of passenger miles (kilometers) accomplished by a given train mile (kilometer). The measure is the equivalent of load factor for buses, boats, or aircraft, but it also adjusts for distortions introduced as cars are added to trains. As an example, 100 people in one rail car of 100-passenger capacity is a load factor of 100%. If a car is added for 10 more passengers, the load factor drops to 55%, yet in many ways, productivity has gone up, not down.

passenger platform — see *platform.*

passenger riding count or check — see *check.*

passenger service time — see *time, passenger service.*

passenger station — see *station.*

passenger traffic — see *passenger flow.*

passenger trip — see *trip, linked; trip, passenger;* and *trip, unlinked.*

passenger vehicle — see *vehicle, passenger.*

passenger volume (line volume) — the total number of passengers carried (boarded) on a transit line during a given period.

passing track — see *siding.*

pass-up — circumstance in which a bus or train is full when it arrives at a stop and waiting passengers are forced to wait for the next vehicle or find another means of making their trip.

path — in planning, any series of links where each succeeding link has the ending node of a previous link as its beginning node.

patron — see *rider.*

patronage — see *ridership.*

peak (peak period, rush hours) — **1.** The period during which the maximum amount of travel occurs. It may be specified as the morning (a.m.) or afternoon or evening (p.m.) peak. **2.** The period when demand for transportation service is heaviest.

peak/base ratio (peak/off-peak ratio) — **1.** The ratio between the number of vehicles operating in passenger service during the peak hours and that during the base period. **2.** The ratio between the number of passengers carried during the peak hours and during the base period. A low ratio (<2-3) characterizes large cities with healthy transit systems.

peak fare — see *fare, time-of-day.*

peak-hour conversion factor — see *peak hour factor.*

peak hour factor (peak-hour conversion factor) — **1.** The ratio of the volume during the peak hour to the maximum rate of flow during a selected period within the peak hour, usually 15 or 20 minutes. **2.** The ratio of the volume during the peak hour to the volume during the peak period, usually the peak 2 hours, typically 60%.

peak-hour pricing — see *pricing, peak-hour.*

peak period — see *peak.*

peak period surcharge — see *fare, time-of-day.*

peak service — see *service, peak.*

pedestrian — a person traveling on foot.

pedestrian conveyor — see *moving walkway.*

pedestrian density — see *density, pedestrian.*

pedestrian-friendly — characterized by features and elements that make walking safe and convenient. A pedestrian-friendly environment near a transit stop might have pedestrian pushbuttons at street crossings and direct, paved access to adjacent development.

pedestrian island — see *loading island.*

pedestrian refuge — a space designed for the use and protection of pedestrians, including both the safety zone and the area at the approach that is usually outlined by protective deflecting or warning devices; see also *loading island.*

penalty, transfer — see *transfer penalty.*

pendulum suspension (K&M) — type of overhead suspension for trolleybuses that provides more flexible wire and allows faster speeds — particularly around curves. Attributed to dominant Swiss manufacturer, Kummler+Matter.

people-mover — an automated transportation system (e.g., continuous belt system or automated guideway transit) that provides short-haul collection and distribution service, usually in a major activity center. Preferred term is *automated guideway transit* although some regard people-mover as a subset of AGT.

people-mover, downtown (DPM) — a people-mover that primarily serves internal movements in a central business district.

performance, on-time — see *on-time performance.*

performance measure (performance indicator, measure of effectiveness) — a quantitative measure of how well an activity, task, or function is being performed. In transportation systems, it is usually computed by relating a measure of service output or use to a measure of service input or cost.

performance measurement system — the measures, data collection procedures, evaluation methods, goals, and reporting methods used to monitor an agency's effectiveness, efficiency, service quality, and goal achievement for the purposes of improving decision-making and meeting objectives.

period, base or off-peak — see *base period.*

period, peak — see *peak.*

peripheral parking — see *parking, fringe.*

permissive block — see *block, absolute permissive.*

person capacity — see *capacity, person.*

person trip — see *trip, person.*

personal rapid transit — see *transit system, personal rapid.*

Personal Transportation Study, Nationwide — see *Nationwide Personal Transportation Study.*

Personalized Public Transit — National ITS Program User Service in which flexibly routed transit vehicles offer more convenient service to customers.

personnel, operating — see *operating employees.*

persons with disabilities —people who have physical or mental impairments that substantially limit one or more major life activities. In the context of transportation, the term usually refers to people for whom the use of conventional transit facilities would be impossible or would create a hardship.

plan, sketch — see *sketch planning.*

plan, system — see *system planning.*

platform — the front portion of a bus or streetcar where passengers board.

platform, ferry — a platform (usually floating) located between the stable approach and vessel, from which passengers embark onto, or disembark from, the vessel.

platform, passenger — that portion of a transit facility directly adjacent to the tracks or roadway at which transit units (vehicles or trains) stop to load and unload passengers. Within stations, it is often called a *station platform.*

platform, center (island) — a passenger platform located between two tracks or guideways so that it can serve them both.

platform, high — a platform at or near the floor elevation of the transit unit (vehicle or train), eliminating the need for steps on the transit unit.

platform, low — a platform at or near the top of the running surface of the transit unit (vehicle or train), requiring the passenger to use steps to board and alight.

platform, mini-high (high block platform) — a small high-level platform that usually provides access only to the first door of a light rail train in order to allow boarding by wheelchairs, scooters, etc.

platform, side — a passenger platform located to the outside of the tracks or guideways, as distinguished from a center platform located between the tracks or guideways.

platform operator — see *operator.*

platform time — see *time, platform.*

platoon, bus — see *bus platoon.*

p.m. peak — see *peak.*

pneumatic brake — see *brake, electropneumatic.*

pocket track — a third track to store spare or disabled trains, or to act a crossover or a turn-back, often located between the two main tracks and often with switches at both ends.

point, maximum load — see *maximum load point.*

point, time — see *time point.*

point, turnover — see *turnover point.*

point check — see *check.*

point deviation — a transit routing pattern in which the vehicle passes through pre-specified points in accordance with a prearranged schedule but is not given a specific route to follow between these points. It may provide door-to-door or curb-to-curb service. See also *service, point deviation.*

points — a pair of linked, movable tapered rails used in rail switches that allow a train to pass from one line to another. Points are also used for the same function in overhead wiring for trolleybuses.

pole, trolley — see *trolley pole.*

policy headway — see *headway, policy.*

pool — see *buspool, carpool,* and *vanpool.*

power, dual — see *propulsion system, dual-power* and *bus, hybrid.*

powered car — see *car, rail motor.*

power rail — see *rail, third.*

power-to-weight ratio — a measure of the performance of locomotives. A higher power-to-weight ratio provides better acceleration characteristics.

preemption, signal — see *signal preemption.*

preferential bus lane — see *lane, bus.*

pre-metro system — see *transit system, pre-metro.*

Pre-Trip Travel Information — National ITS Program User Service that provides information for selecting the best transportation mode, departure time, and route.

Presidents' Conference Committee — see *organizations, Presidents' Conference Committee;* and *car, PCC.*

Presidents' Conference Committee car — see *car, PCC.*

preventive maintenance — see definition of *maintenance.*

pricing — a strategy for charging users. It may be used to ration demand (change behavior), cover costs, or achieve other policy objectives.

pricing, peak-hour — charging higher prices for peak-period service than for off-peak service.

pricing, time-of-day — varying the price of service during the day.

priority lane — see *lane, priority.*

priority lane, bus — see *lane, bus.*

priority system, bus — see *bus priority system.*

private transportation — **1.** Any transport service that is restricted to certain people and is therefore not open to the public at large. **2.** Owned or operated by an individual or group, for his, her, or its own purposes or benefit, not by a governmental entity.

productions, trip — see *trip productions.*

productive capacity — see *capacity, productive.*

productivity — the ratio of units of transportation output to units of input (consumed resource); for example, vehicle miles (vehicle kilometers) per operator hour, or passenger miles (passenger kilometers) per unit cost of operation.

program, National Cooperative Highway Research — see *National Cooperative Highway Research Program* and *National Cooperative Transit Research and Development Program.*

program, Research, Development, and Demonstration — see *Research, Development, and Demonstration Program.*

program, Service and Methods Demonstration — see *Service and Methods Demonstration Program.*

programmed braking — see *braking, programmed.*

progression, automatic — see *automatic progression.*

progression, signal — coordination of a set of traffic signals such that vehicles moving down a street receive green signal indications at several traffic signals in a row.

proof-of-payment — see *fare collection system, proof of payment.*

property (operation, operator, system) — in the transit industry, a public transit agency or a private transit company with responsibility for transportation services such as bus, ferry, rail; see also *transit district.*

propulsion, ferry — the process of driving or propelling by way of a machine consisting of a power-driven shaft with radiating blades, placed so as to thrust air or water in a desired direction when spinning.

propulsion system — the motors, driving mechanism, controls, and other devices that propel a vehicle, frequently assumes electric operation.

propulsion system, dual-power — a propulsion system that is capable of operation from two different types of power sources, for example, an internal combustion engine and electricity.

protection, train — see *automatic train protection.*

proximity card — see *smart card.*

public automobile service system — see *transportation system, public automobile service.*

Public Service or Utilities Commission — see *organizations, Public Utilities Commission.*

public service vehicle — see *vehicle, public service.*

public transit — passenger transportation service, usually local in scope, that is available to any person who pays a prescribed fare. It operates on established schedules along designated routes or lines with specific stops and is designed to move relatively large numbers of people at one time. Examples include bus, light rail, rapid transit.

public transit agency — see *property, transit district.*

public transportation — transportation service to the public on a regular basis using vehicles that transport more than one person for compensation, usually but not exclusively over a set route or routes from one fixed point to another. Routes and schedules of this service may be predetermined by the operator or may be determined through a cooperative arrangement. Subcategories include public transit service and paratransit services that are available to the general public.

public transportation, urban — see *urban public transportation.*

public transportation disability — see *persons with disabilities.*

Public Transportation Management — National ITS Program User Service that automates operations, planning, and management functions of public transit systems.

Public Travel Security — National ITS Program User Service that creates a secure environment for public transportation patrons and operators.

public way — any public street, road, boulevard, alley, lane, or highway, including those portions of any public place that have been designated for use by pedestrians, bicycles, and motor vehicles.

publicly owned transit system — see *transit system, publicly owned.*

público — In Puerto Rico, a transit mode comprising passenger vans or class C buses operating with fixed routes but no fixed schedules. Públicos are a privately owned and operated mass transit service that is market-oriented and unsubsidized but regulated through a public service commission, state, or local government. Públicos are operated under franchise agreements, fares are regulated by route, and there are special insurance requirements. Vehicle capacity varies from 8 to 24, and the vehicles may be owned or leased by the operator.

puller — an articulated bus with the center axle powered.

purpose, trip — see *trip purpose.*

push-pull train — see *train, push-pull.*

push-through — a bus-operating technique used in busy peak-hour street operations when heavy passenger loads can combine with general road traffic delays to create bunching. A push-through is an unscheduled bus that is held at a key point to be inserted by an inspector or street supervisor into a route when a serious gap occurs. It is used to prevent worsening of service.

pusher — an articulated bus with the rear axle powered.

Q

quadrant analysis — method of evaluating customer satisfaction survey results in which the customer-rated importance of an attribute is plotted against the customer-rated satisfaction with that attribute.

quality, ride — see *ride quality.*

quality, service — see definition of *level of service.*

quality control — the system of collection, analysis, and interpretation of measurements and other data concerning prescribed characteristics of a material, process, or product, for determining the degree of conformance with specified requirements.

quality of service — the overall measured or perceived quality of transportation service from the user's or passenger's point of view, rather than from the operating agency's point of view. Defined for transit systems, route segments, and stops by *level of service*.

queue — A line of vehicles or people waiting to be served by the system in which the rate of flow from the front of the line determines the average speed within the line. Slowly moving vehicles or people joining the rear of the queue are usually considered a part of the queue.

queue jump(er) — **1.** A short section of exclusive or preferential lane that enables specified vehicles to bypass an automobile queue or a congested section of traffic. A queue jumper is often used at signal-controlled freeway on-ramps in congested urban areas to allow high-occupancy vehicles preference. It is also known as a *bypass lane* or *queue bypass.* **2.** A person who violates passenger controls.

R

RDC — rail diesel car; see *car, rail diesel.*

ROW — right-of-way.

RPA — regional planning agency; see *organizations, regional planning agency.*

RRIS — Railroad Research Information Service.

rack railway — see *cog railway.*

radial network — see *network, radial.*

rail, contact — see *rail, third.*

rail, continuous welded (CWR) — a number of standard length rails welded together into a single length of 400 ft or more (120 m or more). It provides a smoother running surface and ride than jointed rail.

rail, girder — rail with a built in flange groove used on streetcar and light rail lines that are laid in-street where other motor vehicles must travel.

rail, power — see *rail, third.*

rail, running — a rail that supports and guides the flanged wheels of the rail vehicle.

rail, standard — a 39-ft (11.89-m) section of rail.

rail, third (contact rail, power rail) — an electric conductor, located alongside the running rail, from which power is collected by means of a sliding shoe attached to the truck of electric rail cars or locomotives. Traditionally made of mild steel, composite rail, often aluminum with a stainless steel cover, is appearing on some new systems.

rail, welded — two or more rails welded together at their ends to form a length less than 400 ft (120 m); see also *rail, continuous welded.*

railbus — a light, self-propelled rail vehicle with a body resembling that of a bus or using bus components, two-axle versions are noted for poor ride quality.

rail car, electric — see *car, electric rail.*

rail car, type — see *car, type designations.*

rail car, urban — see *car, urban rail.*

rail car, weight — see *car, weight designations.*

rail diesel car — see *car, rail diesel.*

rail motor car — see *car, rail motor.*

rail rapid transit — see *transit system, rail rapid.*

rail rapid transit car — see *car, rail rapid transit.*

railroad, commuter — see *transit system, commuter rail.*

railroad grade crossing — see *crossing, railroad grade.*

Railroad Research Information Service (RRIS) — a computer-based information storage and retrieval system developed by the Transportation Research Board with financial support from the Federal Railroad Administration. It consists of summaries of research projects in progress and abstracts of published works.

railroad tie — see *crosstie.*

rail transit system — see *transit system, rail.*

rail transport, conventional — see *conventional rail transport.*

rail vehicle, articulated — see *articulated rail vehicle.*

railway — alternate term for railroad, especially Canadian and British.

railway, cog — see *cog railway.*

railway, funicular — see *funicular railway.*

railway, inclined plane (incline) — see *inclined plane.*

railway, metropolitan — see *transit system, rail rapid.*

railway, rack — see *cog railway.*

railway, street — old term for streetcar system, see *transit system, streetcar.*

railway crossing — see *crossing, track.*

railway electrification — see *electrification.*

ramp, moving — an inclined moving walkway.

ramp, meter bypass lane — see *lane, ramp meter bypass.*

ramp metering — **1.** The process of facilitating traffic flow on freeways by regulating the amount of traffic entering the freeway through the use of control devices on entrance ramps. **2.** The procedure of equipping a freeway approach ramp with a metering device and traffic signal that allow the vehicles to enter the freeway at a predetermined rate.

rapid bus— see *transit system, bus rapid.*

rapid, the — see *transit system, rail rapid.*

rapid rail transit — see *transit system, rail rapid.*

rapid transit— generic term introduced in the 1890s to denote any transit that was faster than its predecessor, most particularly for the replacement of horsecars with electric streetcars, now generally used for rail systems on exclusive right-of-way, i.e., heavy rail or metro. See adjacent listings and specific entries under *transit systems.*

rapid transit car — see *car, rail rapid transit.*

rapid transit operator — see *operator, rapid transit.*

rapid transit system — see *rapid transit* and specific entries under *transit systems: bus rapid, group rapid, light rail rapid, personal rapid, rail rapid, rapid.*

rate of flow — see flow *rate.*

ratio, cost recovery — see *cost recovery ratio.*

ratio, fare or farebox recovery — see *fare recovery ratio.*

ratio, operating — see *operating ratio.*

ratio, peak/base or peak/off-peak — see *peak/base ratio.*

ratio, power-to-weight — see *power-to-weight ratio.*

ratio, travel time — see *travel time ratio.*

reader, farecard — see *farecard reader.*

recovery ratio — see *cost recovery ratio* and *fare recovery ratio.*

recovery time — see *time, layover.*

rectifier station — see *electric sub-station.*

reduced fare — see *fare, reduced.*

re-entry delay — see *delay, re-entry.*

refuge, pedestrian — see *pedestrian refuge.*

regenerative brake — see *brake, regenerative.*

regional planning agency — see *organizations, regional planning agency.*

regional rail service — see *service, regional rail.*

regional transit service — see *service, regional transit.*

register or registering farebox — see *farebox, registering.*

regular fare — see *fare, base.*

relationship, speed-flow — see *speed-flow relationship.*

relay, track — see *track relay.*

relay time — see *time, layover.*

reliability — how often transit service is provided as promised; affects waiting time, consistency of passenger arrivals from day to day, total trip time, and loading levels. The service measure of route-level comfort and convenience in the TCQSM quality of service framework.

reroute — to divert to a route other than the scheduled route, usually with preplanning and for a longer period than that for a detour.

Research Information Service — see *Highway Research Information Service, Railroad Research Information Service, Transportation Research Information Services,* and *Urban Mass Transportation Research Information Service.*

Research Program — see *National Cooperative Highway Research Program, National Cooperative Transit Research and Development Program* and *Transit Cooperative Research Program.*

reserved transit lane — see *lane, exclusive transit.*

response time — see *time, response.*

retardation — see *deceleration.*

revenue, farebox — the passenger payments for rides, including cash, farecards, tickets, tokens, pass receipts, and transfer and zone charges but excluding charter revenue.

revenue, non-transportation (other) — revenue earned by activities not associated with the provision of the system's transit service, for example, sales of maintenance services, rental of vehicles and buildings, non-transit parking lots, sale of advertising space, and investment income.

revenue, total operating — the sum of regular passenger revenue, charter revenue, and other miscellaneous revenues, such as those from advertising or concessions.

revenue miles (revenue kilometers) — miles (kilometers) operated by vehicles available for passenger service.

revenue passenger — see *passenger, revenue.*

revenue passenger trips — the number of fare-paying transit passengers with each person counted once per trip; excludes transfer and non-revenue trips.

revenue seat mile (revenue seat kilometer) — the movement of one transit passenger seat over 1 mile (km). In other words, the total number of revenue seat miles (kilometers) for a vehicle is obtained by multiplying the number of revenue seats in the vehicle by the number of revenue miles (kilometers) traveled.

revenue service — see *service, revenue.*

revenue track miles or kilometers — see *track miles, revenue.*

revenue vehicle — see *vehicle, revenue.*

revenue vehicle miles (revenue vehicle kilometers, paid miles or kilometers) — the distance in miles (kilometers) that a revenue vehicle is operated while it is available for passenger service.

reverse commute — see *commute, reverse.*

reverse move — the forward movement of a train going against the normal direction of traffic.

reversible bus lane — see *lane, reversible bus.*

reversible lane — see *lane, reversible.*

ride, check — see *check ride.*

Ride Matching and Reservation — National ITS Program User Service that makes ride sharing easier and more convenient.

ride, one-zone — see *one-zone ride.*

ride, shared — see *shared ride.*

ride quality — a measure of the comfort level experienced by a passenger in a moving vehicle, including the vibration intensity and frequency, accelerations (longitudinal, transverse, and vertical), jerk, pitch, yaw, and roll.

rider — **1.** A passenger on any revenue service vehicle; also known as a *patron.* **2.** In government reporting, someone making an unlinked trip.

rider, captive — a person limited by circumstances to use one mode of transportation; see also *transit dependent* and *transportation disadvantaged.*

rider, captive transit — a person who does not have a private vehicle available or cannot drive (for any reason) and who must use transit to make the desired trip; see also *transit dependent* and *transportation disadvantaged.*

rider, choice — a person who has at least two modes of travel available and selects one to use.

riders, group — riders who have a common origin and destination or some demographic variable in common and travel together in the same vehicle.

ridership (patronage) — the number of people making one way trips on a public transportation system in a given time period.

ridesharing — a form of transportation, other than public transit, in which more than one person shares in the use of the vehicle, such as a bus, van, or automobile, to make a trip.

riding check or count, passenger — see *check.*

riding frequency coefficient (riding habit coefficient) — the number of passenger trips during a designated time period divided by the resident population of the area served, such as transit trips per capita per year.

right-of-way (ROW) — **1.** A general term denoting land, property, or interest therein, usually in a strip, acquired for or devoted to transportation purposes. For transit, rights-of-way may be categorized by degree of their separation: fully controlled without grade crossings, also known as *grade-separated, exclusive,* or *private ROW;* longitudinally physically separated from other traffic (by curbs, barriers, grade separation, etc.) but with grade crossings; or surface streets with mixed traffic, although transit may have preferential treatment. **2.** The precedence accorded to one vehicle or person over another.

right-of-way, controlled access — lanes restricted for at least a portion of the day for use by transit vehicles and/or other high-occupancy vehicles. Use of controlled access lanes may also be permitted for vehicles preparing to turn. The restriction must be sufficiently enforced so that 95% of vehicles using the lanes during the restricted period are authorized to use them.

right-of-way, exclusive — roadway or other right-of-way reserved at all times for transit use and/or other high occupancy vehicles.

right-of-way, exclusive transit — a right-of-way that is fully grade separated or access controlled and is used exclusively by transit.

right-of-way, segregated — roadway or right-of-way reserved for transit use, but which permits other modes to cross the right-of-way at defined locations such as grade crossings.

right-of-way, shared — roadway or right-of-way which permits other traffic to mix with transit vehicles, as is the case with most streetcar and bus lines.

right-of-way miles (right-of-way kilometers, first-track miles or kilometers) — the length of right-of-way occupied by one or more lanes or tracks; see also *route miles.*

road — see *highway, street, or road.*

road, collector — see *street, collector-distributor.*

roadbed — **1.** In railroad construction, the foundation on which the ballast and track rest. **2.** In highway construction, the graded portion of a highway within top and side slopes, prepared as a foundation for the pavement structure and shoulder.

road call — a mechanical failure of a bus in revenue service that necessitates removing the bus from service until repairs are made.

road miles (road kilometers) — linear miles (kilometers) of highway as measured along the centerline of the right-of-way.

road supervisor — see *inspector.*

roadway — that portion of a highway built, designed, or ordinarily used for vehicular travel, except the berm or shoulder. If a highway includes two or more separate roadways, the term means any such roadway separately but not all such roadways collectively.

rolling stock — see *fleet.*

rolling stock capacity — see *capacity, fleet.*

rope — in ropeways, the term rope means wire rope, which consists of several strands twisted together. The terms rope, wire rope, and cable are interchangeable except where, by the context, the general term cable refers to either a wire rope or strand used as a track cable.

ropeway — includes all devices that carry, pull, or push along a level or inclined path (excluding elevators) by means of a haul rope or other flexible element that is driven by a power unit remaining essentially at a single location. See *aerial lift*, *aerial tramway*, *cableway*, *funicular railway*, *inclined plane*, and *surface lift*.

ropeway, continuously circulating — a ropeway providing multiple carriers, cars, or trains that move around a route forming a loop. Examples include *aerial lifts* (*gondolas*), *cable cars,* and *cable-hauled automated people-movers.*

ropeway, reversible — a ropeway that operates in a back-and-forth, shuttle manner. Usually operates with two carriers, but sometimes only one. Examples include *inclined planes* and *aerial tramways.*

round trip — see *trip, round.*

route — **1.** The geographical path followed by a vehicle or traveler from start to finish of a given trip. **2.** A designated, specified path to which a transit unit (vehicle or train) is assigned. Several routes may traverse a single portion of road or line. **3.** In traffic assignments, a continuous group of links that connects two centroids, normally the path that requires the minimum time to traverse. **4.** In rail operations, a determined succession of contiguous blocks between two controlled interlocked signals.

route deviation service — see *service, route deviation.*

Route Guidance — National ITS Program User Service that provides travelers with simple instructions on how to best reach their destinations.

route miles (route kilometers) — various definitions exist for this statistic: **1.** One-way duplicating is total mileage (kilometers) of routes, where the roadway or guideway segments of each individual route are summed up in one direction. For example, a 1-mile (km) segment over which buses operate in both directions would be reported as 2 miles (km); also known as *directional route miles* (kilometers) or *miles (kilometers) of roadway or route*. **2.** One-way non-duplicating is total mileage (kilometers) of routes, where a particular roadway or guideway segment is only counted once regardless of number of routes or direction of travel on that segment; also known as *line miles (kilometers)* or *miles (kilometers) of directional roadway.* **3.** Two-way mileage (kilometers) is total mileage (kilometers) of each route covered from start to finish. No attention is given to direction of routes or number of routes using any particular segment of roadway or guideway.

route structure — **1.** A network of transit routes. **2.** The pattern of transit routes, for example, grid, radial. See *network.*

route supervisor — see *inspector.*

routing, dynamic — see *dynamic routing.*

routing, through — see *through routing.*

rule — in rail operations, a law or order authoritatively governing conduct or action.

run — **1.** The movement of a transit unit (vehicle or train) in one direction from the beginning of a route to the end of it; also known as a *trip.* **2.** An operator's assignment of trips for a day of operation; also known as a *work run.*

run, bus — the daily assignment of a bus, numbered and listed in a master schedule. Each vehicle displays its bus run number.

run, owl — a run that operates during the late night through early morning hours; most commonly, midnight to 0400h or the start of the next day's service. Some systems designate hours after midnight, when operated by vehicles starting the previous day, as 2500h, 2600h and so on.

run cutting — the process of organizing all scheduled trips operated by the transit system into runs for the assignment of operating personnel and vehicles.

run number — a two- or three-digit number displayed on a hand set or flip-dot display in the lower windscreen displaying the run or schedule slot the vehicle is in; primarily used as information to inspectors, street supervisors, or checkers.

running gear — the vehicle parts whose functions are related to the movement of the vehicle, including the wheels, axles, bearings, and suspension system.

running hot (running sharp) — running ahead of schedule. Unacceptable practice on most systems.

running rail — see *rail, running.*

running speed — see *speed, running.*

running time — see *time, running.*

rush hour(s) — see *peak.*

S

SE — Single Ended, rail or streetcar with driving position only at one end, requires loop to turn around at end of line.

SLT — shuttle-loop transit; see *transit system, shuttle-loop.*

SOV — single-occupant vehicle; see *vehicle, single – occupant.*

SU — single unit; see *car, single-unit.*

saddle monorail — see *transit system, monorail.*

safety distance — **1.** Minimum separation of trains with various control systems **2.** In a moving-block signaling system, the specific distance between the target point and the train or obstruction ahead. See *control system.*

safety island — see *loading island.*

scatter service — see *service, one-to-many.*

schedule — **1.** A listing or diagrammatic presentation in time sequence of every trip and every time point of each trip, from start to finish of service, on a transit line or route. **2.** In transit or railroad operations, a published table of departure or arrival times (or both) for arranged service over a transit line or route or a specific section of railroad; see also *timetable.*

schedule check — see *check.*

schedule checker — see *checker.*

schedule speed — see *speed, schedule.*

scheduling — in transit operations, the process of preparing the operating plan (schedule) for a transit line or network on the basis of passenger demand, policy or level of service, and operating elements (travel times, etc.)

school bus — see *bus, school.*

school bus service — see *service, school bus.*

scratch ticket — a ticket on which the user can scratch overprinting off to indicate, zone, and/or month, day (and time) of validity. Commonly used on day passes.

seating or seated capacity — see capacity, seating.

seating, 2+1 — ("two-by-one") transverse seating arrangement providing three seats per row, two on one side of the aisle and one on the other side of the aisle.

seating, 2+2 — transverse seating arrangement providing four seats per row, two on each side of the aisle.

seating, 2+3 — transverse seating arrangement providing five seats per row, two on one side of the aisle and three on the other side of the aisle; not popular with passengers. This seating arrangement constrains aisle width, which may make the provision of wheelchair access difficult.

seating, longitudinal — seats that are placed parallel to the sides of a transit vehicle, so that passengers sit sideways relative to the direction of travel. This seating arrangement increases the aisle width, allowing more standing room, but may be less comfortable for seated passengers.

seating, transverse — seats that are placed perpendicular to the sides of a transit vehicle, so that passengers face forward or backward relative to the direction of travel. This seating arrangement is often used when it is desired for most passengers to have a seat, although it is also possible to have single transverse seats on either side of the vehicle, with a wide aisle in between.

seat mile, revenue — see *revenue seat mile.*

section — for sections of legislation, see *legislation* entries.

section, block — see *block.*

section, extra — see *extra section.*

section, maximum load — see *maximum load section.*

self-propelled locomotive — see *locomotive, self-propelled.*

self-propelled or self-powered car — see *car, rail motor.*

self-service, barrier-free fare collection system — see *fare collection system, open, barrier-free, proof of payment, self-service.*

semi-metro system — see *transit system, semi-metro.*

sensor, induction loop — see *induction loop sensor.*

separation, grade — see *grade separation.*

separation, track — see *track separation.*

separation, train — see *train separation.*

series, time — see *time series.*

series-wound motor — see *motor, series-wound.*

service, arterial — generally major (long or heavily patronized) transit routes that operate on principal or major surface arterial streets.

service, base-period — the level of transit operations during the base period.

service, bus rapid transit — see *transit system, bus rapid transit.*

service, circulator — bus service confined to a specific locale, such as a downtown area or a suburban neighborhood, with connections to major traffic corridors.

service, city transit — transit serving an urban area, as distinguished from short-haul and regional transit service.

service, community — short feeder or loop route serving a local community, often operated with smaller buses.

service, commuter — transportation provided on a regularly scheduled basis during peak travel periods for users commuting to work, school, and similar destinations.

service, crosstown — non-radial transit service that does not enter the central business district.

service, demand jitney — see *service, jitney.*

service, door-to-door — a service that picks up passengers at the door of their place of origin and delivers them to the door of their place of destination. This service may necessitate passenger assistance between the vehicle and the doors. See also *service, curb-to-curb.*

service, express — service that has fewer stops and a higher operating speed than regular service. Often used an alternative term for *limited-stop service*; when agencies provide both types of service, the express service tends to have much longer sections of non-stop running.

service, express bus — bus service with a limited number of stops, either from a collector area directly to a specific destination or in a particular corridor with stops en route at major transfer points or activity centers. Express bus service usually uses freeways or busways where they are available.

service, feeder — **1.** Local transportation service that provides passengers with connections with a major transportation service. **2.** Local transit service that provides passengers with connections to main-line arterial service; an express transit service station; a rail rapid transit, commuter rail, or intercity rail station; or an express bus stop or terminal, see also *service, community.*

service, few-to-few — a service that picks up passengers at a limited number of origins and delivers them to a limited number of destinations.

service, few-to-many — a service that picks up passengers at a few pre-selected origins, typically activity centers or transfer points, and delivers them to many destinations.

service, flag stop — **l.** In paratransit operations, a service accessed by hail. **2.** In rail operations, a nonscheduled stop that may be served if proper notice is given by a passenger or prospective passenger.

service, gather — see *service, many-to-one.*

service, jitney — a route deviation service in which small or medium-sized vehicles, such as large automobiles, vans, or minibuses, are used. The vehicles are usually owned by the drivers and the service is often independently operated. However it is authorized or regulated and distinct from unofficial, and usually illegal, “jitney service” where often-uninsured private cars or vans solicit passengers — often running ahead of transit buses. See also *transportation system, jitney.*

service, level of — see *level of service.*

service, limited — **l.** A transit service that operates only during a certain period of the day, or that serves only specific stops (also known as *limited-stop service)* or in a specified area, or that serves only certain segments of the population. **2.** Line service with some restrictions on boarding and alighting.

service, limited-stop — a bus service, often operated in conjunction with a local service, that does not serve every stop, providing a higher operating speed. It represents a middle ground between high-access, low-speed local service and low-access, higher-speed express service.

service, line haul — **1.** Transportation service along a single corridor, without branches, with stops along the way. Usually service is intensive (high capacity) and may use exclusive right-of-way. **2.** May also be used to describe express service or even main-line service, as opposed to feeder service.

service, local — **1.** Transit service that involves frequent stops and consequent low average speeds, the purpose of which is to deliver and pick up transit passengers close to their destinations or origins. **2.** Transit operation in which all transit units (vehicles or trains) stop at all stations. **3.** Transit service in a city or its immediate vicinity, as distinguished from regional transit service or interurban lines.

service, local bus — a bus service that picks up and discharges passengers at frequent, designated places (stops) on city streets.

service, many-to-few — a service that picks up passengers at many different origins and delivers them to a few destinations.

service, many-to-many — a service that picks up passengers at many different origins and delivers them to many different destinations within the service area.

service, many-to-one (gather service) — a service that collects passengers from many origins and delivers them to a specific point, for example, an office building, train station, or bus stop.

service, one-to-many (scatter service) — a service that picks up passengers at one point of origin and delivers them to many destinations.

service, origin-to-destination — service in which the passenger carrying vehicle will not stop along the way to pick up additional passengers.

service, owl — transit service provided late at night, usually from midnight to between 0300h and start of service the next day.

service, peak — service during peak periods.

service, point deviation — public transportation service in which the transit vehicle is required to arrive at designated transit stops in accordance with a prearranged schedule but is not given a specific route to follow between these stops. It allows the vehicle to provide curbside service for those who request it. See also *point deviation.*

service, public automobile — see *transportation system, public automobile service.*

service, radial — service that connects the CBD with outlying areas.

service, regional rail — alternate term for commuter rail, specific to East Coast; see *transit system, commuter rail.*

service, regional transit — long bus or rail transit lines with few stations and high operating speeds. They primarily serve long trips within metropolitan regions, as distinguished from city transit service and local short-haul transit service.

service, research information — see *Railroad Research Information Service, Transportation Research Information Services,* and *Urban Mass Transportation Research Information Service.*

service, revenue — **1.** Transit service excluding deadheading or layovers. **2.** Any service scheduled for passenger trips.

service, route deviation — public transportation service on an exclusive basis that operates along a public way on a fixed route (but not a fixed schedule). The vehicle may deviate from the route occasionally in response to demand for service or to take a passenger to a destination, after which it returns to its route. It is a form of demand-responsive transit. See also *service, jitney.*

service, scatter — see *service, one-to-many.*

service, school bus — service designed to transport children to or from any regularly conducted public or private school or school-related activities, either on an exclusive or nonexclusive basis.

service, shoppers' special — service provided during off-peak hours that is designed to carry passengers to or from shopping areas.

service, short-haul transit — low-speed transit service for circulation within small areas that usually have high travel density, such as central business districts, campuses, airports, exhibition grounds, and other major activity centers.

service, shuttle — **1.** Service provided by vehicles that travel back and forth over a particular route, especially a short one, or one that connects two transportation systems or centers, or one that acts as a feeder to a longer route. Shuttle services usually offer frequent service, often without a published timetable. **2.** For rail and other guideway systems, a service in which a single vehicle or train operates on a short line, reversing direction at each terminal.

service, skip-stop — service in which alternate transit units (vehicles or trains) stop at alternate sets of stations on the same route. Each set consists of some joint and some alternate stations.

service, subscription bus — **l.** A bus service in which routes and schedules are prearranged to meet the travel needs of riders who sign up for the service in advance. The level of service is generally higher than that of regular passenger service (fewer stops, shorter travel time, and greater comfort), and the buses are usually obtained through charter or contractual arrangements. **2.** Commuter bus express service operated for a guaranteed number of patrons from a given area on a prepaid, reserved seat basis. Subscription buses are often arranged for and partly subsidized by an employer to serve a specific work location.

service, subscription van — service similar to that provided by a subscription bus, except that the van may be privately owned, leased from a public or private company, or provided by the employer. The driver is usually a member of the group.

service, subsidized taxi — a taxicab service in which the fares are lower than actual taxi fares and the taxi company is reimbursed the difference. The service may be provided to the general public or to special groups, such as elderly people. Funds for the subsidy can come from a variety of sources, including local taxes or social service agency program funds. Often an economical way to provide better off-peak service in low-density areas that cannot support fixed routes.

service, taxicab (exclusive ride taxi, taxi service) — demand responsive public transportation service on an exclusive basis, in a vehicle licensed to render that service; see also *shared ride* and *service, subsidized taxi.*

service application — see *braking, service.*

service area — see *area, service.*

service attributes — those aspects of a transportation system that affect travel decisions about its use, such as travel time, reliability, comfort (e.g., crowding, standees), cost, ease of use, and safety.

service brake — see *brake, service.*

service braking — see *braking, service;* and *braking, maximum service.*

service coverage — see *area, coverage*

service denial — circumstance in which a demand-responsive transit trip cannot be provided at the requested time, even though service is operated at that time.

service frequency — the number of transit units (vehicles or trains) on a given route or line, moving in the same direction, that pass a given point within a specified interval of time, usually 1 hour; see also *headway.*

service information — see *user information.*

service measure, transit — **1.** A quantitative performance measure that best describes a particular aspect of transit service and represents the passenger's point of view. **2.** A transit performance measure for which transit levels of service are defined, referred to in the *Highway Capacity Manual* as a *measure of effectiveness.*

service performance or quality — see definition of *level of service.*

service span — see *hours of service.*

service track miles (kilometers) — see *track miles, service.*

service volume — the maximum number of vehicles that can pass a given point during a specified period while a specified level of service is maintained.

share, market — see *market share.*

shared ride — a trip, other than by conventional public transit, on which the passengers enter at one or more points of origin and disembark at one or more destinations and for which each passenger is charged an individual fare. Shared ride taxi service is a way of using taxicabs for paratransit.

sharp, running — see *running hot.*

sheaves — pulleys or wheels grooved for rope.

shedding, load — see *load shedding.*

shelter — see *transit shelter.*

shoe, brake — see *brake shoe.*

shoe, overhead contact — see *overhead contact shoe.*

shoe, third-rail — see *third-rail shoe.*

shoe, trolley — see *overhead contact shoe.*

shoofly — a temporary track to allow rail operations to bypass construction activities.

shop — see *workshop.*

shoppers' special service — see *service, shoppers' special.*

short-haul transit service — see *service, short-haul transit.*

short turn — see *turn back.*

shunt — in rail operations, to shift or switch, as a train car; also the railroad switch itself.

shunt motor — see *motor, shunt.*

shuttle-loop transit — see *transit system, shuttle-loop.*

shuttle service — see *service, shuttle.*

shuttle system — see *transit system, shuttle.*

side platform — see *platform, side.*

side track — see *siding.*

sidewalk, moving — see *moving walkway.*

siding (passing track, side track) — a track adjacent to a main or a secondary track, for meeting, passing, or storing cars or trains, see also *pocket track.*

sign, dash — see *dash sign.*

sign, destination — see *destination sign.*

sign, dot matrix— a type of destination, dash, side or rear sign consisting of electrically actuated dots that present either a matte black or bright (usually fluorescent yellow) face that make up individual letters or numbers. Early designs had very poor visibility and reliability, but improvements and the ability to display upper and lower case and double lines, have made the signs acceptable. Versions with back-lit liquid crystal displays or high intensity light emitting diodes were introduced in late 1990s. Favored for the ease with which signs can be reprogrammed and buses transferred from garage to garage, but this flexibility is often abused by alternating unnecessary messages, such as HAVE A GOOD DAY, that can confuse potential passengers.

sign, head — see *head sign.*

signal, automatic — a signal that is controlled automatically by certain conditions of the track section that it protects.

signal, automatic block — a system in which signals are actuated automatically by the presence of a train on the track section, usually with an electric track circuit to detect the presence of any vehicle, and any broken rails.

signal, block — a fixed signal installed at the entrance of a block to govern trains entering and using that section of track.

signal, cab — see *control system, cab signal.*

signal, fixed — in rail operations, a signal at a fixed location that indicates a condition that affects the movement of a train.

signal, grade crossing protection — a railroad crossing flashing light signal or automatic gate actuated by the approach of a train at a grade crossing.

signal, wayside — in rail operations, a fixed signal that is located along the track right-of-way.

signal, traffic — see *traffic signal.*

signal-actuating device — see *pedestrian signal-actuating device* and *vehicle signal-actuating device.*

signal aspect — **1.** The appearance of a fixed signal conveying an indication, as viewed from the direction of an approaching rail unit. **2.** The appearance of a cab signal conveying an indication, as viewed by an observer in the cab of a rail unit.

signal block — see *block.*

signal indication — the information conveyed by a signal.

signal preemption — in highway operations, an automatic or manual device for altering the normal signal phasing or the sequence of a traffic signal to provide preferential treatment for specific types of vehicles, such as buses or trains.

signal progression — see *progression, signal.*

simple catenary — see *catenary system.*

single-occupant vehicle (SOV) — see *vehicle, single-occupant.*

single-unit car — see *car, single-unit.*

ski lift — a continuously circulating *aerial lift* using chairs as carriers.

skip-stop service — see *service, skip-stop.*

slack time — see *operating margin.*

sleeper — **1.** An inert passenger who remains on a transit vehicle at end of run, often inebriated. **2.** A railroad tie; see *crosstie.*

slow order — a location where trains must temporarily travel more slowly than maximum authorized track speed for that location.

slug — **1.** A commuter, who, lacking membership in a carpool, regularly waits at designated pick-up points, hoping to catch a ride in a carpool vehicle with an unfilled seat. (particular to US East Coast). See also *carpool, casual.* **2.** Persons who, for a fee, will ride in a car so as to increase the occupancy to allow the car to use an HOV lane.

small bus — see *bus, small.*

smart card — stored-value ticket with built-in semiconductor chip. The chip is loaded with monetary value which is decremented for each ride, in flat amounts or, with exit checks, for distance-based fares. Early variants required insertion or contact with farebox or fare gate and were time consuming. Most versions in transit are proximity cards and require only to be held close to the farebox or fare gate inductive detector plate.

soft suspension — see *pendulum suspension.*

space — in the context of transportation vehicle capacity, a space is a seat or the standing area for one passenger, typically a seat consumes 5 ft^2 (0.5 m^2) of floor space and a standing passenger 2.5 ft^2 (0.25 m^2).

space, defensible — see *defensible space.*

spacing — the distance between consecutive vehicles, measured front to front.

special trackwork — see *trackwork, special.*

special work — term for both special trackwork and junctions on overhead electric collection systems.

speed — see *velocity.*

speed, average — see *velocity, effective.*

speed, cruise — see *velocity, cruise.*

speed, cycle — see *speed, overall trip.*

speed, effective operating — see *speed, overall trip.*

speed, line — the speed of the *haul rope* used on a ropeway system, measured in ft/s or m/s.

speed, operating — vague term with different interpretations, see *speed, running;* and *speed, schedule.*

speed, overall trip (effective operating speed, cycle speed) — in transit operations, the average speed achieved per round trip, including layover and recovery time but excluding deadheading time. It is calculated by individual trips, by running time periods, or for the entire schedule.

speed, running — the highest safe speed at which a vehicle is normally operated on a given roadway or guideway under prevailing traffic and environmental conditions; the speed between points, not including stopped time. In some areas, also known as *operating speed,* sometimes *civil speed.*

speed, schedule — the one-way distance between terminals divided by the scheduled travel time between the terminals; exclusive of layover or recovery time, in some areas, also known as *operating speed.*

speed-flow relationship — the relationship between the flow (volume) of units on a transportation facility and the speed of those units. As flow increases, speed tends to decrease.

speed limit, civil — see *civil speed limit.*

spill-back — a situation that may occur in on-street light rail transit operations when trains or motor vehicles fail to clear a signalized intersection and so prevent the following train from entering that block. Particularly acute in downtown streets where the light rail train can be the full length of the block.

split, directional — see *directional split.*

split, modal or mode — see *modal split.*

spot time — see *time, layover.*

stable approach — relative to the passenger loading platform or vessel, the last non-floating structure, including land, that passengers access on their way to the vessel.

staging lot, vehicle — the area provided for vehicles waiting to load onto auto ferries.

standard gauge — see *gauge, standard.*

standard rail — see *rail, standard.*

Standard Railroad Grade Crossing — National ITS Architecture Market Package that manages highway traffic at *highway-rail intersections* where operational requirements do not dictate more advanced features (e.g., where rail speeds are greater than 80 mph or 128 km/h). Both passive (e.g., the crossbuck sign) and active warning systems (e.g., flashing lights and gates) are supported.

standard urban bus — see *bus, standard urban.*

standees — the number of standing passengers on a transit vehicle.

standing capacity — see *capacity, standing.*

station — **l.** An off-street facility (typically) where passengers wait for, board, alight, or transfer between transit units (vehicles or trains). A station usually provides information and a waiting area and may have boarding and alighting platforms, ticket or farecard sales, fare collection, and other related facilities; also known as a *passenger station.* **2.** The location to which operating employees report and from which their work originates. **3.** In transportation planning, the location along a cordon line at which interviews are made. **4.** In railroad operations, a place designated in the timetable by name, at which a train may stop for traffic or to enter or leave the main track, or from which fixed signals are operated.

station, accessible — a public transportation passenger facility that provides ready access, is usable, and does not have physical barriers that prohibit and/or restrict access by individuals with disabilities, including individuals who use wheelchairs.

station, all-stop — in transit systems with skip-stop schedule or express service, a station that is served by all scheduled transit units (vehicles or trains).

station, cornfield — a transit station provided in a relatively undeveloped area, to allow for low-cost parking, to protect against future increases in land costs once the area develops, and/or to allow the planned development of transit-oriented uses around the station.

station, off-line — a station at which a transit unit (vehicle or train) stops outside the main track or travel lane so that other units can pass while passengers board and alight; found on a few automated guideway transit systems and busways.

station, on-line — a station in which transit units (vehicles or trains) stop on the main track or travel lane. This is the common design, and the term is used only to distinguish this station from off-line stations.

station, passenger — see *station.*

station accessibility — see *accessibility, station.*

station platform — see *platform, passenger.*

stinger — a portable cable to connect electric rail vehicles to traction power while in the workshop.

stock, rolling — see *fleet.*

stop, far-side — a transit stop located beyond an intersection. It requires that transit units (vehicles or trains) cross the intersection before stopping to serve passengers.

stop, mid-block — a transit stop located at a point away from intersections.

stop, near-side — a transit stop located on the approach side of an intersection. The transit units (vehicles or trains) stop to serve passengers before crossing the intersection.

stop, off-line — see *station, off-line.*

stop, on-line — see *station, on-line.*

stop, terminal — a transit stop located at either end of a transit route or line.

stop, transit — an area where passengers wait for, board, alight, and transfer between transit units (vehicles or trains). It is usually indicated by distinctive signs and by curb or pavement markings and may provide service information, shelter, seating, or any combination of these. Stops are often designated by the mode offering service, for example, bus stop, car stop.

stopped time — see *time, stopped.*

stored-value card— a magnetic striped or smart (electronic) farecard, purchased with a set monetary value, from which the cost of each trip is decremented, see also *fare collection system, automatic* and *smart card.*

street — see *highway, street,* or *road.*

street, bus-only — a street devoted to bus traffic only.

street, mixed mode — a street carrying mixed traffic, that is, having no exclusive transit lanes or priority lanes for transit.

street, transit — a street reserved for transit vehicles only.

streetcar — an electrically powered rail car that is operated singly or in short trains in mixed traffic on track in city streets. In some areas, it is also known as a *trolley car* and, primarily in Europe and Australia, as a *tram.*

streetcar, heritage — an old streetcar or streetcar built to resemble an older vehicle, electrically operated on rail tracks, generally in downtown areas, for local distribution and tourists. Not to be confused with rubber-tired replica streetcars (see *bus, trolley replica*). Also known as a *vintage streetcar* or *vintage trolley.*

streetcar, vintage — see *streetcar, heritage.*

streetcar, low-floor — a streetcar with low floor for level boarding and exiting. Floor is typically 12-14 in. (300-350 mm) high requiring a platform or raised curb at this height. Wheelchair access is provided directly or by a hinged or removable bridge plate.

streetcar, partial low-floor — a low-floor streetcar with steps or ramps to access high-floor area(s) over trucks and/or any articulations. In this way conventional trucks and propulsion equipment can be used; sometimes termed *hybrid low-floor.*

streetcar operator — see *operator, train.*

streetcar, replica — see *bus, trolley replica.*

streetcar system — see *transit system, streetcar.*

street furniture — equipment placed on the street (off the vehicle lanes), such as lights, benches, signs, bus shelters, kiosks, and plants in containers.

street railway — early term for streetcar system. see *transit system, streetcar.*

street supervisor — see *inspector.*

strip, median — see *median.*

structure, aerial — see *aerial structure.*

structure, fare — see *fare structure.*

structure, route — see *route structure.*

stub terminal — see *terminal, stub.*

study, origin-destination — see *origin-destination study.*

subscription bus service — see *service, subscription bus.*

subscription van service — see *service, subscription van.*

subsidized taxi service — see *service, subsidized taxi.*

sub-station— see *electric sub-station.*

suburb — see definition of *area, urbanized.*

suburban coach or suburban transit bus — see *bus, suburban transit.*

subway — **1.** That portion of a transportation facility or system that is constructed beneath the ground surface, regardless of its method of construction. **2.** An underground rail rapid transit system or the tunnel through which it runs. **3.** In local usage, sometimes used for the entire heavy rail or rapid transit system, even if it is not all beneath the ground surface.

subway car — see *car, rail rapid transit.*

superelevation — **l.** In track construction, the vertical distance that the outer rail is set above the inner rail on a curve, expressed as the vertical distance of the outer rail over the inner rail or as the transverse grade percent. Permits increased operating speed on curves, cannot exceed a maximum, typically 10%, to allow for trains that may stop or operate at below design speed on the curve. **2.** In highway construction, the banking of the roadway on a curve.

supervision, train — see *automatic train supervision.*

supervisor, road, route, or street — see *inspector.*

supported monorail — see *transit system, monorail.*

surface lift— a ropeway on which passengers are propelled by means of a circulating overhead wire rope while remaining in contact with the ground or snow surface. Connection between the passengers and the wire rope is by means of a device attached to, and circulating with, the haul rope, known as a "towing device."

survey, customer satisfaction — survey used to help transit operators identify the quality of service factors of greatest importance to customers; can identify areas and trends of existing passenger satisfaction and the degree to which particular factors influence customer satisfaction.

survey, passenger environment — survey in which trained checkers travel through the transit system and rate trip attributes (such as vehicle cleanliness and audibility of station announcements) to provide a quantitative evaluation of factors that passengers would think of qualitatively.

survey, travel — the collection of data that describe the social, economic, and travel characteristics of people who make trips by various modes of transportation.

suspended monorail — see *transit system, monorail.*

switch — **1.** The movable rails of a turnout that divert the wheels of passing rolling stock from one track to either one of two branching from it. **2.** To move rail cars from one place to another within a defined territory, such as an industry, a yard, or a terminal.

switch, track — see *turnout.*

switch throw and lock time — see *time, switch throw and lock.*

symmetrical monorail — see *transit system, monorail.*

synchronous motor — see *motor, synchronous.*

synfuel or synthetic fuel — see *fuel, synthetic.*

system — see *operator* and *property.*

system, automated highway — see *automated highway system.*

system, automatic train control — see *automatic train control system.*

system, automatic train stop — see *automatic train stop system.*

system, automatic vehicle location — see *automatic vehicle location system.*

system, bus priority — see *bus priority system.*

system, catenary — see *catenary system.*

system, command and control — see *command and control system.*

system, control — see *control system.*

system, fare collection — see *fare collection system.*

system, honor — see *fare collection system, self-service, barrier free.*

system, performance measurement — see *performance measurement system.*

system, propulsion — see *propulsion system.*

system, transit — see *transit system.*

system, transportation — see *transportation system.*

system, trolley — see *transit system, streetcar.*

system effectiveness — system effectiveness is the probability that the system can successfully meet a proper operational demand within a prescribed acceptable time when operated under specified conditions.

system management, transportation — see *transportation system management.*

system performance — see definition of *level of service.*

system planning — in transportation, a procedure for developing an integrated means of providing adequate facilities for the movement of people and goods, involving regional analysis of transportation needs and the identification of transportation corridors involved.

system safety — the application of Operating, Technical, and Management techniques and principles to the safety aspects of a system throughout its life to reduce hazards to the lowest level possible through the most effective use of available resources.

system safety engineering — the application of scientific and engineering principles during the design, development, manufacture and operation of a system to meet or exceed established safety goals.

T

TCRP — Transit Cooperative Research Program.

TDM — Transportation Demand Management.

TEA-21 — Transportation Efficiency Act for the 21st Century. See *legislation, TEA-21.*

TRB — Transportation Research Board; see *organizations, Transportation Research Board.*

TRIS — Transportation Research Information Services.

TSM — Transportation System Management.

TTS — timed transfer system.

TVM — ticket vending machine.

TWU — Transport Workers Union; see *union, transit.*

target point — a continually advancing or fixed stopping point in a moving-block signaling system at which a train must always be able to stop under the most adverse conditions, including partial braking failure. See *control system, moving-block.*

taxicab — a passenger automobile or a specially designed vehicle driven by a professional driver in a for-hire taxi.

taxicab service — see *service, taxicab.*

taxi service, subsidized — see *service, subsidized taxi.*

telecommuting — the substitution, either partially or completely, of transportation to a conventional office through the use of computer and telecommunications technologies (e.g., telephones, personal computers, modems, facsimile machines, electronic mail).

terminal — **1.** The end station or stop on a transit line or route, regardless of whether special facilities exist for reversing the vehicle or handling passengers; also known as a *terminus.* **2.** An assemblage of facilities provided by a railroad or intercity bus service at a terminus or at an intermediate location for the handling of passengers and the receiving, classifying, assembling, and dispatching of trains or dispatching of buses; also known as a *depot.*

terminal, off-street — a transit terminal or turnaround point for transit vehicles that is located away from other vehicular traffic.

terminal, stub — a dead-end terminal in which the entering rail (or other guided) transit unit must depart by the same guideway on which it entered. Because no loop is provided, a bidirectional transit unit (vehicle or train) is necessary.

terminal layout sheet — see *sheet, terminal layout.*

terminal stop — see *stop, terminal.*

terminal time — see *time, terminal.*

terminus — see *terminal.*

territory, train control — see *train control territory.*

theoretical line capacity — see *capacity, theoretical line.*

third rail — see *rail, third.*

third-rail shoe — a graphite sliding contact attached to the trucks of electric rail vehicles for the purpose of collecting current from the third-rail distribution system; uses gravity or spring pressure.

throughput — **1.** The volume of vehicles passing or people transported past a point or series of points during a given period of time. **2.** Traffic.

through routing — the efficient practice of joining the ends of radial transit routes, with similar demand, to travel through downtown instead of having each route turn back in the downtown and return to its origin.

ticket — **1.** A printed card or piece of paper that gives a person a specific right to ride on a train or transit vehicle. **2.** To provide a ticket or tickets.

ticket, commutation — see *commutation ticket.*

tie — see *crosstie.*

time, access — the time elapsed on a trip from the moment of leaving the point of origin (i.e. home or work) to the moment of boarding a vehicle.

time, clearance — all time losses at a stop other than passenger dwell times. It can be viewed as the minimum time between one transit vehicle leaving a stop and the following vehicle entering, including any delay associated with waiting for a sufficient gap in traffic to allow a transit vehicle to re-enter the travel lane.

time, close-in — the minimum time from when a train starts to leave the most restrictive station until the following train can berth at that station (without speed restrictions or stops).

time, deadhead (not-in-service time) — time spent moving a revenue vehicle in non-revenue service.

time, delay — the amount of time by which a transit unit (vehicle or train) in service is delayed from its scheduled time.

time, dwell — the time a transit unit (vehicle or train) spends at a station or stop, measured as the interval between its stopping and starting.

time, egress — the time elapsed on a trip from the moment of alighting from a vehicle to the moment of arriving at the point of destination.

time, excess — time delay associated with travel to or between major transit routes, for example, time spent walking, waiting, or transferring.

time, layover (recovery time, relay time, spot time, turnaround time) — time built into a schedule between arrivals and departures, used for the recovery of delays and preparation for the return trip. The term may refer to transit units (also known as *vehicle layover)* or operators. Note that layover time may include recovery time and operator rest time as two specific components.

time, linked trip (overall travel time, total travel time) — in transportation planning, the time duration of a linked trip, that is, from the point of origin to the final destination, including waiting and walking time at transfer points and trip ends.

time, not-in-service — see *time, deadhead.*

time, operating — the actual time required for a transit unit (vehicle or train) to move from one point to another, including making stops.

time, overall travel — see *time, linked trip.*

time, passenger flow, passenger service — the average time a single passenger takes to pass through a transit vehicle doorway when boarding or alighting, includes any fare collection time.

time, platform — **1.** The time a transit unit is in revenue service **2.**. The period during which an operator is charged with the operation or care of a transit unit (vehicle or train), including operating time in revenue service and deadhead, layover, and other time that the unit may be in operation but not in passenger service. **3.** The time the operator is actually on the assigned transit unit; also known as *work time.*

time, recovery — see *time, layover.*

time, response — in demand-responsive operations, the time between a passenger's request for service and the passenger pickup.

time, running — the actual time required for a transit unit (vehicle or train) to move from one point to another, excluding time for stops.

time, slack — see *operating margin.*

time, stopped — time on a trip spent stationary because of the stoppage of other traffic.

time, switch throw and lock — the time required for the *points* of a rail switch to move from being lined for one direction of travel to being lined for the alternative direction of travel, including any time needed for the points to be safely locked into the new position.

time, terminal — **1.** For passengers, the time required at the ends of trips to park and pick up their private vehicles, including any necessary walking time. **2.** For rail vehicles, the time allowed at a terminal between arrival and departure for turning vehicles, recovering delays, and preparing for the return trip. **3.** The time required for a passenger to pass through a terminal when there is a change of mode.

time, total travel — see *time, linked trip.*

time, transfer — the time required to effect a change of mode or to transfer between routes or lines of the same mode. In transportation modeling this time is weighted, typically by a factor of 1.5.

time, trip — see *time, linked trip;* and *time, unlinked trip.*

time, turnaround — see *time, layover.*

time, unlinked trip — in planning, the time duration of an unlinked trip, that is, one made on a single vehicle.

time, wait — the time spent waiting for a transit vehicle.

time, weighted — a measure of travel time where certain components (e.g., wait time) are factored upward, see also *time, transfer.*

time, work — see *time, platform.*

timed connection or transfer — see *transfer, timed.*

timed transfer focal point — see *hub.*

timed transfer system — a transit network consisting of one or more nodes (transit centers) and routes or lines radiating from them. The system is designed so that transit vehicles on all or most of the routes or lines are scheduled to arrive at a transit center simultaneously and depart a few minutes later; thus transfers among all the routes and lines involve virtually no waiting. Typically used in suburban areas and for night service where headways are long. Transit centers (also known as *timed transfer focal points or hubs)* are ideally located at major activity centers, see also *hub.*

time-of-day fare — see *fare, time-of-day.*

time-of-day pricing — see *pricing, time-of-day.*

time point (timepoint) — a point on a line or route for which the time that transit units (vehicles or trains) are scheduled to pass is specified; usually, the leaving time is used.

time window — a period of time before and after a scheduled demand-responsive trip arrival in which the vehicle will arrive. If the vehicle arrives within that window, it is considered "on time." Time windows are used because the unpredictability of traffic and the shared-ride nature of DRT service make it difficult to predict the exact vehicle arrival time.

timetable — **l.** Usually refers to a printed schedule for the public. **2.** A listing of the times at which transit units (vehicles or trains) are due at specified time points; also known as a *schedule.* **3.** In railroad operations, the authority for the movement of regular trains subject to the rules. It contains classified schedules with special instructions for the movement of trains and locomotives.

token — **1.** A pre-paid, non-monetary stamped piece used in payment for transit service, usually one trip, usually metal, sometimes plastic, sometimes with punched-out center or bi-metal to deter forgery. **2.** An object allowing a train operator possession of a single track section of line, handed-off to a signalman or the operator of the opposing train.

total bus mile equivalents — the number of vehicle miles that would have been operated by a transit mode if the service had been provided by motor buses. Based on average seating plus standing capacity of the vehicle as compared with the capacity including standees (typically 65-75 people) of a standard-size motorbus.

total operating revenue — see *revenue, total operating.*

total travel distance — see *distance, linked trip.*

total travel time — see *time, linked trip.*

total vehicle capacity — see *capacity, vehicle.*

towing device — a carrier, fixed or detachable, used on surface lifts and tows to pull passengers. Classification or description is by the device configuration and action of the extension element (i.e., handle, button, J-bar, T-bar, platter, etc.).

track — **l.** An assembly of rails, supporting ties, and fastenings over which rail vehicles travel. **2.** A linear cam or way that physically guides (and usually supports) any matching vehicle used for transportation. **3.** The width of a wheeled vehicle from wheel to wheel, usually measured between the outsides of the rims. **4.** The distance between the centers of the tread of parallel wheels, as of an automobile.

track brake — see *brake, track.*

track cable — see *cable, track.*

track car — see *car, track.*

track circuit — an electrical circuit that makes use of both rails to detect train occupancy of the track and, in response, to actuate signals, train control devices, and grade crossing protective equipment.

track crossing — see *crossing, track.*

track, double — a section of rail right-of-way where two parallel tracks are provided (i.e., four running rails).

track gauge — see *gauge, track.*

track, passing — see *siding.*

track, pocket — see *pocket track.*

track, side — see *siding.*

trackless trolley— trolleybus, mainly East Coast usage, see *trolleybus.*

track miles (track kilometers) — the sum of the one-way linear miles (kilometers) of all trackage in a system, including all main track and trackage in yards, car barns, switches, and turnouts.

track miles, revenue (revenue track kilometers) — the number of miles (kilometers) of track used in passenger-carrying service.

track miles, service (service track kilometers) — the number of miles (kilometers) of track used exclusively in non-revenue service.

track separation — the distance between tracks. Significant in calculating terminal layover time at turnbacks and junctions.

track special work — see *trackwork, special.*

track switch — see *turnout.*

track trip — a device that is located near the track and interconnected with the signal system so that it triggers the emergency brakes of any train that passes when the signal is red.

trackless trolley— trolleybus, mainly East Coast usage, see *trolleybus.*

trackwork — the rails, switches, frogs, crossings, fastenings, pads, ties, and ballast or track-support slab over which rail cars are operated.

trackwork, special (track special work) — all rails, track structures, and fittings, other than plain unguarded track, that is neither curved nor fabricated before laying.

traction — **1.** Colloquial term for all electric transit. **2.** Grip of wheel on rail or tire on road.

traction motor — see *motor, traction.*

traction interlock, traction safety interlock — in rail transit, a series circuit of electrical switches at each door that prohibit a train from starting unless all passenger doors are closed and locked.

traction pole — pole, mast, or standard supporting electric overhead for streetcars and trolleybuses, sometimes other electric traction modes.

traction sub-station — see *electric sub-station.*

tractive effort (tractive force) — the force exerted by a locomotive or other powered vehicle on its driving wheels. It is equal to the weight on the driving wheels times the coefficient of adhesion.

trade union — see *union.*

traffic, annual average daily (AADT) — daily traffic that is averaged over a calendar or fiscal year.

traffic, annual average weekday (AAWDT) — daily traffic that is averaged over a calendar or fiscal year and that includes only weekdays (Mondays through Fridays). It may also exclude holidays.

traffic, average daily (ADT) — the average number of vehicles that pass a specified point during a 24-hour period.

traffic, mixed (mixed flow traffic) — traffic that contains different vehicle categories or different modes.

traffic, passenger — see *passenger flow.*

traffic assignment — see *trip assignment.*

traffic checker — see *checker.*

traffic control device, grade crossing — see *grade crossing traffic control device.*

traffic control system, centralized — see *control system, centralized traffic.*

traffic count — a record of the number of vehicles, people aboard vehicles, or both, that pass a given checkpoint during a given time period. It may be classified by type of vehicle. See also *count.*

traffic operations, mixed — see *mixed traffic operations.*

traffic signal — a traffic control device that allocates time among conflicting traffic movements that seek to use the same space; uses combinations of green, yellow, and red indications.

trailer car — see *car, trailer.*

train — **1.** Two or more transit vehicles physically connected and operated as a unit; see also *transit unit.* **2.** One or more locomotives or self—propelled rail cars, with or without other cars but with marker lights.

train, bad order — a train that is in need of repair.

train, local — a train that stops at every station on the line; see also *service, local.*

train, push-pull — a locomotive and a set of cars equipped with one or more cab cars from which the locomotive can be controlled. The train is either pulled and controlled from the locomotive in the conventional manner or pushed by the locomotive and controlled from the leading car.

train berth — in rail operations, the space designated for a train of given length to occupy when it is stopped at a station platform, in a terminal, on a transfer track, or at some other designated place.

train control — see *automatic train control system.*

train control system, manual — see *control system, manual train.*

train control territory — the portion of a railroad division or district that is equipped with an automatic train control system.

train density — **1.** The number of trains that can be operated safely over a segment of railroad in each direction during a 24-hour period. **2.** The average number of trains that pass over a specified section of railroad in a specified period. In rail transit, usually expressed in trains per hour.

trainlined brake — see *brake, continuous.*

train operation — the way in which a train is operated, for example, automatic with automatic overspeed control, or manual with either automatic or manual speed control, or skip-stop.

train operation, automatic — see *automatic train operation.*

train operator — see *operator, train.*

train performance — see *performance, train.*

train protection, automatic — see *automatic train protection.*

train separation — in a train signaling system, the minimum distance between trains for a train to come to a complete stop, with a suitable safety margin between it and the train ahead.

train stop system, automatic — see *automatic train stop system.*

train supervision, automatic — see *automatic train supervision.*

tram — see *streetcar.*

tramway — see *transit system, streetcar.*

tramway, aerial — see *aerial tramway.*

transfer — **l.** A passenger's change from one transit unit (vehicle or train) or mode to another transit unit or mode. **2.** A slip of paper, card, or other instrument issued to passengers (either free or with a transfer fee) that gives the right to change from one transit unit or mode to another according to certain rules that may limit the direction of travel or the time in which the change may be made.

transfer, free — a transfer that requires no additional payment.

transfer, paid — a transfer that requires an additional payment *(transfer fee),* either at the time of purchase or at the time of boarding another transit unit (vehicle or train).

transfer, paid area — a transfer in a controlled area, within which all patrons will have paid a fare, that allows boarding of transit units (vehicles or trains) through all doors, without fare inspection — most notably in Toronto.

transfer, timed — **1.** A transfer that is valid only for a specified time. **2.** The scheduling of intersecting transit routes so that they are due to arrive at a transfer point simultaneously, eliminating waiting time for transfer passengers; also known as a *timed connection.* See also *timed transfer system.*

transfer center — see *transit center.*

transfer facility, intermodal — see *transit center.*

transfer fee — see definition of *transfer, paid.*

transfer passenger — see *passenger, transfer.*

transfer penalty — a time value representing additional disutility associated with transferring between transit routes or services beyond passenger-perceived differences in transfer and in-vehicle time.

transfer surcharge — see *transfer, paid.*

transfer time — see *time, transfer.*

transit, mass or public — see *public transit.*

transit accessibility — see *accessibility, transit.*

transit agency or authority — see *transit district.*

transit bus — see *bus, standard urban;* and *bus, suburban transit.*

transit car — see *car, rail rapid transit.*

transit center — a transit stop or station at the meeting point of several routes or lines or of different modes of transportation. It is located on or off the street and is designed to handle the movement of transit units (vehicles or trains) and the boarding, alighting, and transferring of passengers between routes or lines (in which case it is also known as a *transfer center)* or different modes (also known as a *modal interchange center, intermodal transfer facility* or an *hub).*

Transit Cooperative Research Program — a major transit research program provided for in the Intermodal Surface Transportation Efficiency Act of 1991 and established by the Federal Transit Administration in 1992. The program is administered by the Transportation Research Board on behalf of the Federal Transit Administration and the American Public Transportation Association. The program emphasizes the distribution of research information for practical use.

transit dependent — having to rely on transit services instead of the private automobile to meet one's travel needs; see also *rider, captive; rider, captive transit;* and *transportation disadvantaged.*

transit district — a geographical or political division created specifically for the single purpose of providing transportation services. It is a separate legal entity and usually possesses the authority to impose a property tax. Transit agencies can directly operate transit service or contract out for all or part of the total transit service provided. Such political divisions may also be known as a *transit agency* or *transit authority;* see also *property.*

transit facilities, exclusive — see *exclusive transit facilities.*

Transit Fixed-Route Operations — National ITS Architecture Market Package that performs automatic driver assignment and monitoring, as well as vehicle routing and scheduling for fixed-route services.

transit lane, exclusive or reserved — see *lane, exclusive transit.*

Transit Maintenance — National ITS Architecture Market Package that supports automatic maintenance scheduling and monitoring.

transit mall — see *street, transit.*

transit mode — see *mode, transit.*

Transit Passenger and Fare Management — National ITS Architecture Market Package that allows for the management of passenger loading and fare payments on-board vehicles using electronic means. The payment instrument may be either a stored value or credit card.

transit performance measure — a quantitative or qualitative factor used to evaluate a particular aspect of transit service. See *quality of service.*

transit priority measures — a blanket term for measures such as *busways, queue jumpers, signal preemption,* etc. that give transit vehicles priority over other road users.

Transit Security — National ITS Architecture Market Package that provides for the physical security of transit passengers. An on-board security system is deployed to perform surveillance and warn of potentially hazardous situations. Public areas (e.g., stops, park-and-ride lots, stations) are also monitored.

transit service measure — a quantitative performance measure that best describes a particular aspect of transit service and represents the passenger's point of view. See *quality of service.*

transit shelter — a building or other structure constructed at a transit stop. It may be designated by the mode offering service, for example, *bus shelter.* A transit shelter provides protection from the weather and may provide seating or schedule information or both for the convenience of waiting passengers.

transit stop — see *stop, transit.*

transit street — see *street, transit.*

transit-supportive area — see *area, transit-supportive.*

transit system — the facilities, equipment, personnel, and procedures needed to provide and maintain public transit service.

transit system, accessible — a transit system that can transport any mobile person, including those who are physically disabled, and in which the vehicles and stops or stations are designed to accommodate patrons who are confined to wheelchairs.

transit system, automated guideway (automated guideway transit, (AGT) — A transportation system in which automated, driverless vehicles operate on fixed guideways with exclusive right-of-way.

transit system, bus rapid (bus rapid transit, BRT) — an inexact term describing a bus operation providing service similar to rail transit, at a lower cost. BRT systems are characterized by several of the following components: exclusive transitways, enhanced stations, easily identified vehicles, high-frequency all-day service, simple route structures, simplified fare collection, and ITS technologies. Integrating these components is intended to improve bus speed, reliability, and identity.

transit system, commuter rail — The portion of passenger railroad operations that carries passengers within urban areas, or between urban areas and their suburbs, but differs from rail rapid transit in that the passenger cars generally are heavier, the average trip lengths are usually longer, there are few standing passengers, and the operations are carried out over tracks that are part of the railroad system in the area. In some areas it is called *regional rail.*

transit system, diesel light rail (DLR) — A rail transit system similar to *light rail,* but with trains drawing power from diesel engines, rather than from overhead electric wires, and often using freight tracks for a portion of the route. DLR systems differ from commuter rail in that the vehicles used are not FRA-compliant in terms of crashworthiness, and therefore must be separated from freight operations in either space (separate trackage) or time (freight movements only allowed during times when the DLR system is not operating).

transit system, dual-mode — a broad category of systems wherein vehicles may be operated in both of two different types of operation or propulsion, for example, manually steered and guided, on highways and on guideways, or with diesel and electric traction.

transit system, fixed guideway — **1.** A transportation system composed of vehicles that can operate only on their own guideways, which were constructed for that purpose. Examples are heavy rail, light rail, and monorail. **2.** Federal usage of the term in funding legislation also includes bus priority lanes, exclusive right-of-way bus operations, trolley coaches, and ferryboats as fixed guideway transit.

transit system, group rapid (GRT) — an automated guideway transit system that uses medium-sized vehicles operating automatically as single units or coupled trains on exclusive rights-of-way with special guideways. The vehicles are usually rubber tired and electrically propelled. The systems are sometimes referred to as *people-mover systems* but the preferred term is *automated guideway transit.*

transit system, heavy rail — see *transit system, rail rapid.*

transit system, interurban — electric rail transit service between cities and towns, often running on-street within towns. Once common in North America, the Chicago, South Shore & South Bend is the only remaining system.

transit system, light rail (LRT) — as defined by the TRB Subcommittee on Light Rail Transit, "a metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, on aerial structures, in subways, or occasionally, in streets, and to board and discharge passengers at track or car floor level." Automated systems sharing some characteristics of heavy rail are often called *advanced light rail systems.* See also *transit system, diesel light rail.*

transit system, light rail, dual-mode — light rail transit with operation extended over railroad trackage that is shared with other trains. First examples in Karlsruhe and Saarbrucken, Germany, with cars equipped to operate at 750 volts DC and 15,000 volts AC.

transit system, light rail rapid — A Buffalo-only designation referring to a subway system with light rail type equipment and operation on a downtown mall.

transit system, major activity center (MAC system) — a transit system that provides service for short trips within small, densely populated major activity centers, such as shopping centers and downtown areas.

transit system, monorail — a transit system consisting of vehicles supported and guided by a single guideway (rail or beam), usually elevated. The basic types are *supported or straddle,* in which vehicles straddle the guideway or are laterally supported by it; and *suspended,* in which vehicles hang directly below the guideway *(symmetrical monorail)* or to one side of it *(asymmetrical monorail).*

transit system, personal rapid (PRT) — a theoretical concept for an automated guideway transit system that would operate small units (two to six passengers) under computer control over an elaborate system of guideways. Off-line stations would provide demand-responsive service (except, perhaps, during peak periods) with very short headways with travel between origin and destination stations without stopping. Only system with some of these features is in Morgantown, West Virginia.

transit system, pre-metro — a light rail transit system designed with provisions for easy conversion to heavy rail (rail rapid transit).

transit system, publicly owned — a transit system owned by any municipality, county, regional authority, state, or other governmental agency, including a system operated or managed by a private company under contract to the government agency owner.

transit system, rail — any of the family of transit modes with rail technology, see adjacent listings.

transit system, rail rapid (heavy rail, rapid rail) — a transit system using trains of high-performance, electrically powered rail cars operating in exclusive rights-of-way, usually without grade crossings, with high platform stations. The tracks may be in underground tunnels, on elevated structures, in open cuts, at surface level, or any combination thereof. Some local terms used are *elevated, the el, the "L," the rapid, the subway*, *metro*, (*for metropolitan railway), underground* (British), and *U-Bahn* (Untergrundbahn) and *Stadtbahn* (German). (Note that Stadtbahn is distinct from S-Bahn, which is generally a commuter rail type operation.)

transit system, rapid — transit service which is operated completely separate from all other modes of transportation. The term "rail rapid transit" frequently refers both to operation of light rail transit vehicles over exclusive right-of-way and heavy rail transit vehicles; the term "bus rapid transit" refers to operation of motor buses over exclusive bus roads or busways.

transit system, semi-metro — a light rail transit system that uses exclusive right-of-way for much of its length, usually at surface grade but occasionally in tunnels or on aerial structures. Also similar to *transit system, pre-metro* — built for later conversion to heavy rail. Particular to several European countries and now little used.

transit system, shuttle — a transit system that is characterized by a back-and-forth operation, usually over a short distance.

transit system, streetcar (street railway, tramway, trolley) — a street transit system consisting of electrically powered rail vehicles operating in single or multiple-unit, mostly on surface streets with mixed traffic.

transit system availability — a measure of the capability of a transit system to be used by potential passengers, including such factors as the hours the system is in operation, route spacing, and accessibility to persons with disabilities.

Transit Traveler Information — National ITS Architecture Market Package that provides transit users at transit stops and on-board transit vehicles with ready access to transit information. The information services include transit stop annunciation, imminent arrival signs, and real-time transit schedule displays that are of general interest to transit users. Systems that provide custom transit trip itineraries and other tailored transit information services are also represented by this market package.

transit union — see *union, transit.*

transit unit — one or more transit vehicles coupled and operated together. The term includes single vehicles (bus, rail, or other guideway) and multi-car trains (rail or other guideway).

transit unit, bidirectional or double-ended — see *double-ended transit unit.*

Transit Vehicle Tracking — National ITS Architecture Market Package that provides for an AVL system to track the transit vehicles' real-time schedule adherence and updates the transit system's schedule in real-time.

transitway — A dedicated right-of-way or roadway used by transit vehicles (buses or trains). Sometimes used, as in Ottawa, as a synonym for *busway.*

transmission-based control system — see *control system, moving block.*

transponder — electronic device designed to store information. Electronic readers access the information stored on these devices for such functions as toll collection, trucking activities, and transit signal priority.

transport, conventional rail — see *conventional rail transport.*

Transport Workers Union — see *union, transit.*

transportation, department of — see *organizations, department of transportation;* and *U.S. Government, Department of Transportation.*

transportation, intercity — see *intercity transportation.*

transportation, mass — see *mass transportation.*

transportation, private — see *private transportation.*

transportation, public — see *public transportation.*

transportation, purchased — see *purchased transportation.*

transportation, urban public — see *urban public transportation.*

transportation demand management (TDM) — the concept of managing or reducing travel demand rather than increasing the supply of transportation facilities. It may include programs to shift demand from single-occupant vehicles to other modes such as transit and ridesharing, to shift demand to off-peak periods, or to eliminate demand for some trips.

transportation disadvantaged (low-mobility group) — people whose range of transportation alternatives is limited, especially in the availability of relatively easy-to-use and inexpensive alternatives for trip making. Examples include the young, the elderly, the poor, persons with disabilities, and those who do not have automobiles. See also *transit dependent; rider, captive;* and *rider, captive transit.*

transportation facilities — see *accessible transportation facilities.*

transportation improvements, low—capital — see *low-capital transportation improvements.*

transportation interface — the point or facility at which two or more modes of transportation meet or at which two or more transit system routes or lines meet.

transportation modeling system, urban — see *urban transportation modeling system.*

transportation planning process, urban — see *urban transportation planning process.*

Transportation Research Board — see *organizations, Transportation Research Board.*

Transportation Research Information Services (TRIS) — a national network of transportation research information services developed by the Transportation Research Board. TRIS consists of the Air Transport Information Service, Highway Research Information Service, Maritime Research Information Service, Railroad Research Information Service, and Urban Mass Transportation Research Information Service.

Transportation Study, Nationwide Personal — see *Nationwide Personal Transportation Study.*

transportation system — **1.** A system that provides for the movement of people, goods, or both. **2.** A coordinated system made up of one or several modes serving a common purpose, the movement of people, goods, or both.

transportation system, demand-actuated — see *transportation system, demand-responsive.*

transportation system, demand-responsive (demand-actuated transportation system, demand-response transportation system) — passenger cars, vans or buses with fewer than 25 seats operating in response to calls from passengers or their agents to the transit operator, who then dispatches a vehicle to pick up the passengers and transport them to their destinations. A demand-responsive operation is characterized by the following: (a) The vehicles do not operate over a fixed route or on a fixed schedule except, perhaps, on a temporary basis to satisfy a special need; and (b) typically, the vehicle may be dispatched to pick up several passengers at different pick-up points before taking them to their respective destinations and may even be interrupted en route to these destinations to pick up other passengers. The following types of operations fall under the above definitions provided they are not on a scheduled fixed-route basis: many origins–many destinations, many origins–one destination, one origin–many destinations, and one origin–one destination.

transportation system, dial-a-ride — a demand-responsive system in which curb-to-curb transportation is provided to patrons who request service by telephone, either on an ad hoc or subscription basis. It is also known as dial-a-bus when buses are the vehicles used.

transportation system, fixed-route — service provided on a repetitive, fixed-schedule basis along a specific route with vehicles stopping to pick up and deliver passengers to specific locations; each fixed-route trip serves the same origins and destinations, unlike demand response. Includes route deviation service, where revenue vehicles deviate from fixed routes on a discretionary basis.

transportation system, jitney — public transportation rendered in small or medium-sized vehicles that are licensed to render that service at a fixed rate or fare for each passenger. The vehicles operate on fixed routes along public ways, from which they may deviate from time to time in response to a demand for service or to take passengers to their destinations, thereafter returning to the fixed route. The scheduling and organization of this type of system vary among jurisdictions. It is used extensively in cities of developing countries that have inadequate transit service. See also *service, jitney* and *público.*

transportation system, non-fixed route — service not provided on a repetitive, fixed-schedule basis along a specific route to specific locations. Demand response is the only non-fixed-route mode.

transportation system, urban — the system of transportation elements (both private and public) that provides for the movement of people and goods in an urban area. The components include transit systems, paratransit services, and highway or road systems, including private vehicles and pedestrians.

transportation system management (TSM) — that part of the urban transportation planning process undertaken to improve the efficiency of the existing transportation system. The intent is to make better use of the existing transportation system by using short-term, low-capital transportation improvements that generally cost less and can be implemented more quickly than other system development actions.

trap — in railway cars, a manually raised and lowered floor section that covers the steps at the ends of the car. When raised, the trap allows passengers to use the car steps at stations without high platforms. When lowered, the trap provides nearly level boarding at high platform stations, and keeps passengers out of the step area when the train is in motion.

Travel Demand Management — National ITS Program User Service that supports policies and regulations designed to mitigate the environmental and social impacts of traffic congestion. See also *Transportation Demand Management.*

travel distance — see *trip distance, linked.*

travel survey — see *survey, travel.*

travel time, overall or total — see *time, linked trip.*

travel time difference — the door-to-door difference between automobile and transit travel times, including walking, waiting, and transfer times as applicable. A quality of service measure representing how much longer (or in some cases, shorter) a trip will take by transit.

travel time factor — an empirically determined set of factors in which each factor expresses the effect of one particular travel time increment of trip interchanges between zones.

travel time ratio — the ratio that compares travel times between a pair of points via two different modes or facility types.

Traveler Services Information — National ITS Program User Service that provides a business directory, or "yellow pages," of service information.

treatment, edge — see *edge treatment.*

treatment, preferential — see *preferential treatment.*

trip — **1.** A one-way movement of a person or vehicle between two points for a specific purpose; sometimes called a *one-way trip* to distinguish it from a round trip. **2.** In rail operations, a mechanical lever or block signal that, when in the upright position, activates a train's emergency braking system. **3.** The movement of a transit unit (vehicle or train) in one direction from the beginning of a route to the end of it; also known as a *run.*

trip, inbound — a trip toward the central urban area, into the central business district, or to a timed transfer point or major activity center.

trip, linked (linked journey, linked passenger trip) — a trip from the point of origin to the final destination, regardless of the number of modes or vehicles used.

trip, missed — demand-responsive transit trip that is scheduled and booked but for which the transit vehicle does not show up. A measure of reliability.

trip, non-home-based — a trip that has neither its origin nor its destination at a residence.

trip, one-way — see *trip.*

trip, outbound — a trip away from the central urban area, out of the central business district, or away from a timed transfer point or major activity center.

trip, passenger — one passenger making a one-way trip from origin to destination.

trip, person — a trip made by a person by any mode or combination of modes for any purpose.

trip, round — the movement of a person or a vehicle from a point of origin to a destination and then back to the same point of origin.

trip, track — see *track trip.*

trip, unlinked — **1.** A trip made in a single vehicle. **2.** The boarding of one transit vehicle in revenue service; also known as an *unlinked passenger trip.* **3.** Any segment of a linked trip.

trip, vehicle — the one-way movement of a vehicle between two points.

trip arm — see *track trip.*

trip assignment (flow distribution, traffic assignment) — in planning, a process by which trips, described by mode, purpose, origin, destination, and time of day, are allocated among the paths or routes in a network by one of a number of models; see also *urban transportation modeling system.*

trip attraction — in transportation planning, the non-home end of a home-based trip or the destination of a non-home-based trip.

trip distance, linked (total travel distance) — the distance traveled on a linked trip, that is, the distance from the point of origin to the final destination, including the walking distance at trip ends and at transfer points.

trip distance, unlinked — the distance traveled on an unlinked trip, for example, a trip on a single vehicle.

trip distribution — in planning, the process of estimating movement of trips between zones by using surveys or models; see also *urban transportation modeling system* and *model, sequential.*

trip end — a trip origin or a trip destination.

trip generation — in planning, the determination or prediction of the number of trips produced by and attracted to each zone; see also *urban transportation modeling system* and *model, sequential.*

trip generator — a land use from which trips are produced, such as a dwelling unit, a store, a factory, or an office.

tripper — **1.** In transit operations, a short piece of work that cannot be incorporated into a full day's run, usually scheduled during peak hours. **2.** In transit operations, a short work schedule for operators, usually 1-3 hours long; for example, during peak periods. **3.** On some transit properties, a short run that is less than 8 hours long. **4.** On some transit properties, a transit service that operates on only a portion of a route, usually at peak hours.

trip productions — in planning, the number of trips, daily or for a specified time interval, that are produced from and return to a given zone, generally the zone of residence. Trip productions can also be defined as the home end of home-based trips or the origin of non-home-based trips.

trip purpose — the primary reason for making a trip, for example, work, shopping, medical appointment, recreation.

trip time — see *time, linked trip* and *time, unlinked trip.*

trolley — **l.** An apparatus, such as a grooved wheel or shoe, at the end of a pole, used for collecting electric current from an overhead wire and transmitting it to a motor of a streetcar, trolleybus, or similar vehicle, where it is used for traction and other purposes. **2.** Colloquial term for streetcar, and in some cities, trolleybus, vintage, and/or replica streetcar (see *bus, trolley replica).*

trolley bus — alternate spelling for *trolleybus,* the single word is recommended.

trolleybus (electric trolleybus, trolley coach, trackless trolley) — an electrically propelled bus that obtains power via two trolley poles from a dual (positive and negative) overhead wire system along routes. It may be able to travel a limited distance using battery power or an auxiliary internal combustion engine. The power-collecting apparatus is designed to allow the bus to maneuver in mixed traffic over several lanes.

trolleybus, articulated — see *articulated bus or articulated trolleybus.*

trolley car — see *car, trolley.*

trolley coach — see *trolleybus.*

trolley pole — **1.** A swiveling spring-loaded pole attached on the roof of a trolleybus or streetcar that holds a wheel or sliding shoe in contact with the overhead conductor (which usually takes the form of a thick wire), collects current from it, and transmits the current to the motor on the vehicle, for example, a streetcar or trolleybus. **2.** Inexact reference to traction pole or mast support trolleybus or streetcar overhead contact wiring.

trolley replica bus — see *bus, trolley replica.*

trolley shoe — see *overhead contact shoe.*

trolley system — see *transit system, streetcar.*

trolley wire — see *contact wire.*

truck (bogie, *British usage*) — in rail transportation, a rail vehicle component that consists of a frame, normally two axles, brakes, suspension, and other parts, which supports the vehicle body and can swivel under it on curves. A truck usually also contains traction motors.

turbine engine — see *engine, turbine.*

turn, short — see *turn back.*

turnaround time — see *time, layover.*

turn back — **l.** In transit operations, to cut short a transit trip (to turn back before reaching the end of the route or line), usually to get back on schedule or to meet peak passenger demands; also known as a *short turn.* **2.** In rail operations, a point along a track at which a train may reverse direction.

turnout — **1.** In rail transportation, the assembly of a switch and a frog with closure rails by which rolling stock or trains can travel from a track onto either one of two diverging tracks; also known as a *track switch.* **2.** A short side track or passage that enables trains, automobiles, and similar vehicles to pass one another. **3.** A short passing lane on a highway.

turnout, bus — see *bus bay.*

turnover, parking — see *parking turnover.*

turnover point — a point along a transit route at which a large proportion of passengers leave and board a transit unit.

turnstile — a mechanical device used to control and/or measure pedestrian entry or exit from an area. It uses a bar that rotates out of the way when a pedestrian presses against it. When used as a fare gate, the bars unlock only after the correct fare has been paid.

turnstile, fare-registering — see *fare-registering fare gate.*

turntable — a circular, rotating mechanical device that allows a rail car to be turned in place to change its direction of travel. It may be motorized, or as in the case of San Francisco's cable cars, require operators to physically push the car to turn it around.

U

UA — urbanized area; see *area, urbanized.*

UITP — see *organizations, International Union of Public Transport.*

UMTA — Urban Mass Transportation Administration; previous name for FTA, see *U.S. Government, Federal Transit Administration.*

UMTRIS — Urban Mass Transportation Research Information Service.

U.S. DOT — U.S. Department of Transportation; see *U.S. Government, Department of Transportation.*

UTU — United Transportation Union; see *union, transit.*

UZA — used by some to indicate an urbanized area, although the Bureau of the Census uses UA; see *area, urbanized.*

underground — see *transit system, rail rapid.*

unidirectional car — see *car, unidirectional.*

uninterrupted flow — transit vehicles moving along a roadway or track without stopping. This term is most applicable to transit service on freeways or on its own right-of-way.

union, transit — one of the many unions representing various segments of the transit industry's work force. Three major ones in the United States and Canada are the *Amalgamated Transit Union (ATU),* the *Transport Workers Union (TWU),* and the *United Transportation Union (UTU).* Their membership is limited to operators, mechanics, and other non-supervisory employees. A non-affiliated *Independent Canadian Transit Union* has raided older unions and represents some transit systems in Canada, the largest being BC Transit.

unit, basic operating — see *basic operating unit.*

unit, transit — see *transit unit.*

United States Government — see *U.S. Government.*

United Transportation Union — see *union, transit.*

unlimited access — see *access, unlimited.*

unlinked passenger trip — see *trip, unlinked.*

unlinked trip — see *trip, unlinked.*

unlinked trip distance — see *trip distance, unlinked.*

unlinked trip time — see *time, unlinked trip.*

urban ferryboat — see *ferryboat, urban.*

urban fringe — that part of an urbanized area outside the central city or cities.

Urban Mass Transportation Act — see *legislation, Urban Mass Transportation Act of 1964.*

Urban Mass Transportation Administration — see *U.S. Government, Federal Transit Administration.*

Urban Mass Transportation Research Information Service (UMTRIS) — a computer-based information storage and retrieval system developed by the Transportation Research Board under contract to the Federal Transit Administration. It consists of summaries of research projects in progress and abstracts of published works. See also *Transportation Research Information Services.*

urban place — a U.S. Bureau of the Census designated area (less than 50,000 population) consisting of closely settled territory not populous enough to form an urbanized area.

urban public transportation — transportation systems for intraurban or intraregional travel, available for use by any person who pays the established fare. It consists of transit and paratransit.

urban rail car — see *car, urban rail.*

urban transit bus — see *bus, standard urban.*

urban transportation system — see *transportation system, urban.*

urbanized area — see *area, urbanized.*

U.S. Department of Transportation — see *U.S. Government, Department of Transportation.*

user information (service information) — information on fares, stopping places, schedules, and other aspects of service essential to the efficient use of public transit. The term also refers to devices employed to convey such information, including bus stop signs, timetable brochures or books, telephone inquiries, and computerized user-interactive systems.

User Services — services available to users of ITS (drivers, passengers, system operators) as set forth by ITS America.

U.S. Government, Amtrak — see *U.S. Government, National Railroad Passenger Corporation.*

U.S. Government, Department of Energy (DOE) — a cabinet-level federal agency whose responsibilities include improving the energy efficiency of transportation.

U.S. Government, Department of Health, Education, and Welfare (HEW) — a cabinet-level federal agency that provides funds for many specialized transportation services in urbanized and rural areas as part of its social service programs.

U.S. Government, Department of Transportation (DOT) — a cabinet-level federal agency responsible for the planning, safety, and system and technology development of national transportation, including highways, mass transit, aircraft, and ports.

U.S. Government, Federal Highway Administration (FHWA) — a component of the U.S. Department of Transportation, established to ensure development of an effective national road and highway transportation system. It assists states in constructing highways and roads and provides financial aid at the local level, including joint administration with the Federal Transit Administration of the 49 USC Section 5311 (formerly Section 18 of the Federal Transit Act) program.

U.S. Government, Federal Railroad Administration (FRA) — an agency of the U.S. government, established in 1966 as part of the U.S. Department of Transportation. It coordinates government activities that are related to the railroad industry.

U.S. Government, Federal Transit Administration (FTA) — a component of the U.S. Department of Transportation, delegated by the Secretary of Transportation to administer the federal transit program under Chapter 53 of Title 49, United States Code and various other statutes. Formerly known as the Urban Mass Transportation Administration.

U.S. Government, National Railroad Passenger Corporation (Amtrak) — an agency created by Congress in 1970 to operate the national railroad passenger system. It also operates commuter rail service under contract, usually to metropolitan transit agencies.

U.S. Government, National Transportation Safety Board (NTSB) — an independent agency of the federal government whose responsibilities include investigating transportation accidents and conducting studies, and making recommendations on transportation safety measures and practices to government agencies, the transportation industry, and others.

U.S. Government, Urban Mass Transportation Administration (UMTA) — former name of the Federal Transit Administration; see *U.S. Government, Federal Transit Administration.*

utilization coefficient — see *load factor.*

V

VKT — vehicle kilometers of travel; see *vehicle miles of travel.*

VMT — vehicle miles of travel.

validation — the marking of a ticket, pass, or transfer for the purpose of verifying its legitimate use for paid travel, usually giving time and place of marking.

validator — component of ticket vending machine or separate machine that stamps date, time, and sometimes location on pre-purchased ticket or pass to validate or cancel same.

value, default — see *default value.*

van — vehicles having a typical seating capacity of 5 to 15 passengers and classified as a van by vehicle manufacturers. A modified van is a standard van which has undergone some structural changes, usually made to increase its size and particularly its height. The seating capacity of modified vans is approximately 9 to 18 passengers.

van, subscription — see *service, subscription van.*

vanpool — vans and/or buses seating less than 25 persons operating as a voluntary commuter ride sharing arrangement, which provides transportation to a group of individuals traveling directly between their homes and their regular places of work within the same geographical area. The vans should have a seating capacity greater than seven persons, including the driver. It is a mass transit service operated by a public entity, or in which a public entity owns, purchases, or leases the vehicles. Other forms of public participation to encourage ridesharing arrangements such as the provision of parking spaces, utilization of high-occupancy vehicle (HOV) lanes, and coordination or clearing house service, do not necessarily qualify as public vanpools.

vehicle, accessible — public transportation revenue vehicles which do not restrict access, are usable, and provide allocated space and/or priority seating for individuals who use wheelchairs.

vehicle, active — the vehicles that are available to operate in revenue service, including vehicles temporarily out of service for routine maintenance and minor repairs.

vehicle, articulated rail — see *articulated rail vehicle.*

vehicle, dual-mode — a vehicle that operates both manually on public streets and automatically on an automated guideway. May also be used to describe vehicles with more than one source of power; for example, a bus that can be propelled by a diesel engine or an electric motor.

vehicle, high-occupancy (HOV) — any passenger vehicle that meets or exceeds a certain predetermined minimum number of passengers, for example, more than two or three people per automobile. Buses, carpools, and vanpools are HOV vehicles.

vehicle, light rail — see *car, light rail.*

vehicle, public service — a vehicle used for public passenger transport.

vehicle, revenue — a vehicle used to provide passenger transit service for which remuneration is normally required. It is distinct from non-revenue equipment, which is used to build or maintain facilities, provide supervision, and so on.

vehicle, single-occupant (SOV) — a vehicle occupied by the driver only.

vehicle capacity — see *capacity, vehicle.*

vehicle hours — The hours a vehicle travels while in revenue service (vehicle revenue hours) plus deadhead hours. For rail vehicles, vehicle hours refer to passenger car hours. Vehicle hours exclude hours for charter services, school bus service, operator training and maintenance testing.

vehicle layover — see *time, layover.*

vehicle location system — see *automatic vehicle location system.*

vehicle miles (or kilometers) — the miles a vehicle travels while in revenue service (vehicle revenue miles plus deadhead miles). For rail vehicles, vehicle miles refer to passenger car miles. Vehicle miles exclude miles for charter services, school bus service, operator training and maintenance testing.

vehicle miles, revenue — see *revenue vehicle miles.*

vehicle miles of travel (VMT; vehicle kilometers of travel, VKT) — **1.** On highways, a measurement of the total miles (kilometers) traveled by all vehicles in the area for a specified time period. It is calculated by the number of vehicles times the miles (kilometers) traveled in a given area or on a given highway during the time period. **2.** In transit, the number of vehicle miles (kilometers) operated on a given route or line or network during a specified time period.

vehicle occupancy — the number of people aboard a vehicle at a given time; also known as *auto or automobile occupancy* when the reference is to automobile travel only.

vehicle signal-actuating device — a device to control traffic signals that is activated by vehicles.

vehicle staging lot — see *staging lot, vehicle.*

vehicle trip — see *trip, vehicle.*

velocity (speed) — the distance passed per unit of time, or the rate of change in location relative to time. For transportation vehicles, it is usually measured in miles (kilometers) per hour.

velocity, cruise (cruise speed) — the forward velocity that a vehicle maintains when it is neither accelerating nor decelerating. It is usually less than maximum design speed but can be equal to it.

velocity, effective (average speed) — **1.** The average velocity at which a vehicle travels. For transit vehicles, it includes dwell times at stops or stations, acceleration, and deceleration. **2.** Vehicle miles divided by vehicle hours.

velocity, maximum theoretical — the highest theoretical velocity that a vehicle is physically capable of achieving, usually specified on level, tangent road or track with full service load.

viaduct — see *aerial structure.*

vintage streetcar — see *streetcar, heritage.*

vintage trolley — see *streetcar, heritage.*

voltage, high — in rail transportation, the prime propulsion power voltage supplied by an overhead wire or third rail, usually 550, 650, 750, 1,000, 1,500 and 3,000 volts DC; and 11,000, 15,000, and 25,000 volts AC.

voltage, low — in rail transportation, the voltage used for most auxiliary systems (e.g., illumination, fans, public address systems), usually 24 or 72 volts direct current or 110 to 240 volts alternating current.

voltage drop — the decrease in voltage in a current-carrying conductor.

volume — in transportation, the number of units (passengers or vehicles) that pass a point on a transportation facility during a specified interval of time, usually 1 hour; see also *flow rate.*

volume, design hourly — see *design hourly volume.*

volume, line — see *passenger volume.*

volume, link — see *link volume.*

volume, passenger — see *passenger volume.*

volume, service — see *service volume.*

W

wait assessment — A measure of headway regularity. Defined as the percentage of transit vehicle arrivals where the actual headway exceeds the scheduled headway by more than 3 minutes.

wait time — see *time, wait.*

walkway, moving — see *moving walkway.*

walk distance — see *distance, walk.*

walking distance — see *distance, walking.*

wake — wave motion that is left behind the path of a moving vessel.

water sheet — the horizontal surface area of the water available for maneuvering and docking or mooring at a shore facility.

water taxi — **1.** A ferry system in which small watercraft serve short cross-waterway or waterway circulation routes. **2.** Ferry service providing personal, demand-responsive service over water, similar to a taxi. **3.** The type of small watercraft used by water taxi systems.

way, bicycle — see *bicycle route.*

way, public — see *public way.*

wayside — along the right-of-way, usually of rail system.

wayside control system — see *control system, wayside.*

wayside lift — see *wheelchair lift.*

wayside signal — see *signal, wayside.*

weighted time — see *time, weighted.*

welded rail — see *rail, welded.*

wheelchair lift — a device used to raise and lower a platform that facilitates transit vehicle accessibility for wheelchair users and other persons with disabilities. Wheelchair lifts may be attached to or built into a transit vehicle or may be located on the station platform *(wayside lifts).*

wheel flange — in rail systems, a projecting edge or rim on the circumference of a steel wheel that is designed to keep the wheel on a rail.

wheels, driving — see *driving wheels.*

wide gauge — see *gauge, broad.*

windscreen card — a printed or handwritten card usually placed in the bottom of the curb-side windscreen to denote a destination or service information such as "via…", express, limited stop, short turn, and so forth. Often used when the destination blind does not contain the desired destination or to display a secondary destination or route deviation.

wire, contact or trolley — see *contact wire.*

workshop (shop) — section of yard, depot, maintenance and storage facility, or garage where maintenance is carried out on vehicles.

wye — a triangular rail junction to turn trains or streetcars around without the need for a loop.

Y

yard — **1.** In rail systems, a facility within defined limits that has a system of tracks used for making up trains, storing rail cars, and other purposes. **2.** In transit systems, an open storage lot for light rail vehicles, streetcars, electric trolley buses, and motor buses.

yard limits — a slow-speed area on main railroad tracks that often extends 5-10 miles (8-16 km) from either end of a yard. For transit operations, this distance is much shorter: it is usually confined to the yard itself or to a short lead, usually less than 1 mile (1.6 km) in length.

Yellow Pages and Reservation — National ITS Architecture Market Package that enhances the *Interactive Traveler Information* package by making infrastructure-provided yellow pages and reservation services available to the user.

Z

zone, auto-free — see *auto-free zone.*

zone, auto-restricted — see *auto-restricted zone.*

zone, layover — see *layover zone.*

zone accessibility — see *accessibility, zone.*

zone or zoned fare — see *fare, zone.*

LIST OF SYMBOLS

This portion of the glossary lists all of the symbols used in equations in the *Transit Capacity and Quality of Service Manual* and their units. The symbol descriptions given below may be abridged versions of the descriptions given in the text, particularly where a symbol is used in multiple equations.

a	initial service acceleration rate, ft/s^2 *or* m/s^2
a_g	acceleration due to gravity, ft/s^2 *or* m/s^2
A_d	number of disembarking autos, AEUs
A_e	number of embarking autos, AEUs
B	bus facility vehicle capacity, bus/h
b	separation safety factor—surrogate for blocks
B_l	loading area bus capacity, bus/h
B_p	maximum bus capacity of critical bus stop in pattern, bus/h
B_s	bus stop vehicle capacity, bus/h
$B_{s,min}$	minimum bus stop capacity along a bus facility, bus/h
$B_{1\ldots}B_n$	vehicle capacities of a set of routes in a skip-stop pattern, bus/h
c	capacity of a lane, veh/h
c_r	right-turn capacity, veh/h
c_v	coefficient of variation of dwell times
c_v	coefficient of variation of embarking and disembarking times
c_{vh}	coefficient of variation of headways
C	cycle length, s
C_c	car capacity, peak 15 minutes, p/car
C_c	carrier capacity, p/carrier
C_d	disembarking capacity at the constraining point, p/min
C_e	embarking capacity at the constraining point, p/min
C_g	gangway capacity, p/min/channel
C_h	cars operated per hour, car/h
C_{max}	longest cycle length in line's on-street section, s
C_w	capacity of the waiting area exit, p/min/channel
C_x	capacity of the walkway exit, p/min/channel
d	service deceleration rate, ft/s^2 *or* m/s^2
d_1	distance for one-block stop pattern, ft *or* m
d_2	distance for multiple-block stop pattern, ft *or* m
d_c	average carrier/train/car spacing on the line, ft/carrier *or* m/carrier
d_{eb}	distance from front of stopped train to start of station exit block, ft *or* m
d_{ec}	pedestrian crossing delay exceeding 30 s, s
d_p	average pedestrian delay, s
d_s	deceleration rate, ft/s^2 *or* m/s^2
d_{ts}	track separation, ft *or* m
d_x	distance from cross-over to platform, ft *or* m
D	pedestrian density, p/ft^2 *or* p/m^2
D_n	number of doorways
D_w	doorway width, ft *or* m
f	bus (vessel) frequency, bus/h *or* vessels/h
f_a	arrival type adjustment factor for the ability to fully utilize the bus stops in a skip-stop operation
f_b	bus-bus interference adjustment factor
f_{br}	braking safety factor
f_{eff}	effective frequency, bus/h
f_g	grade factor

f_i	adjacent lane impedance factor
f_k	skip-stop capacity adjustment factor
f_l	bus stop location factor
f_m	mixed traffic adjustment factor
f_{min}	minimum frequency to accommodate peak-15-minute passenger demand without overcrowding bus, bus/h
f_p	bus-passing activity factor
f_{pop}	population factor
f_{px}	pedestrian crossing factor
f_r	right-turn adjustment factor
f_s	stop pattern adjustment factor
f_{sa}	switch angle factor
f_{sc}	street connectivity factor
g	effective green time for vehicle or pedestrian signals, s
g/C	ratio of effective green time to total traffic signal cycle length
G_i	grade into station, percent
G_o	grade out of station, percent
h	train headway, s
h_{gs}	minimum grade-separated headway, s
h_j	limiting headway at junctions, s
h_l	line headway, s
h_{lr}	minimum light rail headway, s
h_{os}	minimum on-street train headway, s
h_{st}	minimum single-track headway, s
h_v	vehicle headway, s/auto
l_v	line voltage as a percentage of specification
L	(longest) train length, ft *or* m
L_a	articulation length for light rail, ft *or* m
L_c	vehicle interior length, ft *or* m
L_l	line length, ft *or* m
L_p	platform length, ft *or* m
L_r	distance between the gangway and front of vehicle staging area, ft *or* m
L_{st}	length of single-track section, ft *or* m
L_t	train length, ft *or* m
L_w	walkway length, ft *or* m
L_x	crossing distance for pedestrians, ft *or* m
M	pedestrian space, ft^2/p *or* m^2/p
N	seating arrangement constant
N_b	number of berths at dock
N_c	number of cars per train
N_{ca}	number of channels for autos
N_{ce}	number of channels at the walkway exit
N_{cg}	number of gangway channels
N_{cw}	number of channels exiting the waiting area
N_{el}	number of effective loading areas
N_f	number of fare collectors
N_p	number of buses making the maneuver from the curb lane to the adjacent lane
N_s	number of stops per direction
N_{ss}	number of alternating skip-stops in pattern
N_{st}	number of stations on single-track section
N_v	number of vehicles

P	person capacity, p/h
P	person (auto) capacity on the route’s maximum load section, p/h *or* autos/h
P_{15}	passenger volume during the peak 15 minutes, p
P_a	alighting passengers through the busiest door during the peak period, p/bus
P_b	boarding passengers through the busiest door during the peak period, p/bus
P_c	maximum design load per car, p/car
P_c	maximum schedule load per car, p/car
P_d	disembarking passenger volume, p
P_e	embarking passenger volume, p
P_e	positioning error, ft *or* m
P_h	passenger volume during the peak hour, p
P_i	number of people involved in activity i
P_l	average load per late bus during the peak 15 minutes, p/bus
P_m	linear passenger loading level, p/ft *or* p/m
P_{max}	maximum schedule load per bus, p/bus
PHF	peak hour factor
r	transit stop service radius, mi *or* m
r_0	ideal transit stop service radius, mi *or* m
s	standard deviation of dwell times
S	speed, ft/min *or* m/min
S_a	area of single seat, ft^2 *or* m^2
S_b	single setback allowance, ft *or* m
S_{avail}	space available within the area analyzed, ft^2 *or* m^2
S_i	space required for activity i, ft^2 *or* m^2
S_m	speed margin
S_{mb}	moving-block safety distance, ft *or* m
S_p	walking speed, ft/s *or* m/s
S_{sp}	space per standing passenger, ft^2 *or* m^2
S_t	travel speed, mph *or* km/h
S_w	seat pitch, ft *or* m
t_a	passenger alighting time, s/p
t_b	passenger boarding time, s/p
t_{br}	brake system reaction time, s
t_c	clearance time, s
t_{cg}	pedestrian critical gap, s
t_{cs}	train control separation, s
t_d	dwell time, s
t_{ed}	total embarking and disembarking time, s/vessel
t_f	fare collection time, s/p
t_i	dwell time value that will not be exceeded more often than the desired failure rate, s
t_{jl}	time lost to braking jerk limitation, s
t_l	bus running time losses, min/mi *or* min/km
t_l	terminal layover time, s
t_{oc}	door opening and closing time, s
t_{om}	operating margin, s
t_{os}	time for overspeed governor to operate, s
t_{ps}	pedestrian start-up and end clearance time, s
t_r	base bus running time, min/mi *or* min/km
t_s	switch throw and lock time, s
t_{st}	time to cover single-track section, s

t_v	vessel service time, s/vessel
T	line capacity, train/h *or* carrier/h *or* car/h
T_{avail}	time available as defined for the analysis period, s
T_i	time required for activity *i*, s
TS_{avail}	time-space available, ft^2-s *or* m^2-s
TS_{req}	time-space required, ft^2-s *or* m^2-s
v	pedestrian flow rate, p/ft/min *or* p/m/min
v	traffic volume in a lane, veh/h
v	vehicular flow rate, veh/s
v_a	station approach speed, ft/s *or* m/s
v_b	bus volume in the bus lane, bus/h
v_d	disembarking passenger speed on walkway, ft/min *or* m/min
v_e	embarking passenger speed on walkway, ft/min *or* m/min
v_l	line speed, ft/s *or* m/s
v_l	line speed, mph *or* km/h
v_{max}	maximum line speed, ft/s *or* m/s
v_p	bus volume in pattern, bus/h
v_r	right-turn volume, veh/h
v_v	vehicle entering/exiting speed, ft/s *or* m/s
V	dock vessel capacity, vessels/h
V_b	vessel capacity of the berth, vessels/h
V_{bi}	vessel capacity of berth *i*, vessels/h
V_c	passenger (auto) capacity of the vessel, p/vessel *or* autos/vessel
W_c	vehicle interior width, ft *or* m
W_s	stepwell width, ft *or* m
Z	standard normal variable corresponding to a desired failure rate

PART 9
INDEX

This page is intentionally blank.