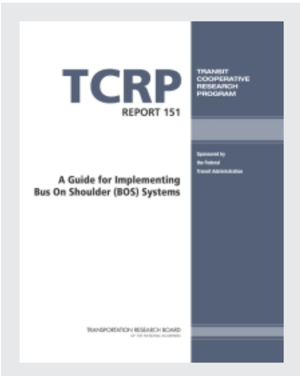


A Guide for Implementing Bus on Shoulder (BOS) Systems

DETAILS

119 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-25820-3 | DOI 10.17226/22809

AUTHORS

Martin, Peter; and Levinson, Herbert S.

TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 151

A Guide for Implementing Bus On Shoulder (BOS) Systems

Peter Martin
WILBUR SMITH ASSOCIATES
San Francisco, CA

Herbert S. Levinson
Wallingford, CT

Texas Transportation Institute
College Station, TX

Subscriber Categories
Public Transportation • Planning and Forecasting

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

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2012
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 151

Project D-13
ISSN 1073-4872
ISBN 978-0-309-25820-3
Library of Congress Control Number 2012939366

Published reports of the

TRANSIT COOPERATIVE RESEARCH PROGRAM

are available from:

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

and can be ordered through the Internet at

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

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

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

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

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

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

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

www.national-academies.org

AUTHOR ACKNOWLEDGMENTS

Many transit agencies, MPOs, State DOTs, and other agencies provided valuable support for this Bus On Shoulders Guidelines research effort. Special thanks are offered to Jennifer Conover (MnDOT), Carl Jensen (MnDOT), Michael Abegg (MVTA), Emerson Barrow (SANDAG), Brent Boyd (SDMTS), Jesus Guerra (Miami Dade MPO), Jill Hedges (Minnesota Metro Transit), Steve Legler (Minnesota Metro Transit), William Lenski (Chicago RTA), Lou Millan (NJ Transit), Doug Moore (COTA), Dave Schumacher (SANDAG), Jim Schwartzwalder (NJ Transit), Pat Scrimgeou (Ottawa Transit), and Fred Silverman (Parsons Corp). Herbert Levinson and Anthony Voigt (TTI) were invaluable sub consultants in this research. And thanks, too, to the TCRP Project D-13 project panel.

FOREWORD

By Stephan A. Parker
Staff Officer
Transportation Research Board

TCRP Report 151: A Guide for Implementing Bus On Shoulder (BOS) Systems provides guidelines for the planning, design, and implementation of BOS operations along urban freeways and major arterials. Making BOS a reality requires a closely coordinated partnership effort involving transit agencies, state departments of transportation (DOTs), metropolitan planning organizations (MPOs), enforcement agencies, and FHWA. The report should be useful as a decision-making guide to assist transit operators, state DOTs, MPOs, and other stakeholders in assessing the feasibility of the BOS concept, developing safe and effective BOS plans, implementing initial BOS operations, and maintaining or expanding ongoing BOS operations.

In the research effort led by Wilbur Smith Associates, Inc., the guide was developed through a review of literature, analysis of existing installations, interviews with agency staff involved in BOS projects, and feedback from bus passengers and bus drivers in BOS communities. Rather than performing the analysis remotely, the research team emphasized on-site observations, discussions, and data collection with BOS stakeholders and users. This approach involved a two-stage process of visits to selected BOS sites. The primary focus of the first set of site visits was to understand BOS implementation decision-making processes. The second set of site visits focused on data collection, analysis, and formulation of BOS guidelines. This guide includes seven "case study" BOS sites, with information on other new and potential BOS communities. The case study communities are:

- Minneapolis-St. Paul, Minnesota;
- Miami-Dade, Florida;
- San Diego, California;
- Old Bridge, New Jersey;
- Ottawa, Ontario, Canada;
- Columbus, Ohio; and
- Atlanta, Georgia.

This guide and a PowerPoint presentation describing the entire project are available on the TRB website at http://www.trb.org/Main/Blurbs/166878.aspx.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

A Guide for Implementing Bus On Shoulder (BOS) Systems

This report provides guidelines for the planning, design, and implementation of bus on shoulder (BOS) operations along urban freeways and major arterials. The guidelines are based upon review of literature, analysis of existing installations, interviews with agency staff involved in BOS projects, and feedback from bus passengers and bus drivers in BOS communities. The guidelines should be useful to communities that are considering BOS implementation and to current BOS communities.

Context

Bus priority treatments on streets and highways have proven effective for about a half century. In the past 20 years the BOS concept has been added to the toolbox of transit priority treatments. The Minneapolis–St. Paul Twin Cities area was a pioneer in implementing BOS systems, and has continually expanded their BOS network to more than 250 miles of shoulder on its freeways and arterials. The Twin Cities BOS operations often serve as both a template and a "can do" example of BOS operations. Planners and engineers from other cities come to the Twin Cities to see BOS operations and return home assured that BOS is a viable concept for possible deployment to help solve their local congestion problems. Early in the Twin Cities BOS history, the philosophy at the partnered agencies was "How can BOS become a reality?" rather than "Can buses be driven on shoulder?"

In the past two decades BOS has expanded from a few early projects in the Twin Cities area, Canada, Seattle, and New Jersey to new projects in San Diego, Miami, Columbus, Cleveland, Cincinnati, Wilmington, the Washington, D.C. area, and Atlanta. New projects are being planned in Chicago, Kansas City, and Raleigh and current communities are looking to expand their pilot projects. This trend reflects the consensus that BOS is a successful concept when properly planned, designed, implemented, and operated. None of the implemented BOS projects have been discontinued due to poor experience.

Bus On Shoulder Concept

The BOS concept, quite simply, is the allowing of buses to use shoulders on freeways and major arterial streets during peak congestion periods to bypass congestion in the general purpose traffic lanes. Most of the current applications have buses using the right-side shoulder, but the new Cincinnati I-71 BOS and the planned Chicago I-55 BOS use the inside or left-side shoulder. Bus passengers love the BOS projects and bus drivers on the BOS routes tend to think BOS is a good idea. Communities tend to like the BOS concept, as it is not obtrusive, requires no additional right-of-way, is low cost, and can be implemented relatively quickly. It has been successful everywhere it has been installed in a wide variety of operating environments. BOS safety experience has been excellent.

BOS differs from shoulders that are open to high-occupancy vehicle (HOV) and general traffic during peak congestion hours. BOS applications carry much lower volumes of traffic than HOV and general traffic use of shoulders. This minimizes problems for emergency response vehicles, as the relatively fewer buses can easily merge back into general traffic flow. In some instances they can even be alerted to the emergency response by dispatch. In addition to much lower traffic volumes, the shoulder speeds are much lower and more controlled than if used by HOV or general traffic. Lastly, BOS drivers are professionally trained and supervised, further adding to safe operations on the shoulders.

BOS operations have had no discernible affect on general traffic flow. By taking bus traffic out of the general purpose travel lanes, some minor benefit possibly might be gained by general traffic.

Transit Operating Guidelines

Speed Protocols

The greatest benefit from BOS operations is achieved where the differential speeds are highest between the congested general traffic lanes and higher-speed shoulder bus operations. Surveys of bus drivers and decades of operating experience suggest 35 mph as the maximum shoulder speed and threshold speed in general traffic lanes for buses to start using the shoulders. Each corridor is different so engineering judgment should be used in setting this speed. As drivers are instructed to use the shoulders at their discretion, they can opt to operate at lower speeds if they feel it is safer.

Most BOS communities use 15 mph as the maximum speed differential between general traffic speeds and speeds that buses are allowed to operate while using the shoulder. Some communities use a 10 mph maximum speed differential. Bus drivers are instructed not to operate any faster than conditions suggest for safety. The maximum BOS travel time benefit, however, comes with maximum allowable speed differentials. The 15 mph "standard" speed differential is suggested for start-up and early years of operations. As operating experience is gained, incrementally raising the speed should be considered. For BOS corridors with significant entry/exit ramp weaving conflicts and with narrow 10-foot shoulders, the 15 mph maximum differential is probably the best long-term maximum. BOS drivers are responsible for judging how fast traffic in general purpose lanes is moving and how much faster they will operate on the shoulder within the maximum allowed speed differential. The 15 mph speed differential is again judged by BOS drivers.

User Surveys

Bus drivers and bus passengers of BOS projects have been surveyed to understand their perception of the concept. Bus passengers tend to love the concept and rate most of its features highly. They are known to urge bus drivers to use the shoulder as general traffic begins to slow. Bus drivers also like the BOS concept. Many would like wider shoulders, but most feel the current operating protocols, signage and markings, and training are good. These surveys confirm that BOS has been carefully planned, designed, and operated in many jurisdictions in North America.

Auxiliary Lanes and Ramp Metering

The Minnesota Department of Transportation (DOT) has found that ramp metering is helpful along BOS corridors to facilitate bus weaving movements at on-ramp conflict points. San Diego's BOS operation is along freeway segments with auxiliary lanes. While many corridors will not have right-of-way for auxiliary lanes, the experience in San Diego demonstrates that these lanes help minimize weaving conflicts at interchanges. Buses essentially operate in the auxiliary lane for the area between the off-ramp and on-ramp at interchanges, where they operate on the shoulder. Thus, the auxiliary lanes simplify the BOS conflicts at interchanges to simple diverge movements from the auxiliary lane at off-ramps and merge movements into auxiliary lanes at on-ramps, rather than crossing weaving movements.

Congestion Fluctuations

Most current BOS applications are along corridors with reoccurring congestion. These congestion conditions substantially worsen in bad weather, during special events and at times incidents further disrupt travel. Congested corridors tend to have unstable traffic flow conditions and minor disruptions or minor demand spikes often lead to major increases to delays. Congestion conditions vary by season, by day and even within a peak hour on a given day.

The benefits of BOS can be greatest at gridlock stop-and-go conditions when traffic is moving at 5 mph or less. The slower the speed general traffic is moving, the greater the travel time benefits of BOS. This would suggest that BOS should be deployed on the core area's most congested roadways. Some of these severely congested roadways do not have 10 foot minimum shoulders for BOS running and many of them have very high on and off-ramp traffic movements (more than 1,000 vph). Some of these severely congested roadways also have dual-lane off- and on-ramps, which complicate BOS operations. Some also have restricted traffic sight distances. If these ramp conflicts can be managed or buses routed to minimize conflicts (e.g., exit at the ramp), these would be the most promising BOS applications.

Design Guidelines

Most general purpose traffic lanes are 11 to 12 feet in width, but many shoulders on older highways are often 10 feet less in width. Buses are 8.5 feet wide and allowing for outside mirrors they have a 10 foot cross-section width. Most BOS projects have been implemented using minimum ten foot shoulders, but some projects have 12 foot shoulders or wider. BOS projects use available shoulder widths to minimize costs and they anticipate that over time older shoulders will be upgraded to 12 foot shoulders. Both the current Cincinnati and planned Chicago inside-shoulder BOS projects utilize at least 12 foot shoulders.

Experience has shown that 10 foot width shoulders generally can be used safely for BOS operations. Engineering judgment must be exercised for each application. On long overpasses, 11.5 foot shoulder widths are recommended. Where possible, 12 foot shoulder widths are desirable. BOS operations using the inside (median) shoulder should be 12 feet wide.

Traffic Guidelines

Signs and pavement markings should conform to the guidelines set forth in the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD). The MUTCD does not provide specific guidance for BOS implementation, but it does provide general rules for regulatory and warning signs that apply to BOS signage. It includes guidance on shape, color, size and placement of signs. Most BOS projects have used the Twin Cities practice for signage. This includes signs along the highway shoulder designating begin and end points, regulatory signs defining eligible users and use and sometimes pinchpoint warning signs. Warning signs are also sometimes installed on on-ramps to alert motorists of bus operating on shoulders. Some communities have complemented the signage with pavement markings. Overall the signage and markings are minimal and consistent with MUTCD's philosophy of not overloading motorists with information.

Buses yield to motorists at exit and on-ramps. The Twin Cities has found that ramp traffic less than 1,000 vph during the congestion peak is not a problem at weaving points. Traffic volumes in excess of 1.000 vph they feel warrants special attention with perhaps having buses remerge with general traffic before these high volume interchanges. Dual-lane on and off-ramps at interchanges also complicate BOS operations.

For left-side shoulders the greatest challenge appears to be how to remerge buses from the shoulder back into the general purpose traffic flow. The merge right has more obstructed sight lines for drivers than the merge to the left. The location of bus drivers on the left side of the bus allows them better sight lines for merging left than for merging right. Downstream bottleneck locations where this remerge can be shifted from congested flow to free flowing traffic should be considered.

Implementation Guidelines

Making BOS a reality requires a closely coordinated partnership planning, design, implementation and operations effort involving transit agencies, state DOTs, Metropolitan Planning Organizations, and enforcement agencies. Within the DOT's traffic operations, highway design, highway maintenance and multimodal departments should be involved. Traffic and enforcement agencies generally include municipalities as well as state agencies. FHWA involvement in this partnership is essential.

Conclusions

BOS has proven successful in corridors where it has been implemented. This is largely the result of tailoring the concept to the corridor in the planning, design, implementation, and operations stages of project development/deployment. With the right partner agencies and disciplines working together, effective and safe BOS projects can be deployed to improve transit bus services. BOS is not the ideal transit or highway solution, but due to its low cost, ability to work within existing right-of-way and relatively quick implementation time, it has proven popular.

SECTION 1

Introduction

Introduction

In many urban areas, traffic congestion commonly delays bus services and adversely affects schedule reliability. Bus priorities on streets and highways have been successfully used for almost a half century. More recently, some communities have adopted policies and regulations that permit buses to use shoulders on arterial highways and freeways to bypass congestion, either as interim or long-term treatments. Bus on shoulder (BOS) operations have been working successfully for nearly two decades in several urban locations. Lack of information on the benefits, issues in its interface with traffic operations, safety issues, and implementation issues have been some of the reasons for reluctance by other communities to use the BOS concept.

The BOS Concept

The BOS concept has been implemented in many forms for a variety of purposes, all with a number of similar traits. All but one of the current BOS applications allows buses to use the right-side shoulder. Cincinnati's BOS application allows buses to use the left-side (median) shoulder. Typically, the BOS projects limit buses using the shoulder to times when traffic on the highway is congested and moving very slowly, and they cap the speed buses are allowed to operate on the shoulder. The Toronto application is an exception, allowing buses to use the shoulder at all times and not restricting bus speeds on the shoulder.

BOS applications minimize congestion-related schedule reliability problems; they improve the competitive travel times for buses versus cars; they reduce bus running times; they are low cost and easy to implement; they do not require new rights-of-way; and they are not obtrusive. BOS's context sensitive design features (low visual impact), low cost, ease of implementation, and support of more efficient and attractive transit services resonate with numerous public policies. In addition, the BOS concept appears to be popular with bus passengers. They seem to like the feeling of preference as their bus passes stop-and-go traffic in the general purpose traffic lanes. It is not uncommon for passengers to suggest that bus drivers move onto the shoulder when traffic begins to slow. The perceived travel time benefits are generally greater than actual, but since perception is a key factor in increasing transit market share, this is a very important benefit. To date, safety experience has been excellent.

TCRP Synthesis 64: Bus Use of Shoulders, a state of the practice, was published in 2006. *TCRP Synthesis 64* found that little information was available on many key issues, as some BOS projects had been implemented without rigorous documentation. Information on early BOS projects is mostly limited to what can be seen on the street. Limited history exists on the institutional, legal, project development process, costs, and performance of these early BOS projects. Better information would be useful to communities considering implementation of BOS and those interested in improving current BOS projects. It may also be valuable for the FTA "New Starts" project alternative definitions and evaluations. Recent implementation of BOS in the San Diego region, in northern Atlanta, three cities in Ohio, Old Bridge, New Jersey, and in Miami, Florida, have more recent and detailed planning development and engineering documentation. These recent efforts provide an opportunity to better describe the "how to" and the state-of-the-practice design elements. This report was initiated to provide technical information on operating practices, design requirements and performances, and agency/passenger response to BOS projects.

Key Research Objectives

TCRP's Project D-13 research objectives were intended to provide a decision-making guide to assist transit operators, state DOTs, metropolitan planning organizations (MPOs), and other stakeholders to assess the feasibility of the BOS concept, develop safe and effective BOS plans, implement, operate, and maintain BOS operations. The primary focus is to recommend measures that safely move people through congested corridors. Accordingly, the research identifies the following key design and operational issues:

- Conditions under which shoulders can be used for bus travel, including design and operational criteria;
- The advantages and disadvantages and the cost/benefit potential of BOS operations programs; and
- Procedures and strategies that may be used by stakeholders to successfully implement BOS projects.

The following key issues, initially identified in *TCRP Synthesis 64,* needed further investigation and research and were the focus of the TCRP Project D-13 research effort:

1. What are the market and patronage benefits associated with BOS and how can project design maximize these benefits? Surveys would be useful to better understand passenger perceptions as well as the perceptions of motorists using the adjacent general purpose lanes. Understanding perceptions of these groups would help better design BOS projects as well as provide guidance to marketing efforts. Quantification of before and after bus patronage in corridors is also needed.
2. What are the bus running time and reliability benefits resulting from BOS operations? Experience indicates that bus running times in general purpose lanes vary widely depending on weather and traffic conditions. Operating speeds on shoulders tend to be more predictable. Thus, the travel time savings and schedule reliability benefits that are provided by BOS are closely linked to traffic speeds and conditions in adjacent travel lanes. Quantification of running time savings and schedule reliability benefits, therefore, should focus closely on traffic conditions in BOS corridors. Driver surveys would help complement the travel time data.
3. What is the safety history of BOS operations and how might the design of BOS applications minimize safety risks? A review of accident data and discussions with enforcement, driver training, and bus safety staff can help assess key safety concerns and identify myths.
4. Most of the BOS projects that have been implemented employed a multi-agency team planning, design, and implementation approach. More information is required on these multi-agency partnership efforts, as well as on the legal aspects of project implementation.
5. What geometric improvements are needed and what are their guidelines for costs? The minimum shoulder widths need further definition. Should shoulders be wider on bridges and underpasses and on other segments with horizontal obstructions nearby? Is there a maximum distance that minimum-width shoulders are tolerable? Should shoulders be wider at sharp curves? What are the desired geometrics for BOS transitions and interchange ramp weave areas? What is the minimum pavement strength required? How important are modifications to drainage inlets? What are the desired and maximum drainage cross slopes for

BOS shoulders? What lighting improvements, if any, are desired for the BOS segments? What minimums can be accepted, particularly for interim applications?
6. What signage and striping guidelines/standards are recommended and should these be included in the next update of the *Manual on Uniform Traffic Control Devices* (MUTCD) and AASHTO's *A Policy on Geometric Design of Highways and Streets*?
7. How might variable or changeable message signs and intelligent transportation systems (ITS) technologies be used to improve BOS safety?
8. How does the design of the BOS facility affect the operating speed? Most BOS operations in the United States restrict bus operating speeds, while Canadian BOS operations allow unrestricted full-speed operations. What are the differences that allow full-speed operation in Canada and how might they carry over to the United States?
9. What is the preferred treatment of shoulder lanes in the immediate vicinity of major entry and exit ramps?

Report Organization

Following this introductory section, this report is organized into six sections:

Section 2—Overview of Current BOS Applications,
Section 3—Operations Guidelines,
Section 4—Design Considerations and Guidelines,
Section 5—Traffic Operations Issues for Bus On Shoulders,
Section 6—Recommended Decision-Making Framework, and
Section 7—Conclusions.

Definitions and Acronyms

AASHTO—American Association of State Highway and Transportation Officials.

Auxiliary Lane (Aux Lane)—Refers to the portion of the roadway adjoining the main travel way for speed change, turning, storage for turning, weaving, truck climbing and other purposes supplementary to through-traffic movement.

BOS—Bus on shoulder.

BBS—Bus bypass shoulder, used in *TCRP Synthesis 64* to describe bus use of highway shoulder lanes to bypass congestion. It does not include shoulders used for general traffic or on-ramp bypasses.

MUTCD—*Manual of Uniform Traffic Control Devices for Streets and Highways*, which is published by the Federal Highway Administration.

Pork Chop—A pork-chop shaped traffic channelization island that is designed to facilitate free right turns at intersections. Transit priority versions of pork-chop islands allow buses to utilize the right-turn approach lane to bypass the through-movement traffic queue at signalized intersections, and once up to the right-turn channelization pork-chop shaped island, to continue straight across the intersection (bus-only movement).

Station Stopping—Describes a mode of bus operations on freeways in which buses on a route make stops at all or most interchanges along the corridor.

Shoulder—Refers to the portion of the roadway contiguous with the travel way that accommodates stopped vehicles, emergency use, and lateral support of sub-base, base, and surface courses.

Queue Jumper—A physical facility that allows eligible traffic (buses) to bypass localized congestion.

HOV—High-occupancy vehicle, which is generally defined as either two or more, or three or more, persons per vehicle.

DOT—Department of transportation.

MPO—Metropolitan planning organization.

NEPA—National Environmental Policy Act.

Direct HOV access ramps—Most HOV lanes are located in the median of freeways and require carpoolers and buses to weave across general traffic lanes to enter and exit the freeway using ramps located on the right side of freeways. Direct access ramps eliminate the weaving for buses and HOVs by providing entry and exit access ramps directly to the center median HOV lanes. These direct ramps are costly, need additional rights-of-way, and add to the visual impact of freeway interchanges.

VPH—Vehicles per hour flow rate.

PPH—Persons per hour flow rate.

SECTION 2

Overview of Bus On Shoulder Projects

Introduction

This research effort was initiated to provide technical information on operating practices, design requirements, performances, and agency/passenger response to BOS projects. *TCRP Synthesis 64* provided an overview of BOS projects as of August 2006. This chapter provides an overview of bus on shoulder projects in North America. It builds upon and extends the state-of-the-art obtained in *TCRP Synthesis 64.* These projects are shown in Table 2-1. Subsequent to the publication of *TCRP Synthesis 64,* six new BOS projects have since been implemented, several BOS projects have been strengthened with new signage, and two new projects are on the verge of implementation. Columbus, Ohio, implemented its first BOS project in November 2006 along I-70 east of downtown; Cincinnati, Ohio, implemented its BOS project on I-71 in July 2007; Cleveland, Ohio, implemented a BOS project on I-90 in May 2008; New Jersey added a second BOS project on Route 9 in Old Bridge; and Miami initiated BOS service on March 27, 2007 on the Don Shula and Snapper Creek Expressways. Figure 2-1 identifies the current locations of BOS operations in North America. In addition to the Figure 2-1 BOS operations, Chicago recently has inaugurated BOS operations on the Stevenson Expressway. Raleigh North Carolina and Kansas City are both about to implement new BOS projects.

Information on seven case-study communities BOS sites is presented in this chapter, followed by information on other new and potential BOS communities. The case-study communities are as follows:

- Minneapolis-St. Paul Twin Cities area;
- Miami-Dade, Florida;
- San Diego, California;
- Old Bridge, New Jersey;
- Ottawa, Ontario, Canada;
- Columbus, Ohio; and
- Atlanta, Georgia.

Minnesota, Twin Cities Area

The Minneapolis-St. Paul Twin Cities area is at the forefront of implementing and operating the bus use of shoulder concept in the United States. It is used by most urban areas as a model of proven design and operations. The Minneapolis-St. Paul Twin Cities area first established BOS operations in 1991 on a six-lane arterial highway (Highway 252). In rapid response to a 1993 flood closure of some major highways, the BOS operations were expanded to the freeway system as well as to several other key highways. The BOS network has continually expanded, and today it consists of 260 miles of shoulders for authorized bus usage.

Table 2-1. Summary of BOS projects as of January 2011.

Location	Type	Description	Use Criteria	Status
Metropolitan Minneapolis-St. Paul Twin Cities area, Minnesota	comprehensive network	260 miles	no BOS time restrictions, primarily transit buses, speeds limited to use when congestion slows to 35 mph—buses allowed to operate 15 mph faster than general traffic	continually expanding since 1991
Virginia near Falls Church	eastbound (EB) queue jumper on Route 267	1.3-mile segment with no interchange weaves	buses limited to maximum speed of 25 mph between 4–8 pm	appears to have been operational for some years
Maryland near Burtonsville	US-29 southbound (SB) and northbound (NB) corridor	4-mile arterial highway segment with several signalized junctions	SB 6–9 am NB 3–8 pm	appears to have been operational for some years
Maryland near Bethesda	I-495 northbound queue jump of I-270 interchange	about 3 miles in length	NB 6–9 am NB 3–7 pm	appears to have been operational for several years
Washington, Seattle Region	SR-520 westbound (WB) corridor BOS	2.7 miles with several interchanges	buses and 3+ carpools use shoulder lane, no restrictions on speed or time of day	early 1970s
Washington, Seattle Region	SR-522 arterial bus bypass shoulder (BBS) corridor	2.2 miles with several signalized intersections	buses only, no restriction on speed or time of day	WB opened in 1970 and EB in 1986
New Jersey near Mountainside	Route 22 EB BOS corridor	about 1 mile in length	buses only, 35 mph speed restriction	appears to have been operational some years
New Jersey near Old Bridge	Route 9 NB and SB arterial BOS	about 4 miles in length	morning NB and evening SB, buses only, no information on speed restrictions	started November 2006 with plans for extension in progress
Georgia near Alpharetta	GA-400 freeway BOS corridor	12 miles	when general traffic drops to 35 mph BOS buses allowed to operate 15 mph faster	opened on September 12, 2005
Delaware near Wilmington	Route 202 SB BOS queue jumper	about 1500 feet with one intermediate signal	no time restriction for BOS use	appears to have been operational for some years
Vancouver BC	Route 1 queue jumper	not available (n.a.)	n.a.	n.a.
Toronto, Ontario	Highway 403 congestion bypass both directions	about 3 miles	when traffic slows to 38 mph BOS allowed to operate 12 mph faster	started in 2003
Ottawa, Ontario	Highways 417 and 174	about 14 miles	BOS buses allowed to operate at posted speed of 62 mph	in operation since 1992
Dublin, Ireland	many segments in the network	50 to 70 miles	rules vary by BOS location	expanding since 1998 initial application
Auckland, New Zealand	several corridors	n.a.	no speed restrictions	expanding since 1991
Miami, Florida Area	SR-821/SR-836	corridor applications	when traffic slows below 35 mph	started March 2007
California, San Diego Area	I-805/SR-52	two year pilot BOS project of about 4 miles	when general traffic slows below 30 mph, buses allowed to operate up to 10 mph faster	started December 2005
Columbus, Ohio	I-70 east of downtown both directions	about 10 miles in length	when general traffic drops to 35 mph BOS buses allowed to operate 15 mph faster	started November 2006
Cincinnati, Ohio	I-71 left-side median shoulders	about 10 miles in length	when general traffic drops to 30 mph BOS buses allowed to operate 15 mph faster	started July 2007
Cleveland, Ohio	I-90 east of downtown both directions	about 10 miles in length	when general traffic drops to 35 mph BOS buses allowed to operate 15 mph faster	started June 2008

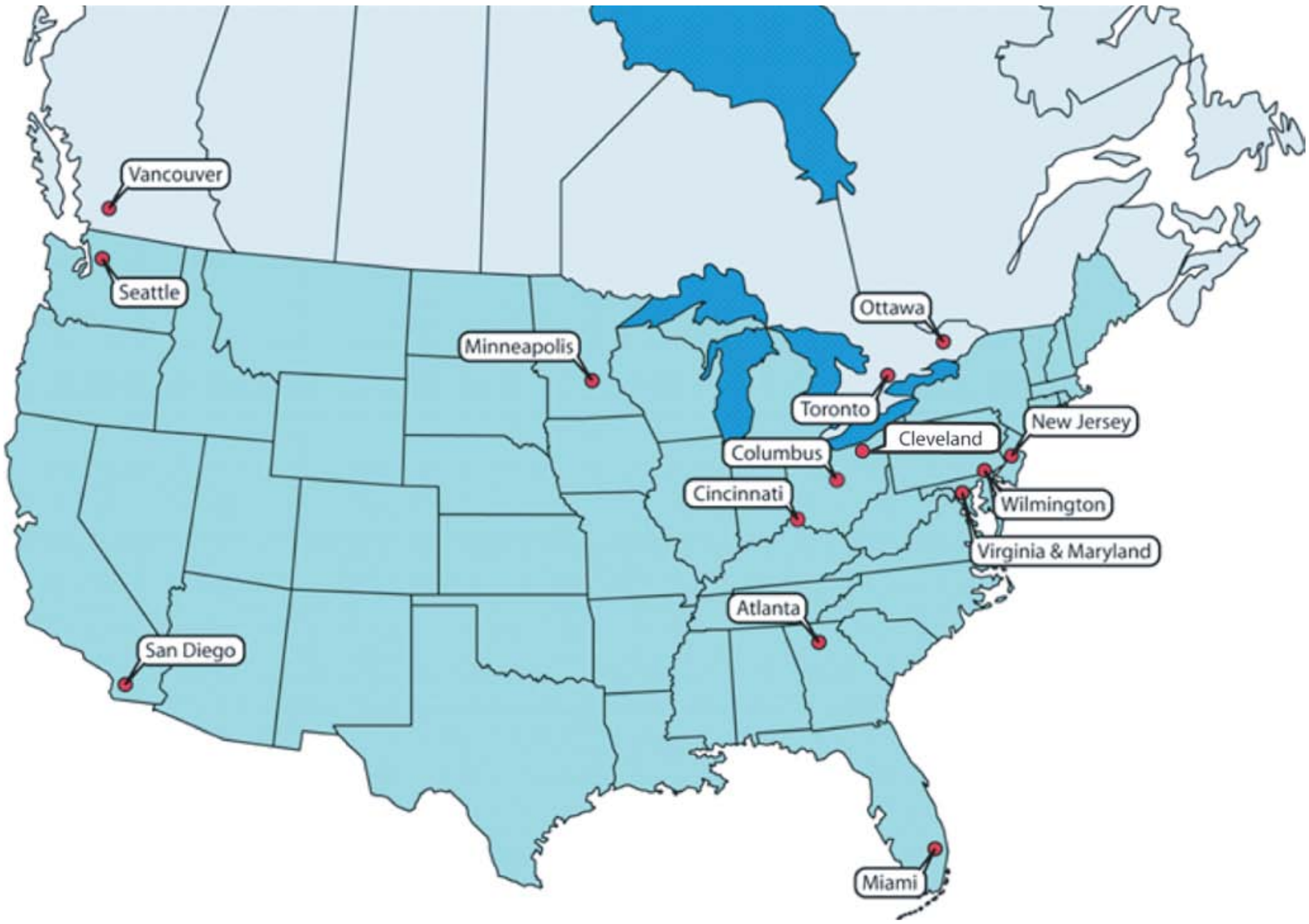


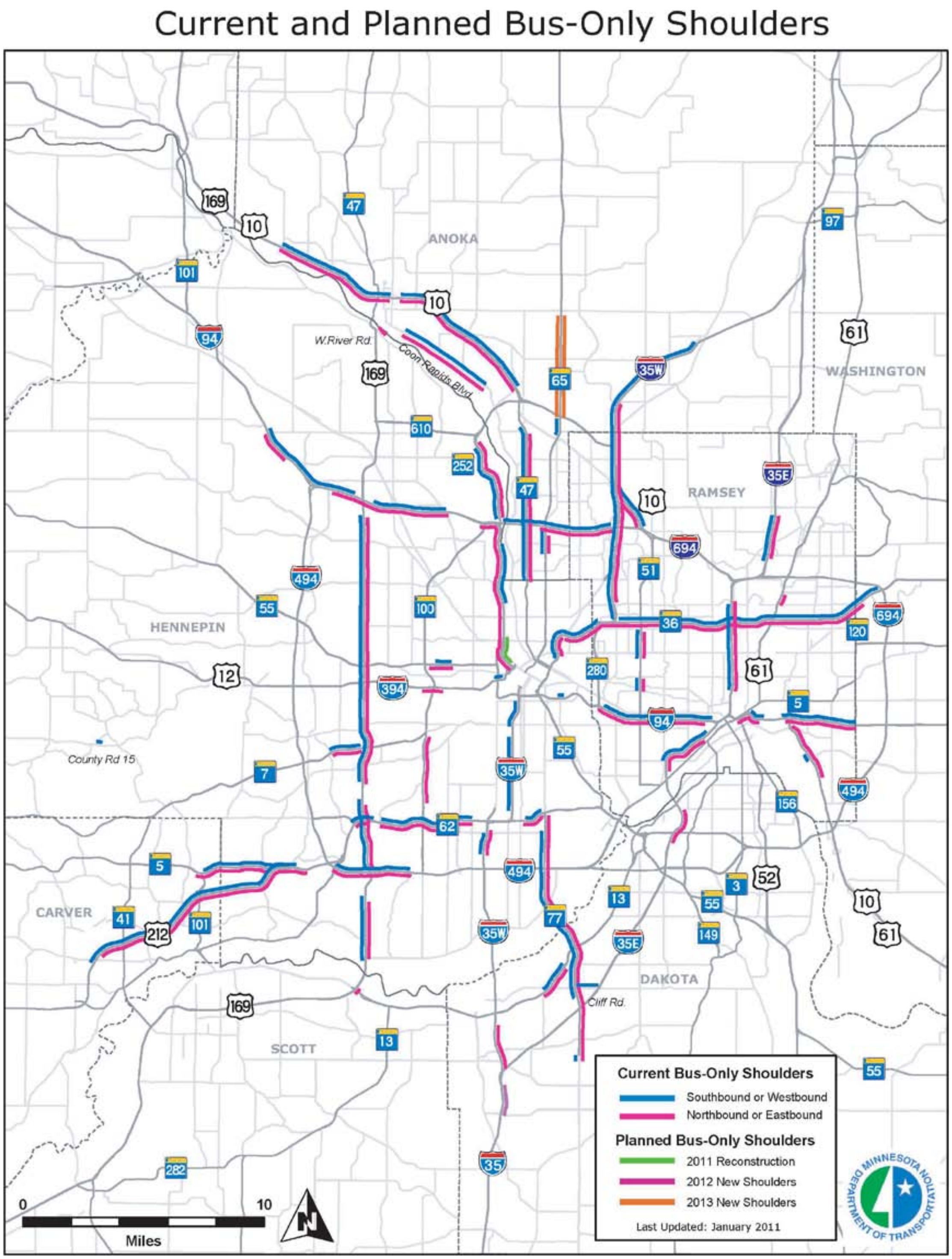
Figure 2-1. BOS locations 2010.

Figure 2-2 shows the comprehensive current BOS network. Bus drivers have the option of using the designated bus shoulder facilities whenever speeds in the general traffic lanes drop below 35 mph. The BOS system involves a minimal level of BOS signing and has no special pavement markings. Signs are periodically placed along the shoulder designating the shoulder for "Authorized Buses Only." Warning signs, such as "Watch for Buses on Shoulders," are also provided on on-ramps prior to the merge with shoulder and freeway traffic. Small yellow advisory signs are also posted along the shoulder at places where the shoulder narrows to less than 10 feet.

BOS Development Process

A good overview of the Twin Cities BOS operations was provided in a 2003 internal memo by the San Diego County Association of Governments (SANDAG) staff describing the findings of their meetings with staff from the Minnesota Department of Transportation and other stakeholder agencies and their field observations of BOS operations. Elements from this memo form the basis for the following discussion of the Twin Cities BOS operations (Schumacher, Williamson, and Roy).

The use of freeway shoulders for transit in the Twin Cities area evolved out of an emergency situation when a Mother's Day flood closed one of the major bridges that crossed I-35 westbound. This bridge was one of the major access points into and out of the city. The governor called an emergency summit to brainstorm how to get more access on the parallel bridges. Use of



Source: Courtesy of the Minnesota Department of Transportation.

Figure 2-2. BOS network.

shoulders on freeways by transit vehicles emerged as an idea worth implementing. The concept was born on a Thursday after the flood and by Monday of the following week the shoulders were re-striped and limited signage was installed for transit to begin operations.

This first test of buses in the shoulders went so smoothly that they began testing operations on other congested freeway segments. "Team Transit" was then formed as a permanent group, consisting of Metro Transit and suburban bus operators, the Minnesota DOT, the Minnesota State Patrol, and the Metro Council of Governments. The deputy commissioner of the Minnesota DOT helped overcome initial agency hesitance. A key contact person at the Minnesota DOT was designated to serve as an advocate for the shoulder policy within the agency. The "Team Transit" group has continued to this day to periodically review existing operations and plan additional shoulder projects. The result is that, as of mid-2007, there are 14 bus routes and 400 buses that use the freeway bus shoulders on a daily basis. Four of the major interstates are equipped with over 200 miles of freeway shoulders used by transit routes.

As the transit use of shoulders became a permanent feature of the freeway system, much of the day-to-day efforts have evolved into discussions of planning and implementation of new shoulders for transit. Rather than being stand-alone improvements, the shoulder projects (whether widening, reconstructing, or restriping) are completed as part of a larger highway improvement/maintenance project along that same freeway segment. As the BOS network is nearing build out, the emphasis is shifting to support facilities such as park-and-ride lots. Interestingly, the Minnesota State Patrol has not been actively involved in recent years due to safe operating experience (they do have the ability to report/cite transit vehicles that violate the shoulder policy).

For the first 5 years of the program, the Minnesota DOT funded all the costs of bus shoulder projects; Metro Transit found that if they brought funding to the table, the Minnesota DOT was more receptive to constructing a project. After the shoulders became "just another part of the highway system," The Minnesota DOT established an annual budget of $1 million for the program, which adds about four to eight miles to the system annually. It is part of the overall annual budget and the Minnesota DOT works with all of the transit operators to prioritize the funds. A construction figure of $250,000 per mile seemed a good overall average cost (2007 dollars) to use for upgrading shoulders, including the rebuilding of drainage grates and overlay paving at a 3- to 5-inch asphalt depth to yield a total of 7 inches.

Standard maintenance on BOS is carried on with mainline maintenance. More extensive repairs or reconstruction of sub-standard thickness (<7″) BOS comes out of the $1 million annual BOS expansion budget. Metro Transit benefits through federal 5307 capital guideway maintenance funding, based on an annual payment of $30,000 per shoulder lane mile (as shown in Section 15 reporting), results in approximately $24 million annually that they reserve to supplement general operations.

The National Technical Information Service distributed an excellent history prepared by the Hubert Humphrey Institute of Public Affairs in 2007: FTA-MN-26-7004.

Corridor/Network Features

The Twin Cities area has a wide range of BOS project types that together provide a comprehensive BOS network. The BOS network development was closely coordinated with service planning and passenger support facilities (park-and-ride lots and transit centers). The 260 miles of BOS includes the following forms of BOS with widths varying from 10 to 12 feet:

- Divided highway with traffic signals, rural section with driveways—example trunk highway (TH-) 10 north of Anoka;
- Divided highway with traffic signals, urban section, limited access—example, TH-252;

- Freeway, rural section—example, TH-10 in Coon Rapids;
- Freeway, rural section, periodic auxiliary lanes replace shoulder—example, TH-36 between Lexington and I-35W;
- Freeway, urban section—example, TH-169 north of TH-55;
- Freeway, urban section, approaching single lane drop—example, I-35W southbound at 46th Street;
- Freeway, urban section, approaching a double lane drop—example, I-94 westbound at Mounds Boulevard;
- Freeway, urban section, with interruption—example, I-94 westbound at Fairview Avenue;
- Divided highway with traffic signals, urban section, catch basins still recessed—example, TH-252;
- Freeway, urban section, catch basins raised flush—example, I-94 at White Bear Avenue;
- Freeway, shoulder on structure—example, TH-77 at Minnesota River;
- Freeway, adjacent to collector-distributor road—example, I-394 eastbound at TH-100; and
- Freeway, coincident with HOV lane—example, I-35W in Richfield.

Operating Protocols

The drivers are able to use the shoulder at any time during the day when congestion exists. They are also able to use them for deadheading, which is a major benefit for the operator. All of the express buses operating in the corridor can use the freeway shoulder. Suburban operators and private operators are also allowed to access the shoulders. School buses do not have this privilege. Figure 2-3 from the Minnesota DOT website illustrates the range of BOS applications.

- Bus drivers use the shoulders only when main lane travel speeds drop below 35 mph. Buses travel only 15 mph faster than mainline traffic speed, up to a maximum of 35 mph. If traffic is moving 35 mph or faster, buses must operate in the regular travel lanes. Transit drivers are not required to use shoulders, but instead use their professional discretion on roadway conditions and personal comfort levels.
- If a disabled vehicle blocks the bus shoulder, or the highway patrol has pulled a vehicle over in the shoulder, the transit vehicle merges into the general purpose traffic lanes to bypass the obstruction. Because the speeds are low for autos in the general purpose lanes and the buses using the shoulders, the merge is a relatively easy maneuver for the transit vehicle.
- Ten feet is considered the minimum acceptable shoulder width. There are some gaps in the bus shoulder sections at locations where bridge abutments are directly adjacent to the shoulder, narrowing the shoulder to under 10 feet. The sections are noted on the listing of shoulder sections given to bus drivers. A small sign is also located prior to the narrowed section to alert the driver. The bus driver simply merges into the general purpose travel lanes to get around the narrow section, and then merges back into the bus shoulder on the other side. Gaps also occur in areas where Metro Transit feels there are too many weaves (e.g., a complex freeway interchange) that could create safety hazards if the shoulders were used.
- In freeway segments with auxiliary lanes, buses will tend to stay in the auxiliary lane rather than the bus shoulder since the auxiliary lane usually is free flow or has only minor congestion.
- Deadheading buses are allowed to use the bus shoulders.
- Buses should use their four-way flashers while using the shoulder.
- Charter buses are allowed to use the BOS if registered with the Minnesota DOT. Use of the BOS facilities is not actively encouraged due to enforcement issues.
- Paratransit vehicles are also allowed to use the BOS facilities.

The operating speed was defined by the bus drivers through a survey of their level of comfort operating at various speeds on the shoulder. Most of the operators in that survey indicated that they did not feel comfortable operating above 40 mph at any time in the shoulders—so 35 mph

Source: Minnesota DOT.

Figure 2-3. Photos of BOS in the Twin Cities area—Team Transit website.

was adopted. The minimum differential speed of 15 mph between buses operating on shoulders and traffic in the general purpose travel lanes was defined by the Minnesota DOT and the FHWA. Because of the cold weather in Minnesota, the operators are given discretion whether or not to operate in the shoulders when visibility is low. Many of the operators choose not to use the shoulder during heavy snow conditions. Since 2008, BOS shoulders are plowed at the same time as mainline lanes.

The restriction of shoulder operations in the Twin Cities area, which limits their use to transit buses, reflects the traffic safety concerns of the Minnesota DOT and the FHWA. Bus drivers are specially trained to use the shoulders, which tend to be narrower than standard 12 foot wide traffic lanes. Drivers of large transit buses have better sight distances than car drivers due to the height of the driver. The lower volume use associated with bus-only use also tends to minimize loss of availability for desired shoulder functions.

BOS Facilities

The mainline highway signage is minimal and limited to, "Shoulder—Authorized Buses Only." These signs are spaced about 1 mile apart along the freeway shoulders. Where there is a merge with an on-/off-ramp, an additional sign is added to caution the auto drivers that buses are operating in the shoulder. Bus drivers are trained to yield to automobiles. Signage is also provided at on-ramps warning motorists that buses might be operating on the shoulder. These yellow warning signs have the message, "Watch for Buses on Shoulder." At narrow shoulder points, small yellow signs with an arrow and bus alert advises bus drivers of pinch points.

One of the features of the Twin Cities BOS concept that, not used by other BOS communities, is the relatively tight weave area at freeway interchanges. Rather than separating the BOS merge weave and the diverge weave at on-ramps, the weave movements are accomplished over a relatively short distance (estimated to be 500 feet). Most other BOS communities provide longer weave areas at freeway interchanges, generally using longer deceleration and acceleration lanes adjacent to the general purpose traffic lanes.

Signage is very simple, as shown in Figure 2-4a–b. Initially when the BOS operations were started in the early 1990s, diamond symbol pavement markings were used. These were found to be unnecessary and tended to confuse some HOV drivers. Some of the early signage also features the diamond symbol.

Rule-of-thumb guidelines for viable BOS ramp weaves are generally that any ramp volume below 1,000 vehicles per hour (vph) is not a problem, volumes of 1,000 to 1,500 vph become worrisome, and any volume over 1,500 vph is a major concern. BOS use across double lane on- and off-ramps is not done.

Ramp metering of on-ramp traffic has proven helpful in breaking up platoons from upstream traffic signals on the on-ramp and helps buses navigate the weave. BOS operations, however, generally work without ramp metering.

During early implementation efforts for BOS in the Twin Cities area, experience indicated that a 10-foot shoulder was the viable minimum. On bridges, the 10-foot shoulder width is acceptable if the bridge length is relatively short (e.g., an overpass). For longer bridges, Metro Transit requires an 11.5-foot shoulder width given the difficulty of driving adjacent to the bridge railing. In some cases, the Minnesota DOT has been agreeable to taking 6 inches from the adjacent travel lanes to create the extra space in the shoulder. The Minnesota DOT has started planning 10-foot minimum shoulders with a desired 12-foot shoulder width.

The Minnesota DOT is extremely proactive on the subject of transit shoulders and allocates funds toward the ongoing maintenance and expansion on the freeway and arterial shoulder

(a)

(b)

Figure 2-4. (a) On-ramp BOS sign—Twin Cities. (b) Begin BOS operation sign—Twin Cities.

program. The operation of buses on the shoulder had been incorporated in most of the freeway programs—for example, freeway shoulders are snowplowed along with the mainline traffic lanes before arterials, and capital programs provide for gutter replacements and asphalt enhancements. The Minnesota DOT has an overall program that looks annually at where freeway bus shoulders for transit can be added and where enhancements can be made. The agency was initially concerned about the ability of storm drains on shoulders to withstand the constant travel of buses over them. Given budgetary constraints Minnesota DOT did not concern itself with shoulder drainage structures initially. Over the years since starting the shoulder lane program, the Minnesota DOT initiated an ongoing program of reinforcing around the drains. Drainage structure improvements include enhancing the concrete structure on the head-end and far-end of the drain structure and raising the structure to surface level when necessary. The drainage structure improvement program is an ongoing project and the remaining structures are to be improved as funds become available. Also, the Minnesota DOT, at the time of new construction of shoulders, ensures that the shoulder is 12-feet wide with a 7-inch pavement rather than the former specification of a 2-inch pavement. Recent shoulder use upgrade costs have been running about $250,000 per mile. Ponding has not proven to be an operational problem along the shoulders.

(a)

(b)

Figure 2-5. (a) TH-252 BOS "pork chop." (b) TH-252 BOS signage and striping.

Among the 260 miles of bus shoulders, several occur on arterial highways. At signalized intersections, a "pork-chop" raised curb section allows cars a free right turn with sufficient length along the raised curb to serve as a queue jump to the front of the signal and as the location for a bus stop (see Figure 2-5a).

New shoulder construction uses a 2 percent drainage cross slope, rather than four percent, which was common on older shoulders.

Legal

The Uniform Vehicle Code (UVC) prohibits driving on shoulders. Minnesota's statutes were amended in May 2005 to formalize the BOS operations. The state patrol reports that it has had very few problems with the bus shoulder operations. Recently, the operating guidelines for freeway bus shoulder use were amended to state law. So now, the state patrol is able to write speeding tickets to drivers of the buses that exceed 35 mph while operating in the shoulder. Prior to it being added to state law, the state patrol had an operating agreement with Metro Transit and the Minnesota DOT that outlined the various rules for bus operation.

In addition to public transit operators, charter buses are now allowed to use the shoulders based on a change in state law 2 years ago. There was also an attempt to allow vanpools to use the shoulders, but this did not pass into state law.

The Twin Cities BOS program would appear to be in conflict with the National UVC. The Minnesota DOT statute, however, avoids the word lane and instead uses the phrase bus shoulder (see Figure 2-5b).

Driver Training

Metro Transit indicated that driver training takes the form of mostly classroom training on the state law, operating rules, and how to respond to issues. The drivers are given extensive in-bus training on driving the shoulders and annual safety updates and briefings on bus shoulder use. A video has also been produced to strengthen driver training and can be viewed on Team Transit's website: www.dot.state.mn.us/metro/teamtransit.

All operators are given wide discretion in how they may operate on the shoulders. If they are not comfortable operating on the shoulders, they do not have to. Many of the newer operators are tentative and often will operate at lower speeds or only in segments where the shoulders are wider. The operators indicated that there is tremendous customer pressure to operate on the shoulders and often will make comments to drivers that choose not to. The operator is also responsible for gauging the speed of the vehicles in the lane adjacent to the shoulder. The operating rules indicate that the bus can only be going 15 miles per hour above the speed of the adjacent lanes traffic. If the speed of the vehicles in the adjacent lanes is operating above 35 miles per hour, the bus must merge into the main traffic lanes and not operate on the shoulder.

Experience to Date

A 1998 passenger survey found time savings with the freeway shoulder lane use were estimated in the range of 5 to 15 minutes depending upon the level of congestion. An average of 7 minutes is saved on most trips during the peak. However, the customer perception of the time savings is much higher. Customers don't only see the use of the shoulders as time savings, but also as a way to minimize their stress of sitting in congestion. Also, the customer's perception of schedule adherence and trip reliability is much higher given the use of the freeway shoulders.

Safety. For the year 2003, a total of 21 shoulder accidents were reported by transit operators, 19 of which were sideswipe mirror hits. The largest damage loss was $3,000 for these 21 accidents. There were no injury or fatality accidents that year. In its first 15 years of BOS operations there has been one injury crash, a fatal accident (bus driver found not to be at fault).

Bus Driver Survey. Key findings from a 1998 survey of bus drivers were as follows:

- Bus drivers on routes using I-35W and TH-5 were surveyed to determine their reaction to, and the degree with which they use, the bus-only shoulders.
- Most of the drivers used the bus-only shoulders during rush hour in congested situations. In good weather conditions, the majority of the drivers reported using the bus-only shoulders on a regular basis only during the PM peak period.
- A majority of the drivers perceived significant travel time savings when using the bus-only shoulders. On a typical day, they perceived a 5 to 20 minute time savings. On a day when traffic is at its worst, they perceived a 10 to 60 minute savings when using the bus-only shoulder lanes.
- A majority of the drivers reported that the bus-only shoulders are not wide enough. Most of the drivers were using I-35W, which initially only had a 9.5-foot shoulder.
- A majority of the bus drivers have experienced conflicts with auto drivers (driving on the edge of shoulder to prevent buses from passing).

Bus Passenger Survey. Key findings from the 1998 passenger survey were as follows:

- Passengers provided the following estimates of travel time savings on a typical day: 1 to 3 minutes (11 percent), 4 to 6 minutes (22 percent), 7 to 9 minutes (12 percent), 10 to 12 minutes (11 percent), more than 12 minutes (18 percent), no answer (42 percent). Travel time benefits were greater on bad weather days.
- 38 percent indicated more reliable schedules.
- There is a general sense that the use of bus shoulders has had a positive influence on ridership. At the same time, it is hard to measure the effect since new service and park-and-ride lots have been implemented over the same period.
- Metro Transit has not evaluated the affect that the shoulder lanes have had on operating costs, but this is something they would like to do in the future. The key benefit cited is trip reliability, a benefit both to the customer and the operator (in terms of ease of schedule writing).
- Passenger reaction has been very positive according to Metro Transit, with 95 percent of riders surveyed indicating they felt they were saving time (generally higher than actual), and 65 percent reporting that they had recommended the service to others.
- The biggest benefits of BOS are achieved when the weather is bad and traffic is very congested.
- Passengers often ask the bus drivers to use the BOS lanes, which is an indication of how much they value the travel time advantage.

Lessons Learned. Lessons learned from the Twin Cities experience suggest that there is potential for the freeway bus shoulder concept to work in other areas for the following reasons:

- Use of the bus shoulders is limited to transit vehicles driven by professional operators.
- Use of the bus shoulders is at the transit operator's discretion; there is no requirement that the operator must use the bus shoulders if he/she feels that conditions are unsafe (e.g., inclement weather).
- Use of the bus shoulders is limited to times when the general lanes are congested; the low speeds in the general traffic lanes, coupled with speed limitations on transit vehicles, allows transit vehicles to adequately respond to potential transit vehicle/automobile conflicts.
- Positive response from both transit passengers (in terms of time savings and trip reliability) and automobile drivers (in terms of accepting buses on the shoulders).
- Most of the express buses operate on 10-minute headways. Since some freeway segments have five or more bus routes operating along them, there could be four to five buses operating in a caravan fashion along the freeway.
- The cooperation between the transit agency and the Minnesota DOT is amazing. They work to support one another with the overall goal to make the project work. The Team Transit group seemed to work very well together and provide a "can do" attitude about making the system work.
- From the standpoint of traffic safety, benefits to transit operations, and public relations, the use of bus shoulders has been a success.

Next Generation of Shoulder Lanes. The Minnesota DOT is currently working on developing a set of guidelines that would outline when bus shoulders are warranted. Possible items that would be included in these guidelines are the following:

- Metered entrance ramps required for bus shoulder use,
- Certain level of congestion during peaks (this is being refined),
- All new freeways include 12-foot shoulders for transit use (planned or future),
- Catch basins are built to support transit use,
- Pavement depth of at least 7 inches to support transit use,

- Number of buses that would use the shoulders (six bus trips on weekdays),
- Length of delay (related to congestion above), and
- Ease of implementation.

Miami, Florida: Don Shula and Snapper Creek Expressways

Bus use of shoulders was implemented March 27, 2007 in Miami-Dade County (MDC) along SR-874 and SR-878. The planning and implementation process shows how the decisions were made to use this treatment to obtain a short-term, cost-effective solution to achieving a quick and reliable high-occupancy transit use corridor.

BOS Development Process

Residents of MDC came together in 2002 to create the People's Transportation Plan (PTP), a plan to improve mobility and relieve traffic congestion in their communities. Under this plan, $17 billion dollars was committed to adding more buses and routes, improving service, and expanding rapid transit service. The rapid transit expansion component of the PTP outlined specific corridors in MDC where rapid transit expansion should be focused.

To complement the rapid transit expansion section of the PTP, the MDC metropolitan planning organization (MPO) completed a study that analyzed the feasibility of special-use lanes in the county. Phase I of the study did a quick examination of freeway facilities and major arterials to determine the feasibility of accommodating various special-use lanes and identifying the most appropriate corridors for their use. The results identified a system of rapid transit corridors composed of Expressway Core routes (freeway) and Arterial Core routes (arterials). Following the Phase I study, the Center for Urban Transportation Research at the University of South Florida was assigned to further study the opportunities for bus rapid transit (BRT). The Phase II study, which focused on shoulder use of the freeway links included in the Expressway Core System, was then completed.

Special lanes were defined as a lane or a system of lanes designed and operated to provide improved vehicle flow during peak periods, when the remainder of the freeway or arterial network is heavily congested. Facilities were selected from the PTP and other major arterials and freeways exhibiting directionality of traffic flow that was heavily skewed in one direction during peak times of the day. These facilities then underwent a two-tier evaluation process that identified which would be appropriate for accommodating special-use lanes. Tier I used eight different criteria to determine if the facility would support these lanes. These criteria are shown in the Table 2-2.

Table 2-2. Special-use lane screening criteria.

Criteria	Threshold
Number of Lanes	≥ 5 lanes (total)
Peak Hour Level of Service (LOS) in Peak Direction	E or F
Peak-Period Directional Split	65/35
Functional Classification	State Principal Arterial, State Minor Arterial
Ease of Conversion	Density of channelized turnbays, landscaped median, overpasses, columns, capacity limitations, physical barriers
Corridor Density	Population ½ mile of corridor, employment ½ mile of corridor, number of bus routes
Origin–Destination	Person Trip Generation for 2025
Bus Frequency	Number of Peak Hour Buses

The screening of the corridors in the Tier I process identified eight of the 16 corridor for further study in a Tier II assessment. All three of the freeway corridors (I-95, SR-826, and SR-836) advanced to the Tier II assessment. The Tier II recommendations suggested express facilities to be studied on all the freeway links as part of a further study. These freeway express facilities would make up the Expressway Core links in the larger freeway/arterial system of special-use lanes connecting the greater MDC.

During this planning process and the identification of the Expressway Core System, use of the freeway shoulder space was suggested as a way to quickly move on the concept. This suggestion was recommended based on the success of the Minneapolis-St Paul Twin Cities shoulder use experience and the low cost and quick implementation period for the project, an overall objective of the plan.

Following the release of the Phase I report in October of 2004, a series of meetings were held to determine how to implement the Expressway Core System. Representatives from the following agencies attended these meetings:

- MPO;
- Office of the County Manager (OCM);
- Miami-Dade Transit (MDT);
- Miami-Dade Expressway Authority (MDX);
- Florida Department of Transportation (Florida DOT); and
- Turnpike Enterprise.

These meeting resulted in the following four major action items:

1. Initiate Phase II of the Special-Use Lane Study for implementing the Expressway Core System,
2. Create an amendment to the Florida statues to authorize the bus use of shoulders along the expressways,
3. Coordinate a meeting with Minneapolis officials involved in the bus use of shoulder project to discuss the pros and cons of the project, and
4. Develop potential routes to be implemented along the Phase I suggested corridors.

In the 2005 Florida legislative session, Section 316.092 of the Florida statues was drafted to allow a pilot program the use of limited-access facility shoulders by public transit buses. To assist in educating the legislature, a fact sheet was created and distributed that summarized the components of the pilot project. This sheet explained the experiences of shoulder use for transit in Minneapolis and identified the proposal for its use in MDC. The Legislative Transportation Committee later determined that the Florida DOT could initiate the pilot project without the drafted legislation in place, but the legislation would be required if the project was implemented long term.

The Phase II report completed a more detailed assessment of the potential for freeway shoulder use as a solution for congestion bypass. The freeway corridors that were further analyzed included the following:

- SR-821 (Florida Turnpike)/SR-836 (Dolphin Expressway),
- SR-826 (Palmetto Expressway) North/South Portion,
- I-75/SR-826 (Dolphin Expressway),
- I-95 (I-395/SR-112 to I-195/SR-826), and
- SR-874 (Don Shula Expressway)/SR-878 (Snapper Creek Expressway).

Shoulder use along these corridors was assessed based on the following factors:

1. Roadway characteristics (interchange spacing, traffic volumes/congestion, shoulder size, accidents, and merge distances);

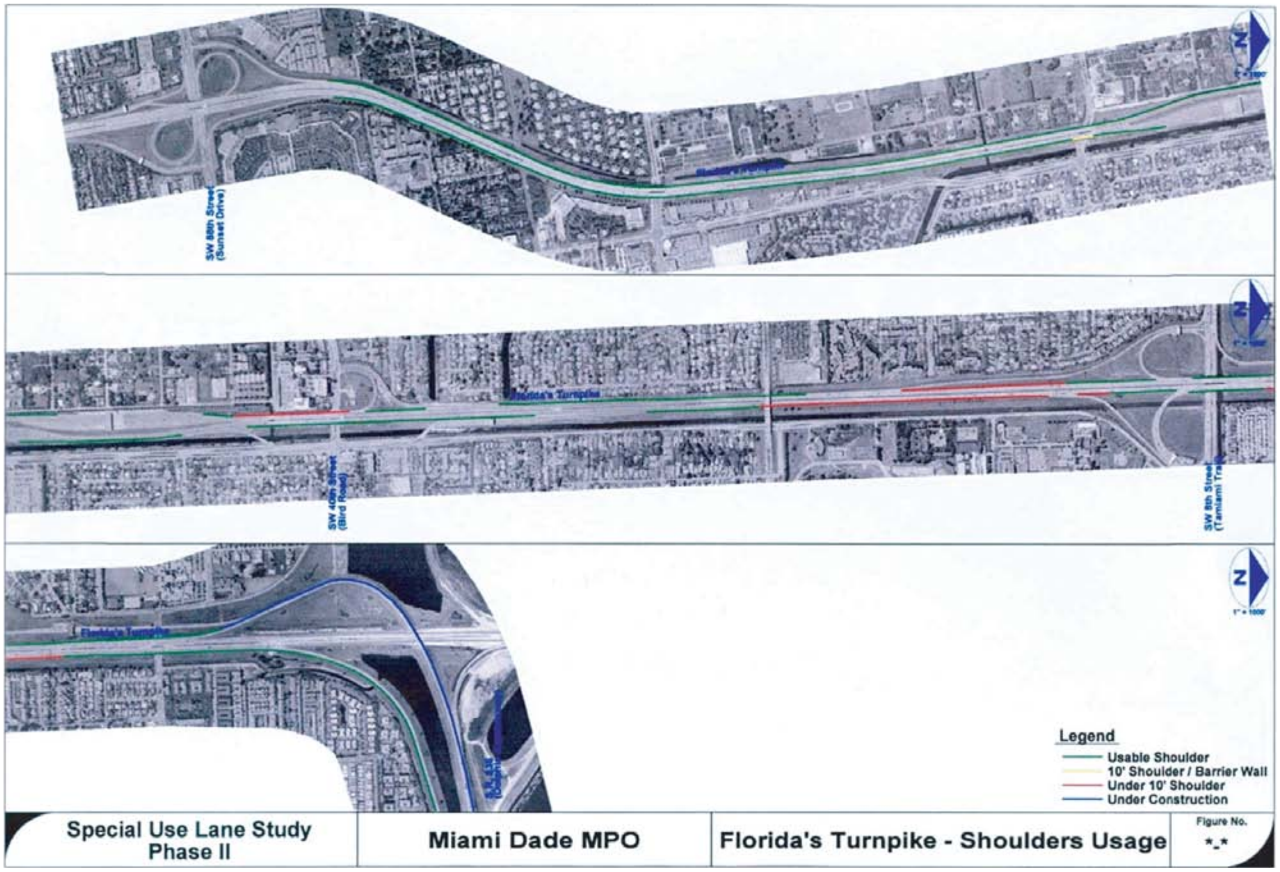


Figure 2-6. BOS shoulder-width assessment map.

2. Programmed corridor improvements;
3. Proposed express transit;
4. Potential for park-and-ride locations; and
5. Usable shoulder segments.

Figure 2-6 describes how shoulder conditions along candidate BOS corridors were summarized in the Phase II report.

The Phase II report outlined specific operational characteristic assumptions for the proposed pilot project. These characteristics included bus load impact on the shoulders, criteria for shoulder use (width, length, and stopping sight distance), freeway congestion, and signage. After profiling the five corridors, the plan highlighted the SR-821/SR-836 as the best candidate for implementing the use of shoulders by transit buses in MDC. A decision was later made to defer this BOS project until later, as construction was planned along the corridor. The SR-874 and SR-878 corridor was then advanced as the first BOS project.

To inform the public of the project, a marketing/education awareness campaign was developed as part of the implementation plan. This plan took the following three approaches to reaching out to the public:

1. Service campaigns on routes selected for shoulder-use service provided routing, headways, travel time, cost, and the location of park-and-ride facilities to the general public and Miami-Dade transit riders.
2. A media event for reporters and elected officials to showcase the time savings provided by the new bus service. This event would place media crews and officials on two different buses,

both leaving the same location at the same time during the morning-peak period. The news coverage would then capture the improved performance of the new service compared to the existing service.

3. A public service announcement informing the public of the buses operating on the freeway shoulders, stressing the enforcement of the use strictly to buses and that others will be punished.

A marketing program was developed to educate motorists of the program and an enforcement program was also developed.

Details of intelligent transportation systems (ITS) features of the bus shoulder-use program are still under development, but are seen to include transponders on buses to allow them to ultimately use the SunPass lanes at toll plazas. The current pilot BOS expressway segments do not include a toll plaza and this need therefore has not yet been addressed.

Corridor Features

As shown in Figure 2-7, the BOS project would extend from SR-990 (Killian Parkway) on SR-874 (Don Shula Expressway) to US-1 South Dixie Highway on SR-878 (Snapper Creek Expressway). The BOS distance would be about 9 miles.

The MPO completed a planning study for these BOS projects in August 2005. The planning study identified the adequacy of the shoulders, level of emergency service vehicle responses using the shoulders, and transit services. Figure 2-7 describes the pilot BOS project's limits. A metrorail station is located at the northeastern end of the BOS segment (SW 72nd Avenue exit from the Snapper Creek Expressway). The Don Shula Expressway is generally four lanes in each direction between Killian Parkway and the Snapper Creek Expressway. The Snapper Creek Expressway is generally two lanes in each direction. Both are fully grade separated and function as urban freeway facilities. Only one interchange exists on the Don Shula Expressway along the BOS segment and it (Kendall Drive) is a partial diamond design. The diamond-type interchange at Galloway Road and the half diamond at SW 72nd Avenue are the only two interchanges along the BOS segment of the Snapper Creek Expressway, aside from the freeway-to-freeway interchange, linking the Don Shula to the Snapper Creek Expressway. The most difficult BOS weave is the southbound segment of the Don Shula Expressway between the Snapper Creek Expressway on-ramp and the Killian Parkway off-ramp. The distance is 2 miles, but the weaving volumes are very significant.

Two express bus routes operate on the Don Shula and three bus routes operate on the Snapper Creek Parkway. All of these bus routes terminate at the metrorail station. Together, more than 20 buses an hour operate during the peak on the BOS segments. These are not full-size transit buses, but are smaller Kendall Area Transit (KAT) 30-foot transit buses.

Operating Protocols

When speeds drop below 25 mph, MDT buses are authorized to use the bus shoulders. Note that 25 mph is lower than the Twin Cities' speed and lower than the initial speed discussed in early planning efforts. Buses are allowed to operate at a maximum speed of 35 mph while using the shoulders. Buses using the shoulder are not to operate 15 mph faster than traffic in the general purpose lanes. Buses must yield to entering, merging, and exiting traffic and to emergency and law enforcement vehicles. Where disabled or law enforcement vehicles, construction, or other obstacles occupy the shoulder, metrobuses operating on the shoulders shall move into the general purpose traffic lanes. Buses using the shoulder are instructed to use their four-way flashers.

Figure 2-7. Miami, Florida, BOS location.

BOS Facilities

Design features for the BOS shoulders were a minimum 10-feet wide (12-feet wide where truck volumes exceed 250 vehicles per hour) and cross slopes of between 2 to 6 percent. It is unclear if improvements were made to the shoulders, as the earlier planning studies had reported that much of the shoulders along these expressways in the BOS project area were less than 10-feet wide. The shoulders do not appear to have been strengthened or otherwise upgraded. BOS signage consists of mainline signs and on-ramp signs. No pinch-point signs were observed. The mainline signs initially included a diamond symbol and the message “Emergency Stopping Only on Shoulder—Authorized Bus Lane” (Figure 2-8a). The diamond symbol was being removed to avoid carpool confusion. Unlike the mainline signs in other BOS communities, the signs were located about 30 feet from the edge of shoulder to minimize signage saturation. (At most BOS sites, signs are located about 10 feet from the edge of shoulders). The on-ramp signs read “Buses Traveling on Shoulder” (Figure 2-8b). These are diamond-shaped yellow warning signs with a diagonal vertical mounting. Clearly the signage reflects FDOT’s desire to inform motorist that the shoulders can be used for disabled vehicles, with the trained bus drivers already aware of their eligible use.

(a)

(b)

Figure 2-8. Miami–Dade BOS signage.

Legal

Initially, a Letter of Agreement (LOA) was envisioned as the legal basis for the BOS operation. Special legislation was also anticipated, but the Florida DOT was found to have the authority to cover the 3-year pilot project. It was ultimately decided that an Interlocal Agreement between MDT and District 6 of the Florida DOT would be the simplest and best form of agreement. The Interlocal Agreement authorizes a 3-year pilot program to demonstrate the feasibility of BOS and prescribes that it would be implemented in accordance with the Special-Use Lane Study recommendations. It identifies MDT having primary responsibility for the operation of the buses, the training of operators, and for all operating and program-related expenses. The MPO is charged with the responsibility to monitor the pilot program and produce semiannual reports. The Florida DOT would install the signage and bill the county for the cost.

Florida law requires motorists to yield to buses as they enter and exit highway shoulders. The fine for failure to yield to buses or following a bus on the shoulder is $133.50 as well as points on the driver's record.

Driver Training

A PowerPoint-based classroom training program was developed and implemented as required by the Interlocal Agreement.

Experience to Date

The pilot project has been operational for 4 years. Immediately after implementation bus service experienced a 50 percent reduction in late buses operating on the BOS segments. Quotes include:

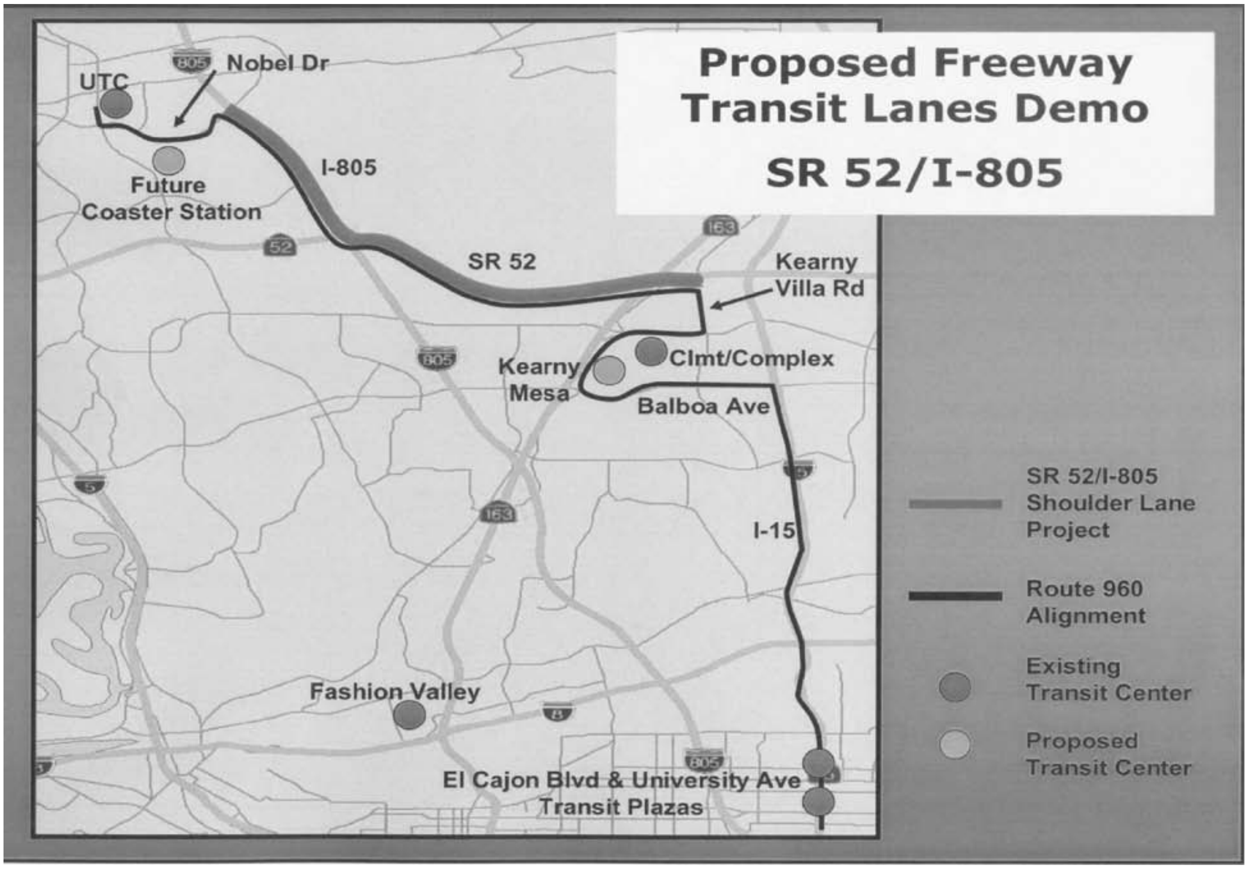
- The Florida DOT District Secretary, Johnny Martinez—"the BOS program is a last resort. Traffic is just too overwhelming and shoulders are underutilized."
- MDX Executive Director—"So far it is working fine from our perspective. MDX hasn't seen any major problems or issues, though we needed more signs alerting drivers that buses are working on the shoulder and to be careful. The program has potential to greatly relieve traffic congestion if it is expanded to other highways—including the Dolphin Expressway and the Palmetto Expressway—after construction ends on those sites."
- Florida Highway Patrol Public Affairs Officer, Lt. Pat Santagelo—"These bus drivers are thoroughly trained to operate on the emergency lanes. They drive very slowly on the shoulders, but slow is better than stopped. We are trying to get people out of their cars and on the buses. If we can make it work, getting around in Miami will be much easier."

San Diego, California: SR-52 and I-805

A key element of the San Diego Association of Government (SANDAG) Transit First strategy is the use of transit priority measures along freeways and arterials to bypass congested areas to increase transit speeds and improve schedule reliability. The BOS concept is one aspect of the Transit First strategy and is primarily seen as an interim improvement measure until Managed Lanes or other high cost, long-term improvements can be implemented. While the BOS concept was seen to operate very well in the Twin Cities area, and since no precedent existed in California for the concept, a 2-year pilot project was developed to test it. The San Diego BOS demonstration project is evaluating the feasibility of converting freeway shoulder lanes on SR-52 (between Kearny Villa Road and I-805) and I-805 (between SR-52 and Nobel Drive) to transit-only lanes that would be used by existing express bus Route 960. After gaining approvals from key agencies, the demonstration project opened in December 2005. Figure 2-9 describes the BOS segments that were implemented.

The intent of the freeway transit lane demonstration project was to gain local operational experience with the conversion of the existing shoulder lanes to transit lanes during the peak periods. In turn, this operational experience would help define the physical elements required to successfully operate freeway transit-only lanes in other freeway corridors where existing express services and future BRT services will operate. The demonstration project was to address five key objectives:

- Safety—was there any change in accident rates with buses using the transit-only lanes, and did Highway Patrol officers and the California Department of Transportation (Caltrans) maintenance crews experience safety-related problems?
- Bus Travel Time and Reliability—did buses experience a measurable and repeatable travel time savings and enhanced trip reliability (on-time performance)?
- Bus and Auto Driver and Bus Passenger Perception—did bus drivers feel safe using the transit-only lanes and were auto drivers comfortable with buses merging in and out of the transit-only lanes; also, did transit riders perceive improved travel time and trip reliability, and did they feel safe with the bus operating in the transit-only lane?
- Maintenance—did any reduction in freeway levels of service result from the transit-only lanes, and was there an increased level of maintenance required?
- What kinds of physical improvements to shoulder lanes would be required if this concept were to be implemented permanently?



Source: Courtesy of San Diego Association of Governments.

Figure 2-9. San Diego BOS.

The demonstration project work plan would develop a detailed service plan on how the transit-only lanes would operate, as well as interagency agreements regarding liability, maintenance, and enforcement.

The following benefits were anticipated:

- Implementation of Transit First Vision.
- Demonstration of the usefulness of freeway shoulders as transit lanes during periods of heavy congestion for transit operations.
- Measurement of bus passenger, bus driver, and auto driver perceptions.
- Determination of the affects to travel time reliability.
- Monitoring of the operating benefits and safety of the conversion of the shoulder lanes to transit lanes.
- Assessing the applicability of converting freeway shoulders to transit lanes on other freeways sections.

These pilot BOS SR-52 and I-805 freeway segments represented prime candidates for the demonstration project due to the presence of several positive characteristics, including sufficient existing shoulder width, no existing or planned construction activities, and heavy peak-period congestion levels.

BOS Development Process

This project included a formal agreement with Caltrans to allow for the implementation of a 2-year pilot project. This formal agreement between Caltrans and SANDAG described the key elements and strategy for the planning, design, and implementation of this project. Caltrans took over the lead for this project, which opened in December 2005. Caltrans led the preparation of the signage and striping plans and of processing National Environmental Policy Act (NEPA) environmental clearance for the project and the MPO, SANDAG and transit operator, Metropolitan Transit System, developed the bus operating plan and a training program for bus drivers.

Corridor Features

SR-52 is primarily a six-lane freeway and I-805 is primarily an 8-lane freeway. Both have auxiliary lanes. Some of the on-ramps are metered, but not all. There is one intermediate diamond-type interchange on both SR-52 and I-805 and one complex freeway-to-freeway interchange in the middle of the pilot project. Auxiliary lanes help the buses make the interchange weaves. The segment does not have any double lane on- or off-ramps involving BOS weaves. Several of the on-ramps are metered. Route 960 operates along the demonstration corridor with about five morning and six evening round trips.

SANDAG staff, in conjunction with Caltrans, performed an inventory of shoulder lane conditions along both SR-52 and I-805 and then developed a preliminary operating plan. This information, along with identifying potential operating conflicts and coordination with Caltrans headquarters and the California Highway Patrol (CHP), was compiled into a technical report. The report was used to complete a Project Study Report (PSR) and to gain approval from Caltrans headquarters to implement the project.

Operating Protocols

Use of the BOS lanes is restricted to authorized buses only. San Diego Metropolitan Transit System (MTS) buses are only permitted to use the BOS lanes when speeds on the general traffic lanes drop to 35 mph or less. When using the shoulders, buses are only allowed to travel at 10 mph faster than traffic in the general traffic lanes. There are no time limitations on the use of the BOS shoulders, but the Route 960 service is essentially peak-period commute oriented.

BOS Facilities

The San Diego project uses the Twin Cities project as a template for its signage and markings improvements. The shoulders did not require strengthening (for light-use pilot period), but initial thoughts were to restripe the shoulder lane by narrowing the right most traffic lane. In order to avoid traffic disruptions on the freeway, it was decided not to restripe the shoulder lane for the pilot project. The cost of implementing the 8-mile BOS project was about $100,000. The mainline freeway BOS signs were “Transit Lane—Authorized Buses Only” (see Figure 2-10a). These were placed about every half mile. Unlike the Twin Cities template, San Diego also used pavement markings: “Only Buses Transit” (see Figure 2-10b). The pavement markings after 1 year of service look somewhat faded. The CHP requested some additional markings after the project open.

(a)

(b)

Figure 2-10. (a) San Diego BOS signage (b) San Diego BOS striping.

Legal

While transit vehicles have been using freeway shoulder lanes safely and successfully in Minnesota for nearly 20 years, there was no analogous California experience. There was agreement for some time between Caltrans District 11 and SANDAG staff on the potential benefits of freeway shoulder lane use to existing freeway express transit and future BRT services. Currently, however, the California Streets and Highways Code prohibits use of the shoulder lanes as a travel lane. Allowing even a limited number of transit vehicles in the shoulders during the peak period is apparently not currently allowed either. The California State Streets and Highways Code allows for creation of transit-only lanes provided engineering studies are conducted on the effect of such lanes on safety, congestion, and highway capacity. The San Diego BOS is therefore technically defined as a "transit lane," although it operates like a BOS facility.

Driver Training

All drivers using the BOS shoulders must be trained according to the demonstration project agreement. Training included both classroom and field training. A PowerPoint-type of presentation was employed for the classroom sessions.

Six-Month Assessment

- Safety:
  - No accidents have occurred.
  - No issues related to enforcement or Caltrans maintenance.
- Bus Travel Time and Reliability
  - Route 960 buses 99 percent on-time performance.
  - Up to 5 minutes travel-time savings for buses during heavy congestion.
- Freeway Level of Service and Maintenance:
  - CHP and Caltrans report no changes in freeway levels of service.
  - Transit operator indicates need for additional maintenance to remove debris on shoulders.
- Structural Changes:
  - 10-foot shoulder width is optimal.
  - Buses can safely operate in narrower shoulders, but it does slow operations.
- Perceptions:
  - 72 percent of bus drivers feel use of shoulders is safe.
  - 86 percent of bus drivers believe use of shoulders is a good idea.
  - 91 percent of passengers feel use of shoulders provides travel time savings.
  - 90 percent of passengers feel safe with buses on shoulders.

Old Bridge, New Jersey: Route 9

BOS Development Process

One bus use of shoulder project has been in operation for decades on Route 22 in Mountainside. It is a short, eastbound segment of an arterial road leading toward Perth Amboy. This project has minimal BOS signage (Buses May Use Shoulder) and no special pavement markings. It has proven successful and helped demonstrate that the concept might work on other congested corridors.

In November 2006, the New Jersey DOT implemented a second bus use of shoulders project on US-9 in Middlesex County near the town of Old Bridge (Figure 2-11). The Old Bridge BOS project on US-9 is about 4 miles long. The project is an element of the New Jersey DOT Enhanced Bus Improvement Program and is designed to reduce delays and increase on-time performance of bus service. The BOS operation project includes two nearby segments of Route 9 between Spring Valley Road and Cindy Street and between Fairway Lane and Perrine Road.

Route 9 Corridor Features

US-9 is a six-lane arterial highway with an 18-foot wide grass median. The segment in between the two BOS segments has grade separations and is not as congested as the two BOS segments. BOS operation serves northbound buses toward New York City during the morning commute peak and southbound buses during the afternoon commute peak. The hours of operation were extended 1 hour after initial start-up in response to passenger requests. Approximately 440 buses and 6,800 passengers use the Route 9 corridor daily, almost all during the peak commute BOS hours. As Route 9 is an arterial street, buses operating on shoulders share the shoulder with right turning vehicles at driveways and intersections. Bus stops are nested into intersections to minimize turning conflicts. Figure 2-12 illustrates the nested bus stop concept.

Operating Protocol

Buses are limited to 35 mph when using the shoulder. Protocol is for drivers to use “low beam” headlights, and only to use four-way flashers in an emergency. All buses are expected to

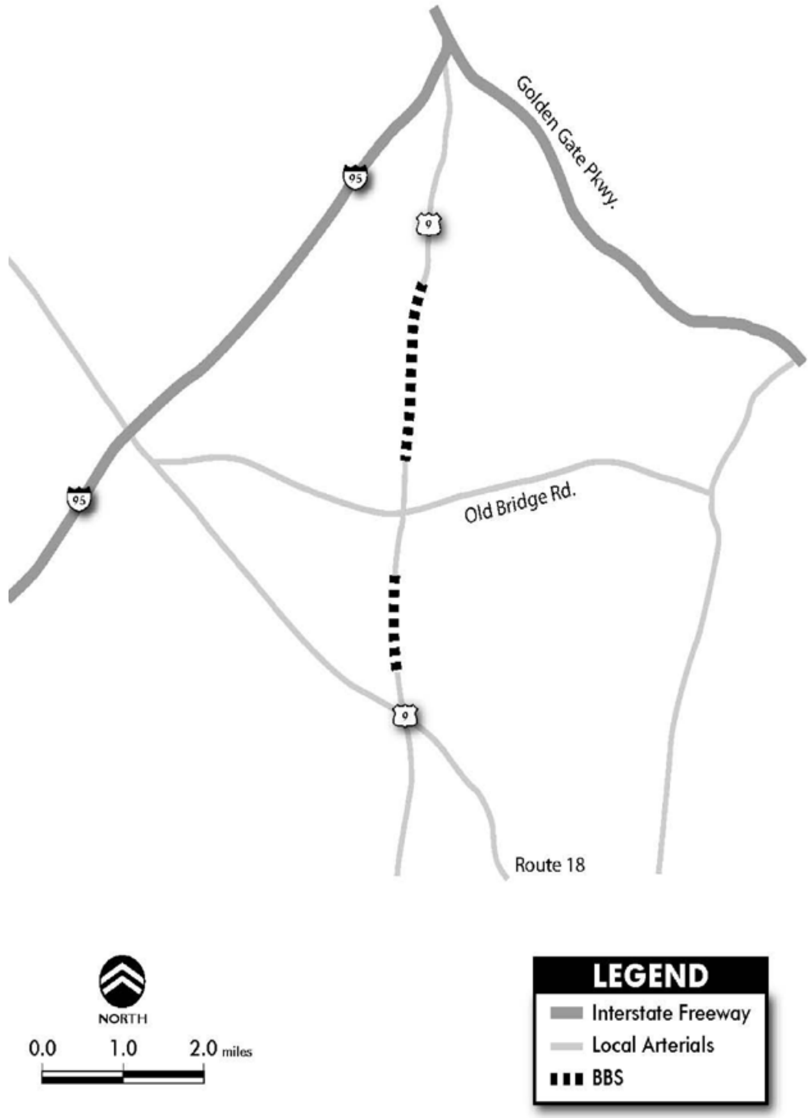


Figure 2-11. New Jersey Route 9 BOS.

use the shoulder unless use of the general traffic lanes would be faster. Bus drivers should not use the shoulder for layovers. Drivers are advised to use caution when using the shoulder and reduce speed if another bus is in the bus stop.

BOS Facilities

The project cost about $8.5 million, which includes new sidewalks, pedestrian refuge islands, new bus shelters as well as shoulder improvements. Existing 12-foot wide shoulders were improved with full-depth pavement for buses. The drainage cross slopes of the shoulders were upgraded from their current 4 percent to 2.5 percent. To maintain effective drainage, 78 new drainage inlets were constructed for the BOS segment. Bus cutouts large enough to accommodate two buses are provided at bus stops along the BOS segments. Pavement markings for the US-9 project consist of "Bus Only" markings and signage indicates "Bus Only" with the

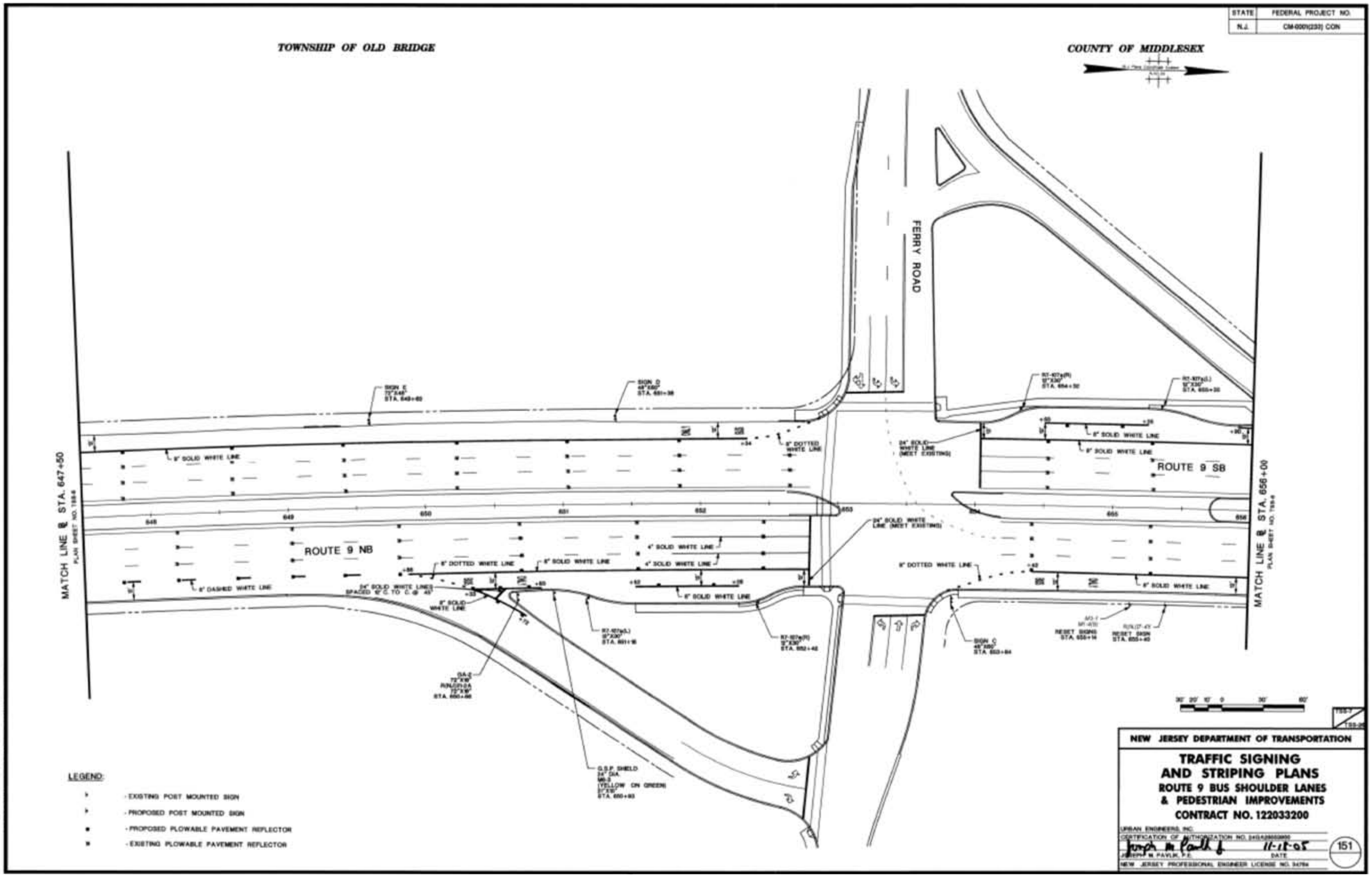


Figure 2-12. Nested bus stop—Route 9.

(a) (b) (c) (d)

Figure 2-13. Route 9 BOS markings and signage.

hours of BOS operations. Posting "Yield to Bus" signs was suggested for the beginning of the BOS operations. Dashed pavement markings are used at intersections to denote bus-only use. (See Figure 2-13a–d.)

Legal

New Jersey's vehicle code includes the "yield to bus" right-of-way rule, by which motorists are required to yield the right-of-way for buses merging back into traffic. Bicycles are allowed to use the shoulder on Route 9, and bus drivers are instructed to remerge into general traffic to bypass cyclists.

Experience to Date

There have been no reported accidents since the BOS was implemented on Route 9 in 2006. Bus drivers are reported to like the 12-foot shoulder priority treatment for buses and passengers love it. About 3 to 4 minutes are saved on average for each peak direction peak period bus trip. Discussions are ongoing to extend the BOS segment.

Figure 2-14. Buses carry more people than lanes of traffic—Ottawa BBS.

Ottawa, Ontario

Ottawa's official plan states that the city will "improve the speed and reliability of transit services by providing transit priority measures to lessen delays on transit vehicles caused by other traffic and traffic control signals." Bus use of shoulders is one of the transit priority measures. In Ottawa, BOS is technically a 24-hour bus lane operating on the freeway shoulder. Graveled shoulders adjacent to the paved bus shoulders are provided for disabled vehicles. (See Figure 2-14)

BOS Development Process

BOS projects have been developed as part of Ottawa's Transit Priority Task Force. These are interim priority measures that are linked to the region's plans to expand their successful transit way network.

Corridor Features

Ottawa has two BOS corridors, Highway 174 on the east side and Highway 417 on the west side. The Highway 174 BOS project functions as an extension of Ottawa's bus transitway. The bus transitway, which connects from downtown, terminates at the Blair Station (Figure 2-15). A set of direct bus-only ramps connects to Highway 174's bus shoulder lanes. Highway 174 is a four-lane freeway. Between this direct interchange and the eastern BOS terminus at Place D'Orleans there are two intermediate freeway interchanges over the 4.3-mile BOS segment (Figure 2-15). As shown in Figure 2-16, the Highway 417 BOS segment runs between the Bayshore Transit Center and Eagleston (3.7 miles). Only one intermediate interchange is located along Highway 417's BOS segment. In total, Ottawa operates 14 miles of bus use of shoulders. Highway 417 is a six-lane freeway. About a dozen bus routes operate on highway 417 and almost 20 operate on Highway 174. There are plans to extend the transitway to the Bayshore Transit Center and then westward to Eagleston. The long-range goal is also to extend the eastside transitway to Place D'Orleans.

Operating Protocol

Only public transit buses are allowed to use the shoulder lanes. No special speed restrictions are defined, and buses are allowed to operate up to the posted speed (100 kph or 62 mph) at

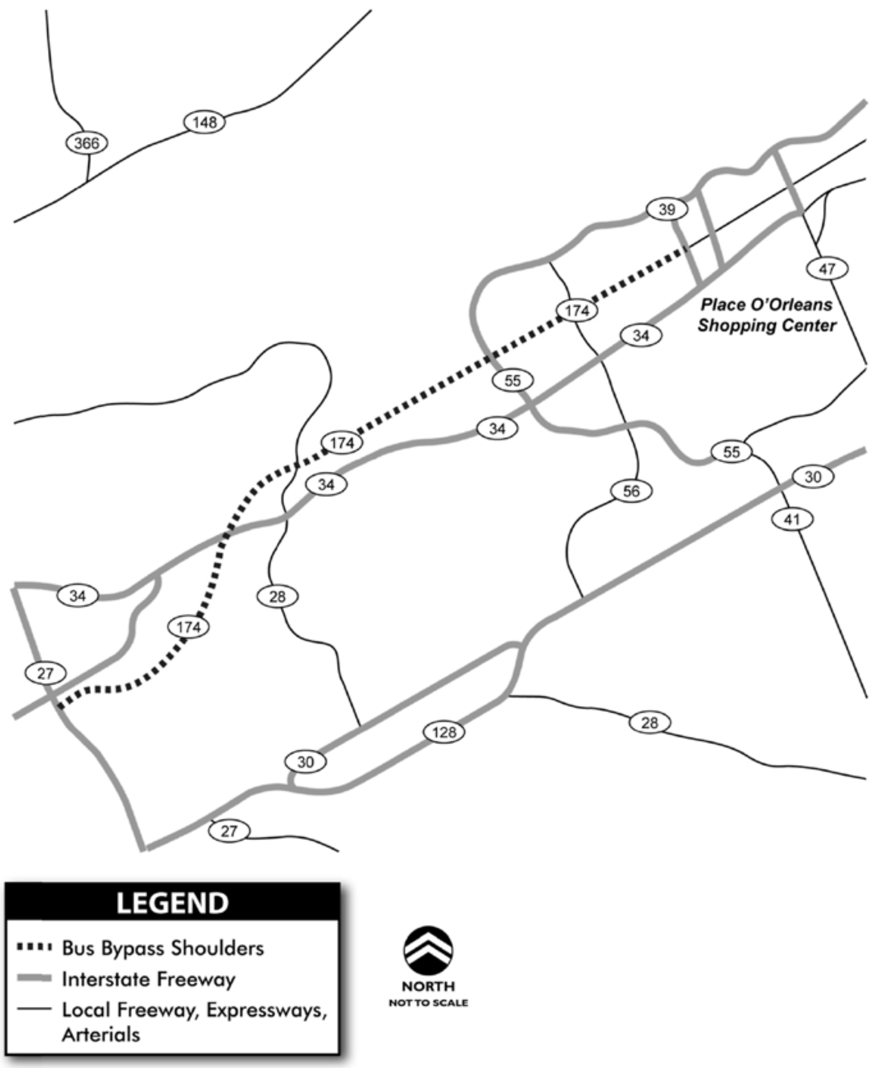


Figure 2-15. Ottawa, Ontario, HWY 174 BOS segments.

their discretion. Thus, buses can operate at substantially different speeds than vehicles in the adjacent general purpose traffic lanes. Some buses get on and off at intermediate interchanges to make "station stops" and this helps to minimize conflicts with traffic at the ramps. Even late in the evenings and on Sundays when traffic is light, buses operate on the shoulder lane. Peak hour bus volumes on Highway 174 are estimated at about 100 buses an hour and on Highway 417 at about 60 buses an hour.

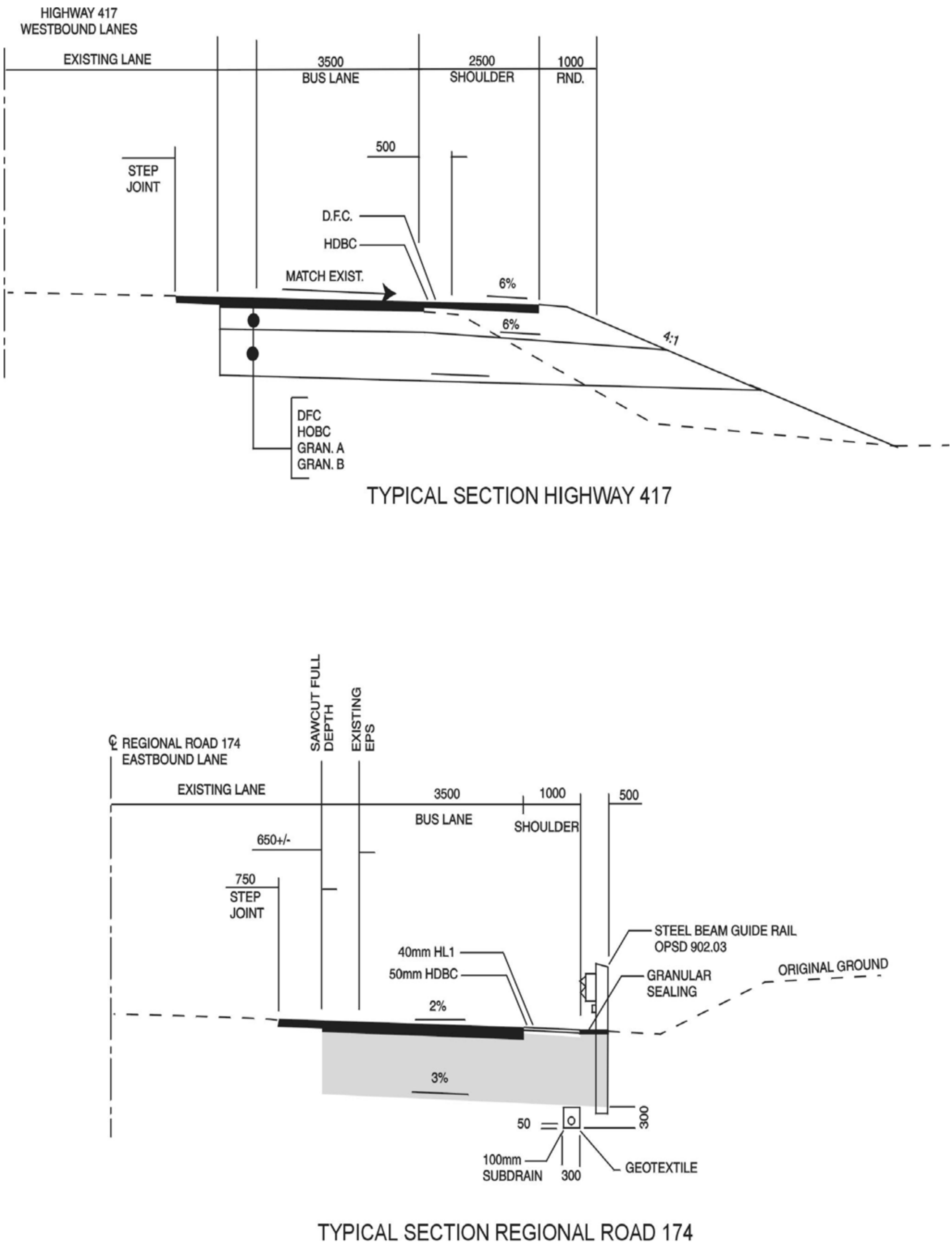
BOS Facilities

BOS signs are in English and French, with the English sign normally about 300 feet before the French sign. The pavement has been upgraded to full traffic standards, but the ride on some sections is a little rough. Signs and markings are according to Canadian *Manual on Uniform Traffic*

Figure 2-16. Ottawa, Ontario, HWY 417 BOS location.

Control Devices (MUTCD) guidelines. The mainline BOS signs on Highway 174 were initially installed every half mile and have now been strengthened to quarter mile spacing. The width of the pavement stripe was increased from 8 inches to 15 inches.

Figure 2-17 describes two cross-section plans for bus use shoulders in Ottawa. Regional Road 174 was open for bus use in 1992 and has a 5-meter (16.4 feet) width to edge of pavement. A two percent cross slope is allowed. Regional Road 417's bus use of shoulders operation is more recent. Its shoulder cross section spans 7 meters (23.0 feet) and includes a 3.5-meter bus shoulder, plus a 1-meter shoulder and 1-meter refuge edge area. The adjacent general purpose lane is 3.75 meters (12.3 feet). The Ottawa experience suggests that where an emergency shoulder can be provided adjacent to the bus shoulder, it is desirable but not essential. Again, these shoulder cross sections allow buses to operate at speeds up to 62 mph. Bus volumes are relatively high



Source: John Bonsall, McCormick Rankin International

Figure 2-17. Typical Ottawa shoulder bus lane sections.

(100 buses per hour), and these high volumes might help to minimize surprises to motorists in the adjacent general purpose lane.

At two interchanges OC Transpo has passenger-activated call buttons that signal buses operating along Highway 174 and Highway 417 to exit the freeway and pick up passengers. The call buttons are connected to indicators along the freeway that alert bus drivers passengers are waiting. The call buttons have a positive feedback signal at the passenger stop confirming that the call is active.

Legal

Most of the BOS shoulders are within the city boundaries, but the westernmost segment of Highway 417 is under the jurisdictional control of Ontario Province. On the Ontario Province–controlled segment, only OC Transpo transit buses are allowed.

Driver Training

New hire bus drivers are trained on shoulder use, and OC Transpo has a cyclical training program that includes BOS operations. Since so many buses operate on the BOS segments, all drivers are trained in its use. A suburban bus operator is also allowed to use the Highway 174 bus shoulders (Leduc Bus Lines).

Columbus, Ohio: I-70

On November 20, 2006, a new BOS operation was opened on I-70. The 10-mile segment east of downtown to Reynoldsburg Road (two interchanges past the I-270 beltway) was the result of a collaborative effort between the Ohio DOT, the Central Ohio Transit Authority (COTA,) and the Mid-Ohio Regional Planning Commission (MORPC). The City of Columbus, FHWA, the Ohio Highway Patrol, and the Columbus Police were also involved in the development of the BOS project. The project segment, which is shown in Figure 2-18, extends from I-70's interchange with I-71 (Miller/Keaton Avenues) to Reynoldsburg Road (SR-256). The design and operating protocols follow the Minneapolis-St. Paul Twin Cities area model.

BOS Development Process

The project development process involved monthly collaborative discussions between the project partners and used the Twin Cities BOS project as its model. In Columbus, the project partner team is called the "Transit Advantage Group Partners." It was implemented as a 1-year pilot project. The goal of the pilot project is to determine the viability of transit buses using the shoulders. This segment of the freeway system was selected for the pilot program because it regularly experienced speeds of less than 35 mph, had shoulders of 10-feet width or more and had full-depth shoulder pavement.

Corridor Features

COTA operates three bus routes on the segment (Routes 44, 45, and 47), which total about 20 bus trips on an average weekday. I-70 is generally a six-lane freeway and operates without severe congestion most days. During commute peaks, speeds generally drop below 35 mph, particularly at key congestion points. There are six intermediate interchanges over the length of the BOS segment—Brice Road, I-270, Hamilton Road, James Road, Highway 33, Winchester

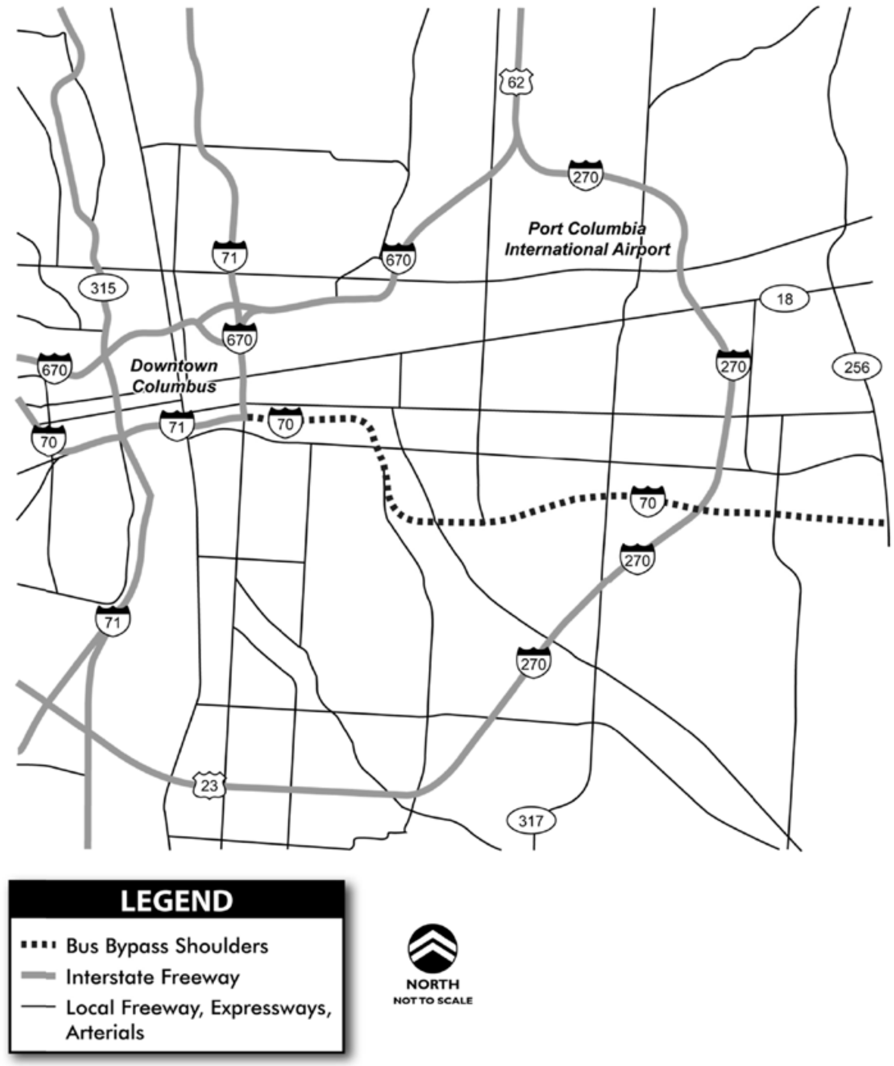


Figure 2-18. Columbus, Ohio, I-70 BOS location.

Pike, Livingston Avenue, and Kelton/Miller Avenue. The junction of I-70 with I-71 tends to be a congestion point as does the I-70 and I-270 interchange area east of downtown. Both the I-270 and I-71 interchanges have double lane on- and off-ramps. The traffic weave between I-270 and the Brice Road interchange is heavy. Another difficult interchange is the eastbound off-ramp at Hamilton Road. During the evening commute peak, traffic backs up onto the freeway and blocks shoulder lane passage at the Hamilton Road interchange.

Operating Protocols

The operating protocols are virtually the same as for the Twin Cities area: buses use shoulder only when speeds drop below 35 mph, they do not exceed 35 mph when using the shoulder, and they do not run more than 15 mph faster than traffic in the general purpose travel lane. Deadheading buses are allowed to use the shoulder. Buses yield to on and off-ramp traffic and driver discretion is the cornerstone for safe operation. On-ramps are not metered. Buses are allowed to travel through interchanges using the shoulder and are not directed to merge back into general traffic to pass through interchange weaving areas. Drivers are specially advised to use caution when using shoulders crossing bridge decks during poor weather. Four-way flashers must be used when using the shoulders.

BOS Facilities

The signage and markings are virtually the same as for the Twin Cities. Special pavement markings are not used. Mainline signs are the same as the Twin Cities, including the yellow warning signs at narrow shoulder locations. The only signage difference is the use of a more traditional yellow warning sign for the on-ramps. These signs are diamond shaped (square with one diagonal vertical). The Twin Cities area on-ramp warning sign is yellow, but is mounted squarely. Approximately $10,000 was invested in implementing the BOS signage.

The Ohio DOT attempts to clear obstructions from the shoulders as a high priority. Their freeway incident response team (FIRST) is actively involved with the pilot BOS project. Debris clearance efforts have been increased from once every three weeks to once a week.

Legal

Section 4511.25 of the Ohio Revised Code forms the legal basis for buses using shoulders. Only COTA buses are allowed to use the shoulder during the pilot period. The City of Columbus Police and the Ohio State Highway Patrol are both engaged in enforcement of the BOS project. To date, abuse has reportedly not been a problem.

Driver Training

Drivers must undergo training to use the BOS segments. As not all drivers were trained on opening day, some were unable to use it even when pushed by passengers to use the shoulder. Some drivers are reluctant to use the shoulders over concern about COTA's policy of dismissal for three preventable accidents.

Atlanta, Georgia: GA-400

The Georgia Regional Transportation Authority (GRTA) and the Georgia DOT opened a BOS operation in September 12, 2005 for the GA-400 freeway between the North Springs Metropolitan Atlanta Rapid Transit Authority (MARTA) rail station and Mansell Road (Figure 2-19). The BOS has since been extended northward to the Windward Parkway. GA-400 is a high volume six- to eight-lane freeway serving the northern suburbs of Atlanta. The initial segment was about 6 miles and the total now is about 12 miles. GRTA, which operates regional express bus services, was the principal champion of the project with the Georgia DOT as its major partner. FHWA staff was involved over the course of the planning for the BOS application. The Minneapolis-St. Paul BOS project served as template for the overall design and operation. The Georgia DOT considers the GA-400 BOS project to be an interim solution, until such time as the freeway can be further widened with managed lanes.

BOS Development Process

The design efforts primarily consisted of team meetings and a review of the Twin Cities template. A general estimate of patronage increase was developed using the regional travel model,

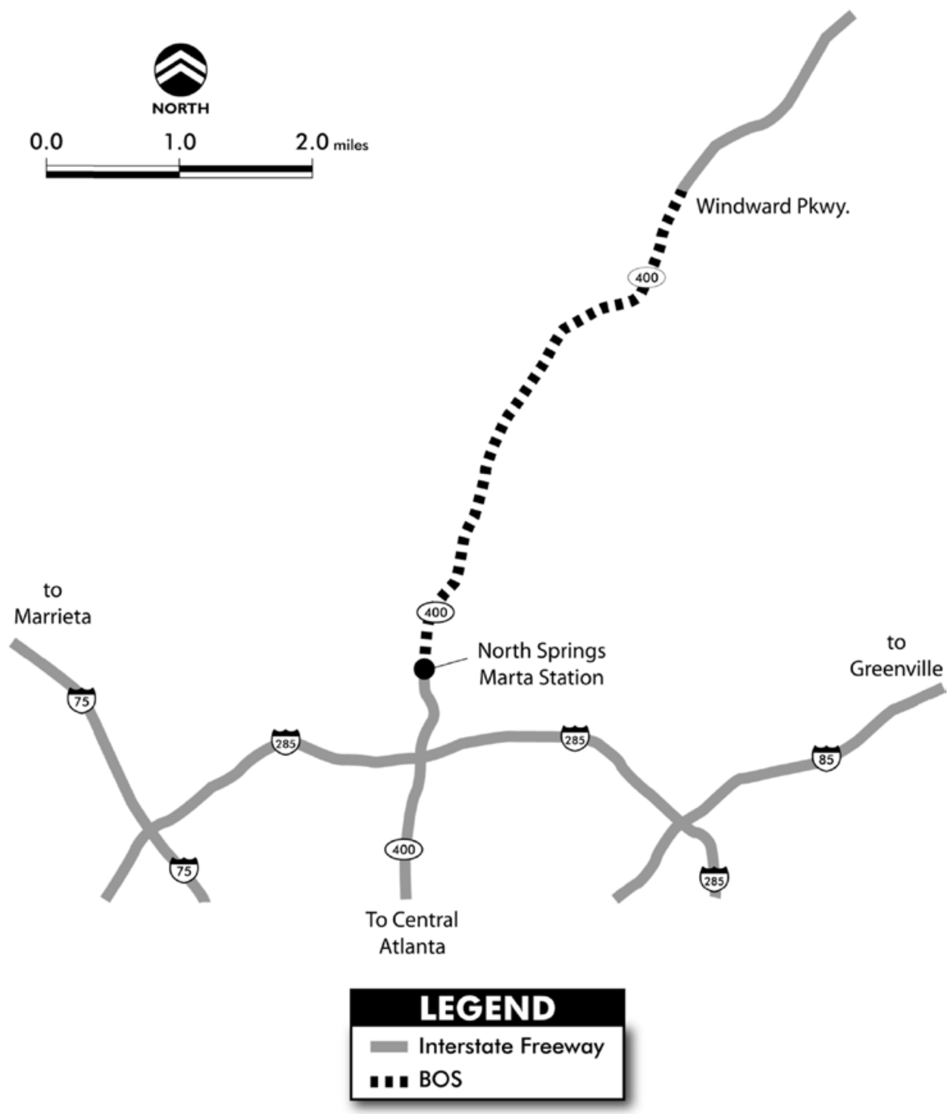


Figure 2-19. Georgia 400 BOS.

but this was not critical in designing the GA-400 project. Documentation for the project development includes good baseline data as well as forecast benefits. BOS signs were placed according to in-the-field engineering assessments.

Corridor Features

GRTA operates about four buses an hour during the commute peaks and MARTA operates about eight buses an hour on the BOS segment. When the BOS operation initially opened, commute buses were estimated to average a savings of 5 to 7 minutes of travel time and savings of up to 25 minutes at times when major blockages occur. Recent widenings of GA-400 reportedly have reduced commute congestion, but buses still benefit from the shoulder use. GRTA is not aware of any BOS accidents to date.

Operating Protocols

The operating plan allows GRTA and MARTA buses to use shoulders when general traffic speeds drop below 35 mph. Buses are only allowed to operate a maximum 35 mph, but no more than 15 mph faster than general traffic is moving. The key operating protocol difference from the Twin Cities area is the instruction for buses to remerge into general purpose traffic lanes in advance of interchange off-ramps and not re-enter the shoulder until after the on-ramp weave. The rationales for this difference are to minimize motorist surprise at these interchange weave areas and that some shoulders are narrower at interchange underpasses and overpasses. Most of the bus drivers are understood to follow the operating rules through interchanges.

BOS Facilities

The southern portion of the BOS, which opened first, included raised markers (buttons) along the shoulder to discourage copycat drivers from using the shoulders. They proved not to be needed and the newer northern section does not have the raised markers. The buttons on the southern segment are slowly being lost due to bus traffic wear and they are not being replaced. Like many of Georgia's urban highways, GA-400 has paved accident investigation sites (shoulder pockets) located just adjacent to the shoulder. On GA-400 these are located about every half mile and help minimize disabled vehicle blockage of the shoulders themselves. Shoulders of GA-400 were widened by 2 feet and reinforced to accommodate the shoulder use at a cost of about $2.8 million. Several of the on-ramps are metered and the Georgia DOT is moving toward metering more of its on-ramps along all interchanges. In some locations, the Advanced Traffic Management Systems (ATMSs) facilities were hardened, and in others they were relocated.

The signage is the same as in the Twin Cities area, with one exception. The on-ramp sign used is a regulatory sign (rectangular with black on white background) rather than the black on yellow background that is used in Minnesota. Mainline freeway signs read "shoulders—authorized buses only," and in a couple of narrow sections, the Minnesota yellow arrow signs are deployed to warn bus drivers to merge into the general purpose lanes. "End" and "Begin" signs are the same as used in the Twin Cities area. The mainline signs are placed about 10 feet from the edge of the shoulder, similar to the Twin Cities model.

Legal

A draft was prepared to amend the Official Code of Georgia to permit BOS operations. The understanding of the research team, however, is that the Commissioner of the Georgia DOT authorized the BOS operation as a demonstration project and the draft code changes were not pursued. Initially school buses and other buses used the shoulders, but the authorization is just for public transit buses and non-transit buses have since stopped using the shoulders. A categorical exclusion was used to clear the project environmentally.

Driver Training

No formal training programs are given to the bus drivers on the use of shoulders. They are simply "talked to" about the operating protocols prior to assignment to the BOS routes.

Other New Projects

Discussions are underway in Kansas City, Austin Texas and North Carolina. Chicago, Cincinnati and Cleveland recently implemented BOS projects.

Chicago Area (PACE Transit), Illinois

Discussion of BOS in the Chicago region dates back to 2003 and research included a field review of the Twin Cities operations in 2005. PACE Transit, the Illinois DOT, and the University of Illinois, Chicago explored implementation of the BOS concept in the region. Early discussions identified passage of disabled vehicles on the shoulder as a concern. Also, when buses need to reenter the general purpose traffic lane, does this create a "shockwave" that adversely affects traffic upstream? The following were among the corridors initially discussed for BOS:

- I-55 from Illinois Route 53 to Damen,
- I-57 from Dixie Highway to 99th,
- Illinois Route 83 from I-290 to Higgins,
- I-94 from Dempster to Half Day Road,
- I-290 from Desplaines to I-90, and
- I-394 from Sibley to 95th.

The Illinois DOT and Regional Transportation Authority have completed a more detailed assessment of BOS along I-55 (Stevenson Expressway) using the inside shoulder. The BOS on I-55 is a 2-year demonstration that began in November 2011. BOS piggybacks with a resurfacing project and includes signage and pavement markings as well as relocation of the shoulder rumble strip. The 14-mile project is anticipated to save about 7 minutes per peak bus trip and is estimated to cost about $200,000 in addition to the resurfacing improvement costs. The boundaries extend from Cicero Avenue to Kedzie Avenue. Signage conforms to the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) legibility requirements. Use of the inside left shoulder is proposed.

Cincinnati, Ohio

Metro and the Ohio DOT have moved forward with the implementation of the nation's first left shoulder BOS project (see Figure 2-20). This new BOS project began operation in July 2007. It is about a 10-mile segment of I-71 in the northeastern part of the metropolitan area (see Figure 2-21).

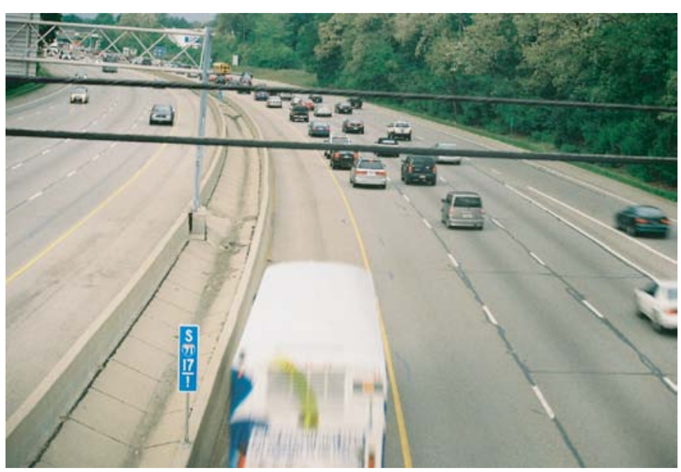


Figure 2-20. Cincinnati BOS.

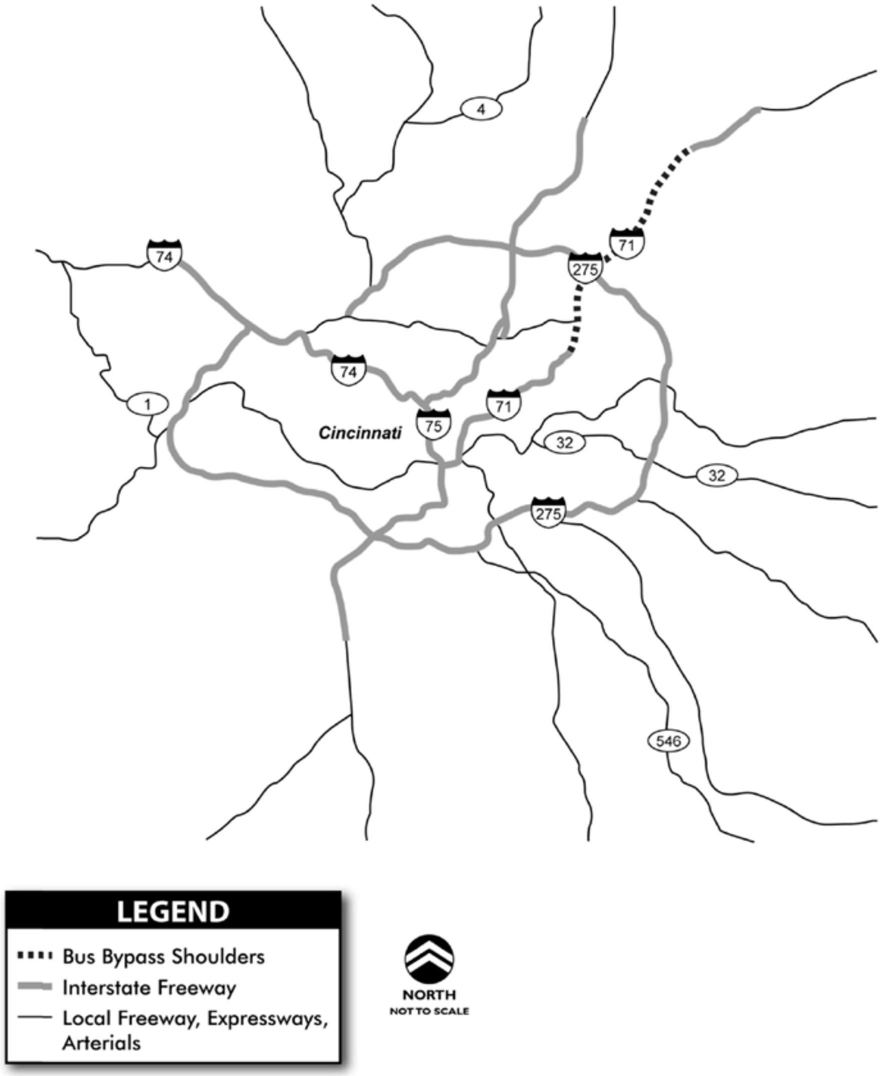


Figure 2-21. Cincinnati Ohio I-71 BOS.

The limits are from Kenwood Road in the south to Kings Mill Road in the north. A large theme park, Kings Island Park, which is located at Kings Mill Road, provides a large park-and-ride facility for express bus services. The project is a 1-year pilot with the shoulders available for use anytime traffic slows to less than 30 mph. Shoulders in both directions of travel will allow bus use. About seven morning and seven evening bus trips are made on these freeway segments, so for the pilot period, the shoulders function as peak period-peak direction BOS facilities. The left-side shoulders are generally 12-feet wide with a rumble strip running down their centers. As this is a 1-year pilot, the rumble strips are not being milled away. Drainage cross slopes are reported around 2 percent. Buses operating on the shoulder are allowed to run up to 15 mph faster than traffic in the general traffic lanes and thus could operate at a speed of 45 mph. Four-way flashers are to be used while using the shoulder. In the northbound direction, buses coming from downtown weave into the left shoulder at Kendall Road and begin the transition out of the shoulder about 3 miles before Kings Mill Road. In the southbound direction, buses weave into the left shoulder when they enter I-71 at Kings Mill Road and stay in it until it ends at Kendal

Road, where they operate in shared traffic lanes to downtown. At the I-275 interchange, the southbound shoulder narrows slightly and buses must merge back into general traffic lanes for a short distance. A Twin Cities–type yellow pinch point sign is used to remind drivers. Bus drivers are required to use the shoulder when traffic drops below 30 mph unlike the Twin Cities area, where they are given discretion to use the shoulder. In addition to the Ohio DOT and Metro, the FHWA and several jurisdictions have been involved in the project planning. The driver training included both classroom and road sessions. One week before passenger service began, a media ride was held to highlight the new service and alert motorist of the changed use for the shoulder. The Ohio DOT plans on upgrading its sweep clearance of the shoulders from the current twice a month to twice a week for the BOS segments.

Cleveland, Ohio

The Greater Cleveland Regional Transit Authority (GCRTA), Laketran, FHWA, the Ohio State Highway Patrol, and the Ohio DOT implemented a BOS project on the I-90 and SR-2 East Shoreway Corridor in 2008. The project consists of two separate BOS segments. On I-90 between SR-283 and East 260th Street in Euclid, the right shoulder serves buses operating in both directions during peak commute hours. A second BOS segment is operating on I-90 westbound from East 55th Street to the SR-2 East 9th Street interchange. Signage is similar to that use in the Twin Cities. Only GCRTA and Laketran transit buses are authorized to use the shoulders.

Kansas City, Kansas

The Kansas DOT and Johnson County are developing plans for BOS operations along I-35. Reportedly it would extend from 95th Street and Lamar Avenue employing similar features as the Twin Cities BOS network. Bus drivers are being trained and service is planned to start in early 2012.

Raleigh, North Carolina

A new BOS application is planned for a 12 mile segment of I-40 near the Research Triangle employment center. The project limits would be from US 15-501 to the Durham Freeway continuing for eastbound traffic only from the Durham Freeway to Page Road. Operations would start in mid-2012.

Montreal, Canada

BOS on Highway 20 in Lachine began in November 2011. The project limits are 55th and 1st Avenues.

Texas

Texas is seeking legal authority to implement BOS in Travis, Bexar, El Paso, and Denton counties. The effort would likely follow operating protocols proven in the Twin Cities area.

ITS Research

The FTA is sponsoring several research efforts with potential application to BOS. FTA's Vehicle Assist and Automation Program researches and develops the technology that automates movement of buses to allow precise operations in extremely narrow lanes. The vehicle guidance aspect will allow bus drivers to control the speed of forward motion, but automates the lateral movement of the bus. The FTA research is sponsoring three specific demonstration projects:

- CA and OR Demonstration involving Caltrans, PATH, AC Transit, and Lane Transit. Uses magnet marker sensing and differential global positing system/inertial navigation technology for lateral guidance of buses.
- San Diego BOS Service involving SANDAG, Caltrans, the Metropolitan Transit System, and CHP. Uses optical and radar based sensors for lateral guidance on I-805.
- Minnesota Driver Assist System uses differential global positing system for lateral guidance on outside shoulder of TH-77/TR-62/I-35W.

The University of Minnesota has completed a two-volume study looking at ITS improvements to help increase the safety of BRT vehicles that operate in unique environments. Freeway shoulder space is a prime example of a unique environment where roadway conditions are limited and room for driver error is minimal. This situation often times results in a 9.5-foot wide transit bus (including rear view mirrors) operating in a 10-foot wide roadway. Volume I of the study focused on technologies associated with lane keeping (lateral guidance) and forward collision avoidance (obstacle detection) tasks. Volume II of the ITS study looked at virtual mirror technology as it relates to lane assistance to increase the safety of BRT vehicles.

For the Minnesota vehicle lane guidance concept, implementing lateral guidance technologies to assist in BOS operations requires a highly accurate spatial database of the roadway network and a sufficient global positioning system (GPS). These components inform the bus of its position in the real world relative to the roadway's lane markings. The Minnesota vehicle is also equipped with a special steering and lateral control mechanism that assists the driver in the guidance tasks. The following three types of feedback are then provided to the driver to improve their driving accuracy:

1. Visual (heads-up display—or HUD, virtual mirror);
2. Haptic (actuated steering wheel); and
3. Tactile (vibrating seat).

Forward obstacle detection is provided through a set of radar sensors that relays input to a HUD for the driver. The sensors (two) would be mounted into the front bumper of the bus. Icons presented on the HUD screen notify the driver that something is ahead, but exactly what is unclear to the driver. There is still some discussion for what the most appropriate icon should be to represent this obstacle.

Although mirrors are a critical component of navigation for all drivers, they oftentimes create blind spots, become dirty, magnify glare, and, in the case of bus shoulder use, increase the width of the bus leading to possible accident situations. Virtual mirrors provide one option for replacing traditional mirror usage on buses. These virtual mirrors provide electronically generated images of the surrounding environment on a HUD panel located inside the vehicle for the driver's use. These images are created using GPS and light detection and ranging (LIDAR) sensors mounted on the buses that work together to convey the outside world to the bus drivers. Since 90 percent of accidents in BOS operation are attributed to mirrors, this form of technology may be especially useful for this form of bus operations.

Variable message signs along with ITS monitoring of buses and traffic are other key ITS tools with application to BOS projects.

Summary

BOS operations have been operating successfully for almost two decades. Minnesota, Virginia, New Jersey, Maryland, Delaware, Florida, California, Ohio, Georgia, Illinois, and Washington have applications in operation. North Carolina is on the verge of implementation. The BOS applications have been low investment measures to improve reliability and travel times for transit services. They utilize available right-of-way and tend to be very low-cost options for widening of highways for exclusive bus lanes or added highway capacity. Implementation has involved partnerships with state DOTs, transit operators, MPOs, state and local police, and the FHWA. Increasingly, the partnerships have adopted more rigorous processes for implementation, but they continue to be relatively nimble measures to implement. Virtually all of the BOS projects restrict shoulder use to congested commute periods when general traffic speeds are below 35 mph and they limit the differential speed that buses can operate while on the shoulder (15 mph). As a result of thoughtful planning, design, implementation, and operation none of the BOS projects have been abandoned due to safety or other failures. The safety experience has been excellent. Concerns about copycat motorists using the BOS shoulders also have not proven to be a problem.

SECTION 3

Operations Guidelines

Introduction

Like other forms of transit preferential treatment, BOS is primarily designed to benefit transit passengers and to help grow the number of corridor travelers using public transit. Watching a bus moving along the shoulder, while waiting in the congested general purpose traffic lanes, clearly conveys the message to motorists that they should have taken the bus rather than drive. Similarly, passengers on BOS buses moving unimpeded on the shoulder pass stopped cars feel how smart they were to take the bus. Transit passenger benefits include quicker travel times and more reliable travel times. Passengers and bus drivers were surveyed to understand perceived benefits and to help define guidelines for operating BOS transit services.

BOS Passenger Surveys

The first attempt to quantify passenger benefits of BOS was performed in 1997 and published in 1998 for the Minnesota DOT, about 5 years after introducing BOS on its road network. More recently, the San Diego MTS, Miami-Dade Transit, and the Minnesota Valley Transit Authority (MVTA) in the Twin Cities Area surveyed passengers in coordination with this TCRP research. During the same timeframe, the Southwest Ohio Regional Transit Authority (SORTA) in Cincinnati surveyed passengers regarding the left-side shoulder BOS project. These surveys provide valuable insight into passenger attitudes and perceptions of BOS.

1997 Survey—Twin Cities BOS

The 1997 Minnesota DOT–sponsored survey included 1,398 passengers using the I-35W BOS facility during the morning rush hour. It found that the following:

- 76 percent of the respondents noticed their bus driver using the shoulder;
- 60 percent indicated that on a typical day, the shoulder use resulted in time savings: 11 percent reporting 1 to 3 minute savings, 22 percent reporting 4 to 6 minute savings, 12 percent reporting 7 to 9 minute savings, 13 percent reporting 10 to 30 minute savings, and 41 percent not responding with an estimated savings;
- On days when traffic is at its worst, the greatest savings perceived by bus passengers was given as 1 to 3 minutes (5 percent), 4 to 6 minutes (10 percent), 7 to 8 minutes (13 percent), 10 to 12 minutes (11 percent), 13 to 40 minutes (18 percent), and 42 percent not responding;
- 4 percent responded that they ride the bus more due to the BOS;
- 38 percent responded that they experienced better reliability in their morning trip; and
- 20 percent of respondents indicated that BOS caused them to recommend the bus to others.

Cincinnati I-71 Inside-Shoulder BOS

The Cincinnati survey by SORTA included 204 passenger responses. The I-71 BOS operated by SORTA utilizes the inside (left-side) shoulder. Key findings were as follow:

- 50 percent of respondents indicated that they had ridden buses using shoulders during both the morning and afternoon commute periods, 37 percent only rode buses using the shoulder in the afternoon, 5 percent only rode buses on shoulders in the morning, and 6 percent indicated that their buses had not used the shoulder. Overall, it seems more buses use the shoulder in the afternoon than in the morning-peak period;
- Almost all respondents felt that the shoulder operations improved their commute—with some passengers indicating 5 to 25 minute travel time savings;
- All but two of the respondents indicated that they felt safe when the driver used the shoulder, and over 95 percent reported that they felt the drivers seemed confident when using the shoulders;
- A few respondents commented about the amount of debris on the shoulder and a few commented on motorists drifting—usually unintentionally, in the opinion of the respondents—into the shoulder area;
- Many respondents were unhappy when drivers did not use the shoulder and some reported changing their trip time for a driver using the shoulder.

Miami Don Shula and Snapper Creek Expressway BOS

The BOS surveys in Miami and the Twin Cities area used a similar survey template developed by this TCRP project. Miami-Dade Transit collected 350 responses and MVTA in the Twin Cities area collected 1,223 responses from passengers. The surveys asked passengers about their estimates of travel time savings on typical and bad traffic days; and on how strongly they agreed with the following statements:

- This bus generally runs on-time,
- Traffic congestion is a daily problem for this highway,
- Ride comfort is good on the shoulders,
- Use of shoulders is safe,
- I enjoy passing cars stopped in traffic, and
- Allowing buses to use the shoulder is a good idea.

Strongly agree was given a score of 1, somewhat agree a score of 2, no opinion a score of 3, somewhat disagree a score of 4, and strongly disagree a score of 5.

Riders of Routes 204 Killian Parkway, 272 Sunset Drive, and 288 Kendal Drive using the Don Shula and Snapper Creek Expressways BOS facilities were surveyed. The three bus routes feed a Metrorail Station and utilize a narrow 10-foot shoulder. Miami-Dade Transit riders estimated 12 to15 minutes of travel time benefits on a typical day and 19 to 21 minutes on a bad traffic day. Actual travel time benefits were estimated at around 5 minutes by the Parsons Transportation Group, which conducted the passenger surveys and measured highway travel times.

Thus, passengers seem to assess travel time savings at three times the actual savings. Most respondents felt that their BOS bus generally runs on time with the weighted average being between 1.7 and 2.2 for the three bus lines using the BOS segment. Overall they somewhat agreed that their BOS bus runs on time. They somewhat agreed that traffic congestion is a daily problem for the BOS highways with weighted average scores ranging from 1.8 to 1.9 for the three BOS bus routes. Passengers gave ride comfort a better score than on time and highway being congested. The weighted average ranged from 1.4 to 1.6 for the three BOS routes, which all operated over the same BOS segments. Use of the shoulder is safe scored a weighted average of 1.5 to 1.8 for the BOS routes, indicating that passengers somewhat to strongly agreed with this statement.

The weighted average for the statement, "I enjoy passing cars stopped in traffic," ranged from 1.6 to 1.8 for the BOS bus routes. This response is not as strong as one would have anticipated. "Allowing buses to use shoulders is a good idea" scored between 1.2 and 1.3, indicating a very strong agreement from passengers.

General comments to the survey were as follows:

- Happy with the bus service, continue the route;
- More bus drivers should use the shoulder, it saves time, encourages transit use, and provides better service;
- Buses are not dependable, they come early or late; and
- Transit service needs to improve—routes need more buses to run more frequently, earlier, later, on weekends, and on holidays.

Comments specific to the BOS project from the 350 respondents included the following:

- Improve shoulder surface for better ride (2 comments);
- Provide more signs so that cars don't drive on shoulders (1 comment);
- Safety is more important than using the shoulder (5 comments);
- Shoulder should be wider (2 comments);
- Shoulder should be used only during heavy traffic (1 comment); and
- Shoulder should be used as long as they don't interfere with emergency vehicles (1 comment).

Miami-Dade Transit buses are only allowed to use shoulders when general traffic speeds drop below 35 mph, and bus drivers are instructed on how to minimize conflicts with emergency vehicles. Thus, perhaps a couple of the respondents were not familiar with the operating rules for using the BOS shoulders.

Twin Cities Highway 77 BOS

MVTA surveyed riders in the Twin Cities area on bus routes using Highway 77 BOS facilities. Most of the respondents to MVTA's survey rode the 470, 477, and 480 bus routes. Respondents weighted average scores were as follows:

- This bus generally runs on time—1.29 (strong agreement) with only 16 of 1,223 respondents disagreeing with this statement;
- Traffic congestion is a daily problem for this highway—2.08 (somewhat agreement);
- Ride comfort is good on the shoulder—1.58 (strong to somewhat agreement);
- Use of shoulder is safe—1.68 (strong to somewhat agreement) with only 5 percent (65 of the 1,223) disagreeing with the statement;
- I enjoy passing cars stopped in traffic—1.38 (strong agreement); and
- Allowing buses to use the shoulder is a good idea—1.17 (very strong agreement).

Not surprisingly, passengers like the shoulder operation. A few respondents were unhappy that not all drivers use the shoulder to bypass congestion. This is consistent with comments from drivers that passengers sometimes urge them to use the shoulders when traffic begins to slow.

Bus Driver Surveys

Bus drivers of BOS applications in San Diego, Miami, the Twin Cities area, Columbus, Ohio, and New Jersey were surveyed for their experiences and thoughts regarding BOS implementation. A total of 313 responses were received from drivers including 73 from Miami-Dade Transit, 41 from the San Diego MTS, 36 from MVTA in the Twin Cities, 31 from Central Ohio

Transportation Authority (COTA) in Columbus, and 132 from New Jersey Transit. Drivers were asked if they strongly agreed, somewhat agreed, had no opinion regarding, somewhat disagreed, or strongly disagreed with a number of statements, including the following:

- Traffic congestion is a problem on this route,
- Using the shoulder shortens the trip,
- Using the shoulder improves schedule time,
- Using the shoulder is safe,
- The shoulder is wide enough to drive on,
- Signs and pavement markings are adequate,
- Training was adequate,
- Ride comfort is good,
- Other motorist accept buses using shoulders, and
- Using the shoulders is a good idea.

Table 3-1 summarizes the results of the survey findings by community. The San Diego, Columbus, and Miami surveys were conducted shortly after implementation, whereas the Twin Cities and New Jersey Transit surveys were conducted at least a year after implementation. Most of the BOS projects were freeway segments, except for New Jersey, which is an arterial operation.

Surveys of bus drivers using BOS segments in San Diego, Miami, the Twin Cities, and New Jersey included the following two speed-related questions:

1. What is the biggest challenge to operating on the shoulder? Do you feel it would be safe to operate at higher speeds on the shoulder?
   - Yes, with current shoulder widths—how fast?
   - Yes, with standard traffic lane–width (12 feet)—how fast?
   - No, current maximum speed is good.
2. Current rules allow buses to use the shoulder when general traffic speeds drop below 35 mph. At what speed for general traffic do you think buses should be allowed to use the shoulder?
   - In the Twin Cities area, MVTA BOS drivers felt that the biggest challenges to operating buses on the shoulders were motorists wandering onto the shoulder (mostly due to inattention, in the opinion of the drivers) and to snow removal sometimes not totally clearing the shoulder for safe running. MVTA drivers generally confirmed the 35 mph threshold speed and maximum speed as being the right speeds. About 25 percent of the drivers suggested a slower speed, another 30 percent suggested a higher speed and the remaining 45 percent felt the 35 mph speed was best.
   - In San Diego, MTS bus drivers felt that the biggest challenges were the shoulder being too narrow (26 percent), traffic conflicts (15 percent), traffic encroachment into the shoulder, particularly large trucks (10 percent), and objects on the shoulder (7 percent). Seventy-three percent of San Diego MTS drivers felt that the current 35 mph speed is good. No clear direction was provided on increasing the speed. Sixty-one percent of the MTS bus drivers felt that 25 mph would be the best speed at which to begin using the shoulder, 20 percent responding that the current 35 MPH threshold was best, and another 22 percent responding that speeds higher than 35 mph would be best.
   - In Miami, bus drivers felt that the biggest challenges were that the shoulder is not wide enough, merging onto the shoulder and back into traffic is a problem, the shoulder pavement is a problem or seam between the outer travel lane and the shoulder is rough. Nearly 70 percent of the drivers felt that the current maximum 35 mph maximum speed is good. Eleven percent felt the maximum speed might be higher and 15 percent indicated the maximum speed could be higher with wider shoulders.
   - COTA bus drivers in Columbus Ohio felt that the current 35 mph maximum speed for BOS operations is good (71 percent of respondents). Eleven percent of the drivers felt that

Table 3-1. Survey findings by community.

	Strongly Agree (1)	Somewhat Agree (2)	No Opinion (3)	Somewhat Disagree (4)	Strongly Disagree (5)	Weighted Score
Congestion is a Problem						
San Diego	61%	34%	5%	0%	0%	1.44
Miami	54%	33%	1%	6%	6%	1.75
Twin Cities	31%	33%	14%	19%	3%	2.30
Columbus	55%	16%	13%	10%	6%	1.97
New Jersey	59%	31%	4%	3%	3%	1.61
Shortens Trip						
San Diego	55%	33%	5%	0%	7%	1.71
Miami	51%	32%	7%	1%	8%	1.83
Twin Cities	58%	31%	3%	8%	0%	1.61
Columbus	47%	10%	17%	7%	20%	2.43
New Jersey	60%	26%	5%	2%	6%	1.65
Improves Schedule Time						
San Diego	59%	34%	2%	2%	2%	1.52
Miami	56%	23%	7%	5%	8%	1.94
Twin Cities	58%	31%	0%	11%	0%	1.64
Columbus	36%	21%	7%	14%	21%	2.64
New Jersey	67%	27%	2%	2%	2%	1.44
Is Safe						
San Diego	24%	44%	10%	17%	5%	2.35
Miami	16%	33%	7%	18%	26%	3.04
Twin Cities	25%	36%	11%	17%	8%	2.40
Columbus	10%	35%	6%	23%	26%	3.19
New Jersey	14%	55%	8%	18%	5%	2.45
Is Wide Enough						
San Diego	10%	41%	2%	22%	24%	3.09
Miami	11%	21%	7%	33%	43%	3.65
Twin Cities	22%	36%	3%	22%	17%	2.85
Columbus	19%	26%	10%	19%	26%	3.06
New Jersey	32%	45%	3%	18%	5%	2.15
Signs and Markings are Adequate						
San Diego	22%	32%	7%	37%	2%	2.65
Miami	20%	36%	11%	14%	18%	2.72
Twin Cities	11%	44%	6%	25%	17%	2.93
Columbus	10%	42%	16%	10%	22%	2.94
New Jersey	28%	40%	8%	16%	6%	2.32
Training was Adequate						
San Diego	37%	29%	22%	12%	0%	2.09
Miami	68%	23%	7%	0%	2%	1.48
Twin Cities	50%	36%	11%	3%	0%	1.67
Columbus	26%	29%	32%	10%	19%	2.42
New Jersey	42%	37%	15%	5%	1%	1.86
Ride Comfort Good						
San Diego	22%	46%	22%	10%	0%	2.20
Miami	25%	36%	11%	20%	8%	2.49
Twin Cities	36%	42%	6%	16%	0%	1.86
Columbus	10%	33%	27%	10%	20%	2.97
New Jersey	39%	45%	8%	5%	3%	1.88
Motorists Good Acceptance						
San Diego	20%	29%	15%	22%	15%	2.83
Miami	10%	21%	7%	32%	32%	3.53
Twin Cities	8%	33%	6%	39%	14%	3.10
Columbus	3%	45%	23%	3%	26%	3.03
New Jersey	14%	36%	11%	22%	17%	2.92
Good Idea						
San Diego	68%	32%	0%	0%	0%	1.32
Miami	49%	25%	12%	1%	12%	2.01
Twin Cities	67%	19%	3%	8%	3%	1.58
Columbus	35%	23%	10%	3%	29%	2.68
New Jersey	66%	25%	2%	2%	5%	1.55

the speed could be increased with 40 mph the most cited speed. One respondent felt the maximum speed should be 30 mph. Drivers felt that the threshold speed for using the shoulder should be 35 mph (48 percent), with 22 percent suggesting 25 mph, 15 percent suggesting 30 mph, 7 percent suggesting 40 mph, and another 2 percent suggesting 45 to 50 mph.

- Fifty-seven percent of the New Jersey Transit BOS bus drivers felt that the current maximum speed of 35 mph is good, while 14 percent felt the maximum speed could be increased, and 29 percent felt the speed could be increased if the shoulders were wider. In New Jersey, for the arterial BOS on Route 9, 45 percent of the BOS bus drivers indicated that the current speed of 35 mph is good, 39 percent felt that the threshold speed could be increased with current shoulder widths, and 16 percent of the drivers felt the speed could be increased if shoulders were wider. The BOS speed threshold for general traffic most commonly indicated was 35 mph (33 percent) with 40 mph receiving 25 percent of the responses. Nineteen percent of the drivers suggested speeds under 35 mph and 22 percent of drivers suggested speeds above 40 mph.

Bus drivers were also asked the following:

- How often do you encounter a motorist in the general traffic lanes trying to block buses using the shoulder?
- Which is the more challenging weave at interchanges—at off-ramp or at on-ramp?
- Have you ever encountered drainage blockages of the shoulder during rainy weather (San Diego only question)?
- How would you best describe passenger attitudes on buses using the shoulder—love it, like it, ambivalent, or do not like it?

San Diego MTS bus drivers reported experience with some motorists attempting to block buses on a daily basis (24 percent), several times a week (30 percent) and less than once a week (24 percent). In Miami, bus drivers report a higher incidence of motorists trying to block shoulders with 44 percent indicating they encountered this daily, 24 percent just several times a week, and 32 percent less than once a week. In Columbus Ohio, most bus drivers indicated that motorists blocking the shoulder occurred less than once a week (58 percent).

San Diego MTS drivers were evenly split on bus weave conflicts at on- and off-ramps, with the off-ramp weave getting 55 percent of the votes and the on-ramp getting 45 percent. Miami-Dade Transit BOS drivers felt that the weave with traffic exiting at an off-ramp was more challenging than weaves at on-ramps. Fifty-nine percent of Miami bus drivers felt the off-ramp weave was more difficult than the on-ramp weave (41 percent). Columbus Ohio COTA bus drivers were evenly split on which ramp weaving movement is the most challenging.

About 10 percent of the San Diego MTS bus drivers reported encountering ponding problems on the shoulder during rainy weather.

With respect to passenger attitudes, drivers think it is quite popular. Thirty-five percent of San Diego MTS drivers felt that passengers loved it, 53 percent felt they liked it, and felt that 12 percent did not seem to care. In Miami, 48 percent of bus drivers felt that passengers loved BOS. Another 39 percent felt passengers seemed to like it and only 3 percent felt passengers did not like BOS. MVTA bus drivers in the Twin Cities area felt that 33 percent of passengers loved the BOS, 56 percent felt passengers seemed to like it, and 11 percent felt that passengers did not like riding on the shoulder. COTA bus drivers felt that passengers generally loved the BOS (50 percent) with another 33 percent reporting that passengers seemed to like it. Overall 47 percent of the bus drivers felt that passengers seemed to like BOS, another 47 percent felt that passengers did not seem to care, and 6 percent felt that passengers did not like buses riding on the shoulder.

MVTA bus drivers in the Twin Cities area were evenly divided about the amount of motorist blocking of shoulders. Thirty-three percent report experiencing it on a daily basis, 31 percent on a several times a week basis, and 36 percent on a less than once a week basis. Most of the MVTA bus drivers (86 percent) felt that the BOS concept was a good idea.

The most common comment from COTA bus drivers was the need to be careful when passing large trucks and the need to better remove debris from the shoulder.

New Jersey Transit drivers felt the BOS was a good idea. A few drivers felt the signage should be strengthened and a few commented that passenger drop-offs of "kiss'n ride patrons" created conflicts. About two of five drivers (38 percent) indicated that motorists intentionally blocked the shoulder on a daily basis, 32 percent reported that they encountered it several times a week, and 30 percent indicated that they encountered this problem less than once a week. About half of the bus drivers felt the blockage was intentional and another half indicated that they felt it was equally split between intended and unintended blockages. On Route 9, bicyclists are allowed to use the shoulder and 20 percent of bus drivers reported encountering some conflicts with pedestrians and bicyclists.

Potential Benefits

The passenger and driver surveys helped to identify perceived benefits in travel times, running times, reliability, ridership, and service refinements.

Travel Time Savings

The amount of travel time saved by BOS largely depends on the degree of congestion in the general purpose lanes and how many miles this congestion extends. The longer the BOS segment, the greater the travel time savings. The more congested and slower the speeds of general traffic, the greater the BOS travel time savings. Obviously, the more hours of the day general traffic is congested, the greater the potential BOS benefits. Since traffic congestion tends to vary daily based on weather, incidents, demand levels, and other factors, BOS travel time savings will also vary substantially for a given BOS segment.

Since traffic congestion varies substantially in most corridors during a typical 2-hour commute peak period, BOS trips during the heart of the peak period tend to provide greater time savings than trips during the shoulder of the peak period. The Minnesota DOT electronically collected travel time data for general purpose traffic lanes and BOS shoulder travel times for a "typical day." Table 3-2 summarizes the travel time findings. It shows the length of the BOS segment, free-flow travel time, the total number of bus trips operating during the peak hour, the number of bus trips using the shoulder, the average travel time savings for BOS trips and the maximum travel time savings for a BOS trip compared to travel times in the congested general

Table 3-2. BOS travel time experience.

BOS Segment	Peak	Direction	Miles	Free-Flow Time	Bus Trips	BOS Trips	BOS Average Time Savings	BOS Maximum Time Savings
I-94	PM	East	5.2	5.67	49	25	2.21	3.92
I-94	PM	West	5.9	6.47	48	11	0.40	0.91
Hwy 36	AM	West	6.2	6.81	36	17	2.29	4.71
Hwy 36	PM	East	6.4	6.97	48	22	1.57	2.76
Hwy 77	AM	North	10.5	11.41	36	18	2.52	5.14

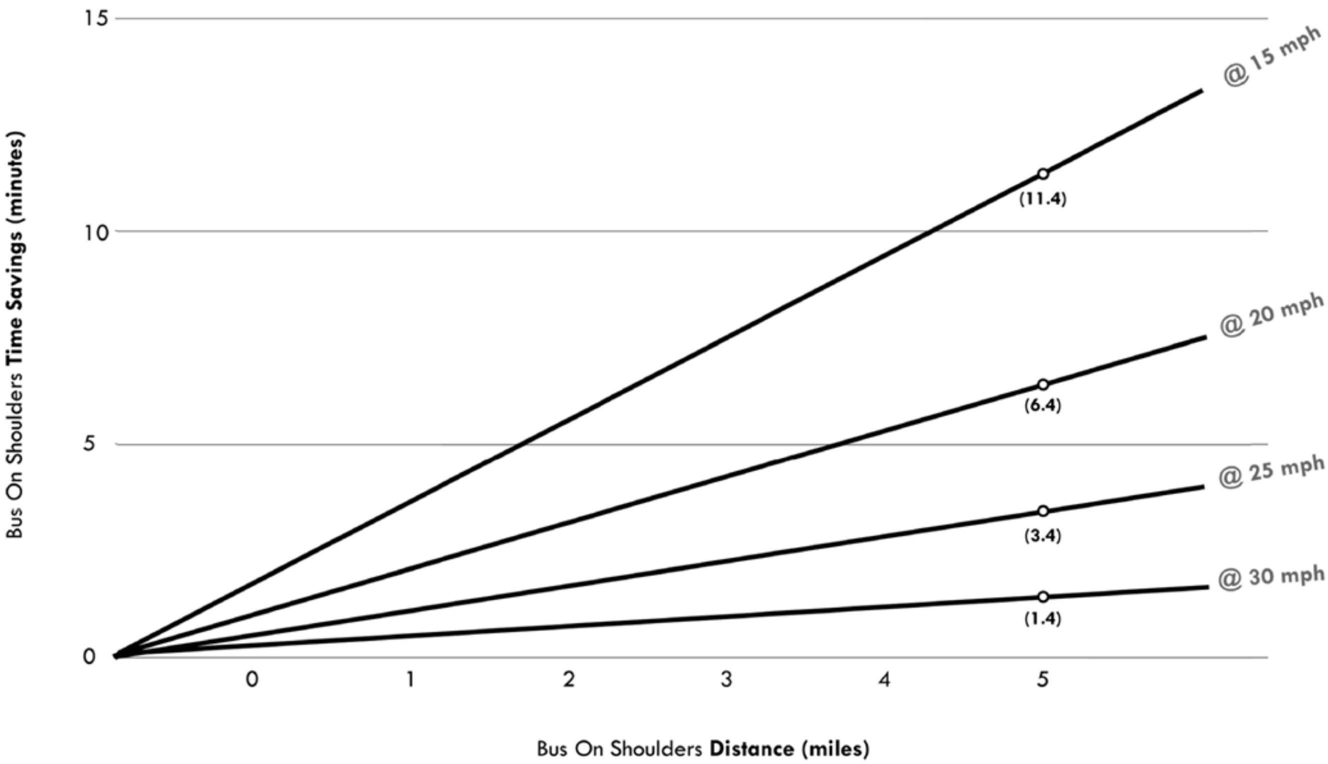


Figure 3-1. BOS travel time savings.

purpose traffic lanes. The data clearly shows that travel time benefits vary by corridor and that most of the benefits occur to buses operating in the core of the peak period.

As shown in Figure 3-1, the simplified amount of travel time savings can be estimated by relating the BOS travel speed difference to the running length of the BOS facility. In actual practice, the speed differential varies along the BOS segment. Most BOS operations limit BOS buses using the shoulder to no more than 15 mph faster than general traffic due to safety concerns, with a maximum speed of 35 mph while using the shoulder. Thus for a 5-mile BOS segment, a bus traveling at 35 mph could complete the trip in 8 minutes and 34 seconds (514 seconds total). If stuck in the general purpose travel lanes moving at 5 mph, it would take the bus 60 minutes to complete the 5 miles—51 minutes and 26 seconds longer than using the shoulder. If the general purpose traffic lanes were moving at 10 mph, it would take the bus 30 minutes to complete the 5 miles or 21 minutes and 26 seconds longer than using the shoulder. Similarly, general traffic speeds of 20 mph, 25 mph, and 30 mph would require bus travel times of 15 minutes, 12 minutes, and 10 minutes respectively. These travel times are greater than the 8 minute and 26 second shoulder-use travel times. Travel time benefits would be proportionately shorter for BOS segments of less than 5 miles and proportionately longer for segments greater than 5 miles in length.

Table 3-3 summarizes the amount of travel time potentially saved over a 5-mile long BOS segment for several allowable differential speeds. The slower the traffic in the general purpose lanes, the greater the potential BOS travel time benefits. Benefits also increase with higher BOS speed differentials.

If the differential speed for BOS use were to be increased to 20 mph (with wider shoulders and few weaving movements), the BOS travel time advantage would also increase. The hypothetical five mile BOS segment referenced above could save buses 48 minutes at general traffic speeds of 5 mph and 20 minutes at general traffic speeds of 10 mph. Essentially, the more congested the

Table 3-3. BOS travel time savings.

General Purpose Lanes									
Speed	0 mph	5 mph	10 mph	15 mph	20 mph	25 mph	30 mph	35 mph	40 mph
Travel Time	NA	60 min	30 min	20 min	15 min	12 min	10 min	8.6 min	7.5 min
Times for BOS Speed Differentials									
0 mph	NA	60 min	30 min	20 min	15 min	12 min	10 min	8.6 min	7.5 min
5 mph	60 min	30 min	20 min	15 min	12 min	10 min	8.6 min	7.5 min	6.7 min
10 mph	30 min	20 min	15 min	12 min	10 min	8.6 min	7.5 min	6.7 min	6 min
15 mph	20 min	15 min	12 min	10 min	8.6 min	7.5 min	6.7 min	6 min	5.5 min
20 mph	15 min	12 min	10 min	8.6 min	7.5 min	6.7 min	6 min	5,5 min	5 min
BOS Travel Time Savings									
0 mph	NA	0.0 min	0.0 min	0.0 min	0.0 min	0.0 min	0.0 min	0.0 min	0.0 min
5 mph	NA	30.0 min	10.0 min	5.0 min	3.0 min	2.0 min	1.4 min	1.1 min	0.8 min
10 mph	NA	40.0 min	15.0 min	8.0 min	5.0 min	3.4 min	2.5 min	1.9 min	1.5 min
15 mph	NA	45.0 min	18.0 min	10.0 min	6.6 min	4.5 min	3.3 min	2.6 min	2.0 min
20 mph	NA	48.0 min	20.0 min	11.4 min	7.5 min	5.3 min	4.0 min	3.1 min	2.5 min

highway and the slower the general purpose traffic speeds, the greater the potential travel time savings for BOS projects. The allowable safe speed differential also has a major affect on travel times savings.

The actual travel time savings tend to be modest (but important) near 35 mph and they increase as speeds in the general traffic lanes reach 5-mph crawl speeds and total stop speeds. The longer the congested BOS segment of highway, the greater the benefits. Even a very short segment of BOS shoulder in a 5-mph traffic segment can yield substantial travel time savings. For example, a quarter mile segment with 5-mph speeds could save buses more than 2 minutes of running time. As noted earlier, passengers tend to perceive travel time benefits at two to three times the actual savings. Since perception directly influences mode choice decisions, even small savings can be important.

Travel time benefits are a simple calculation in which time equals distance divided by speed. If distance and speed are defined in terms of miles and hours, they may need to be converted to minutes and feet.

Recognizing that each corridor has different congestion profiles, the best way to estimate BOS travel time benefits is to measure bus travel times along the potential BOS segment and compare these travel times per bus trip to a 35-mph BOS speed. Some bus trips at the beginning and end of the commute peak period might not use any, or just a short, segment of the BOS facility. During the core of the peak, most bus trips likely will use the entire BOS segment. By measuring current pre-BOS bus trip travel times, the total, the average, and the maximum BOS trip benefits could be estimated.

Running Time Savings

Running faster can save transit operators money but only if it reduces shift payments or allows buses to be more efficiently deployed. BOS applications are oriented toward the commuter market. Providing transit services at the beginning and the ending of commuter workdays often incurs premium overtime wages for operators. If BOS facilities can minimize overtime costs, they can save operators money. Typically, the BOS travel time savings should be more than 5 minutes to promise savings in overtime costs. If BOS operations can reliably complete peak hour bus runs faster, there is potential to schedule a second peak-direction trip for the bus or to interline it to another line for added passenger service. The latter is primarily oriented to morning-peak bus trips, as the afternoon bus trips typically go directly to the garage for servicing.

A few minutes of travel times savings is important to passengers, but the savings typically must be more than a few minutes to translate into significant savings for transit operators. The three Miami-Dade Transit bus routes that use the BOS segment are somewhat typical of express bus services. They have one-way peak direction running times of 40 to 45 minutes. Accounting for deadheading, or reverse off-peak direction running, very few buses are able to make more than one peak-direction trip during commute peaks. For a hypothetical service with a 45 minute one-way peak-direction running time and 30 minute reverse deadhead time and 10 minute layover period, the route would have a schedule cycle time of 85 minutes. Two peak-direction trips would require an envelope of 130 minutes (two 45 minute runs, a 30 minute deadhead, and a 10 minute layover). In order to get two peak bus trips in a 2 hour peak-commute period, 5 minutes would need to be shaved off the peak trip with the BOS operation. If the bus services operate on 10 minute headways, only one bus could make the two peak-direction trips, even with BOS shaving 5 minutes off the peak bus running times. For shorter distance bus routes, savings opportunities might be greater.

Reliability Benefits

Reliability varies significantly from day to day on many congested highways where BOS might be applicable. Travel time can even vary substantially within the same peak hour commute day on a given highway. Reoccurring congestion typically is due to demand peaks that reach and exceed capacities. Non-reoccurring congestion typically results from traffic accidents, construction activity, bad weather, and special events. To deal with reliability issues, motorists and transit riders often build into their trip schedule buffer time. This buffered travel time estimate is used by commuters to help make mode choice decisions. In general, the more congested highway segments become the more variable travel times become. Small influences of weather etc. can lead to huge delays. Also small demand spikes can destabilize traffic flow and cause significant delays,

Miami-Dade Transit found that all three of its bus routes using the Don Shula and Snapper Creek BOS facilities improved their on-time performance. These routes operate over relatively long sections of arterial streets before they jump onto the BOS expressway segments. Thus, it is difficult to isolate the reliability improvements associated only on the BOS segment. One route improved its on-time performance marginally (less than 2 percent), while the second and third bus routes that use the BOS facility improved 7 percent and 19 percent respectively.

The proposed inside-shoulder BOS application on I-55 in the Chicago area appears to offer substantial reliability benefits. The current average travel speed during peak hours is 28 mph, but this drops to 22 mph on 16 percent of weekday commute times and on some days drops to 7 to 9 mph for the 24-mile BOS distance. The differential travel times over 24 miles measured from the average 28 mph rush-hour speed are 14 minutes for 16 percent of days when speeds drop to 22 mph and much longer than 1 hour when speeds drop to 8 mph. Thus, even if BOS only allows buses to maintain a reliable 28 mph, it would provide substantial benefits to passengers.

Ridership Impacts

It is difficult to isolate patronage changes resulting from the implementation of BOS. There many influences on patronage and patronage itself tends to fluctuate on a day-to-day basis, even on commuter bus routes. The affect of BOS on patronage also will vary by location and the degree that BOS provides travel time and reliability benefits. Applications in less congested corridors will have correspondingly less affect on patronage than those in severely congested corridors. Miami-Dade Transit performed a before and after study of its BOS implementation in 2007. Patronage on the three routes increased from 4,483 to 4,532 weekday patrons despite a reduction in revenue miles of bus service. The 3 percent increase in patronage was achieved even with a 9 percent reduction in service. Boardings per bus-hour of service increased about 10 percent.

A 1997 analysis of BOS ridership impacts in the Twin Cities area found that ridership on nine routes increased 9.2 percent over 2 years following implementation of BOS operations. Total ridership on Metro Transit increased 6.5 percent over this two year period.

Service Refinements

None of the BOS communities actually modified their routing plans to implement BOS. Instead they have used BOS as a means to operate with more reliability in congested corridors. Typically, implementation of BOS does not shorten running times enough to mandate revisions to schedules, and BOS typically does not substantially increase patronage to mandate provision of more service. Nevertheless, opportunities should be examined to fully exploit BOS segments and assure that bus operations have a good fit with the BOS project.

Depending on the length of the BOS segment and the severity of congestion in the corridor, BOS could afford the opportunity to tighten published arrival times and perhaps allow an interlined additional trip to be added. By shaving a few minutes off scheduled driver shifts, it might also allow trimming some overtime.

Operating Guidelines and Protocols

As the primary beneficiary of BOS projects, transit operators are often the lead proponent of its implementation. A clear purpose needs to be defined and a partnership with other stakeholders needs to be constructed. With the team established and a purpose defined, the transit operators should work through a number of important issues to gain consensus. These include:

- Modifications, if any, to corridor-service concept;
- BOS speed protocols;
- Operating protocols while using the BOS;
- Driver training; and
- BOS start-up measures.

Field review of an existing BOS project at an early point in the planning process involving DOT and enforcement staff is useful at allaying safety concerns.

The following guidelines emerge from the passenger surveys, bus driver surveys, and interviews of staff at BOS communities.

Service Concepts

Frequent, fast, and reliable bus services are essential components of BOS. The BOS bus service is normally part of a longer bus route that brings riders from home to their job site downtown or in other major employment centers. Transit priority and passenger access improvements (e.g. park-and-ride lots) can complement BOS operations.

Congestion and weaving features along the BOS segment might also suggest minor refinements to bus routes to avoid weaves and congestion. For example, the Columbus Ohio I-70 westbound BOS segment ends before it reaches downtown to avoid weaving conflicts with a dual-lane off-ramp link to I-71. BOS buses currently exit I-70 at 3rd Street to reach downtown. COTA considered the option of routing the westbound BOS onto I-71 to Broad Street to reach downtown. This reroute would have allowed the westbound BOS to be extended to the I-71 interchange and allowed COTA buses to use more of the priority lane. While this modification has not been implemented, it does illustrate how minor bus routing revisions can potentially be fit to BOS facilities and minimize traffic conflicts.

BOS Speed Protocols

At what general flow traffic speeds should buses be allowed to use BOS facilities? How much faster than general traffic should buses be allowed to operate when using the BOS facilities? What is the maximum speed buses should operate when in the BOS facility? These are all important questions, and the answers depend on local BOS conditions and the degree of tolerable risk.

The safest operating environments are those in which all vehicles operate at the same speed, particularly when all vehicles are completely stopped. Higher speeds tend to experience higher severity of accidents than lower speeds. While having all vehicles completely stopped might be the safest operating environment, it is clearly not an acceptable service objective for highways or transit. Two decades of operating experience has demonstrated that buses can safely operate on shoulders as narrow as 10 feet at 35 mph. Toronto. Ottawa and Seattle allow buses to operate at higher speeds, but these communities tend to have wider shoulders. At all BOS sites bus drivers are given special training and operations are continually monitored to preserve safety.

Based on extensive BOS operating experience and feedback from bus drivers, 35 mph is recommended as the initial maximum operating speeds for buses while on bus shoulders. Every corridor is different, so engineering judgment should be used to tailor this maximum to the local application. This local judgment should include buy-in by all of the stakeholder agencies that are involved with the implementation. Field tests of buses operating on the shoulder should be used to confirm that 35 mph can be safely and comfortably operated on the shoulder. This maximum shoulder speed should be carefully monitored in the early months of operations and periodically revisited over the years of operation. The shoulder speeds are not posted and represent agreement between transit, highway, and enforcement stakeholders. Thus, they can be adjusted higher or lower based on operating experience. As the BOS shoulder speeds are not posted and drivers are instructed to operate on the shoulders using discretion, lower maximum speeds and speed differentials are possible. The maximum speeds are limits and not mandatory.

Based on supportive feedback from bus drivers and other traffic safety and operations experience inputs, the threshold BOS speed and maximum speed differential should be periodically reviewed for increases as well as reductions in these speeds A lower initial maximum speed might be appropriate for arterial street BOS applications that have numerous driveway conflicts. However, New Jersey's Route 9 BOS, which has some driveway conflicts, seems to be operating safely with the 35-mph maximum speed. SORTA's inside-shoulder BOS application in Cincinnati also uses 35 mph as its maximum operating speed for its 12-foot wide shoulders.

BOS bus driver surveys that were conducted in San Diego, Twin Cities, Columbus, Miami, and New Jersey. Driver inputs, along with traffic safety experience and application of established traffic engineering principles, provide a good framework for defining BOS speed protocols. To date, traffic safety experience has been excellent, with few accidents and problems reported from the BOS communities. Most of the shoulder operations accidents that have occurred have been minor side-mirror sideswipe accidents.

The Twin Cities Team Transit BOS speed protocols have remained unchanged over the past two decades. They were defined soon after start-up by asking bus drivers how safe shoulder operations would be at various speeds. Drivers were asked to raise their hands if the speed seemed safe and Team Transit tested speeds at 5-mph increments. At 40 mph, some drivers stopped raising their hands, so it was decided that 35 mph would be a prudent maximum speed. As noted, about

90 percent of the BOS shoulders in the Twin Cities area are the minimum 10-foot wide shoulders. More recent input from MVTA bus drivers favored 35 mph (42 percent of respondents). The remaining responses were evenly split at higher and lower than 35 mph, suggesting that 35 mph is a good speed for Highway 77.

The BOS shoulders in San Diego are generally 10- to 12-feet wide. Bus drivers in San Diego felt that the 35-mph shoulder limit was good practice.

Bus drivers on Route 9 in New Jersey, an arterial BOS, felt that 35 mph was the appropriate speed threshold and shoulder-operating speed maximum.

The BOS shoulders in Miami are 9-feet, 10-inches to 10-feet wide and often without edge treatments. Some Miami-Dade bus drivers felt that the shoulders were not wide enough (26 percent) and that merging onto the shoulder or back into traffic was a problem (26 percent). Fourteen percent of the drivers responding felt that the shoulder pavement is a problem or that the seam between the travel lane and shoulder is rough. In response to a specific survey question, “Width of shoulders is adequate?”—75 percent of the drivers disagreed with the statement.

It would be illogical to define the eligibility speed threshold for using shoulders at a higher speed than the maximum speed allowed on the BOS shoulder. If speeds on general purpose traffic lanes are higher than the 35-mph maximum shoulder operating speeds, for instance, buses would operate faster staying in the general purpose lanes. Thus 35 mph speeds on the general purpose traffic lanes are also recommended as the starting point for discussion of local BOS projects.

Driver judgment is needed to estimate how fast to travel on the shoulder. Travel speeds in the general purpose travel lanes are easy for drivers to determine when they are operating in those lanes. The 35-mph threshold speed is therefore quite easy to judge. When general travel speeds drop below 25 mph, BOS drivers must estimate this speed to determine how fast they might operate while using the shoulder. A differential speed of 15 mph is equivalent to about 22 feet per second (fps). Allowing for gaps, an average car length in crawl traffic conditions might be 50 fps, or passing 100 cars per minute.

Operating Protocols

Consideration should be given to using flasher lights while running on the shoulder. The lights appear to help increase visibility of buses operating on the shoulder.

Use of the shoulder is optional, giving drivers considerable discretion, particularly during very bad weather. Bad weather, however, tends to provide the greatest travel time benefits as that is when traffic congestion is at its worst.

Driver Training

Driver training should include a presentation on the BOS project and its timeline for start-up. It should include background of BOS projects in other cities such as a video review of the Minneapolis Team Transit training video, which can be downloaded from www.dot.state.mn.us/metro/teamtransit. The video provides an excellent overview of BOS operations and the site also includes several other video clips of BOS operations. Complementary information describing local protocol differences should be presented. For example, if signage differs, or operating speeds differ, this should be included in a complementary presentation. Details of the specific BOS segment should also be covered including begin/end points and pinch points as well as traffic weaving sections at interchanges. When and how to use and not use the shoulder should be covered along with protocols for dealing with manifesting risks (use of high beams and tapping horn) and communications with dispatch.

Before an operator begins to use the shoulders with passengers on board, bus drivers should operate a bus without passengers while using the shoulders in order to allow them to acclimate to the new operation without the distractions of passengers and without risking injury to passengers. The need for the training to be accompanied by escort vehicles should be a local judgment based on the tightness of the operating environment and the level of traffic conflicts. The training should include peak traffic congestion conditions, but the training runs could be at speeds less than the 35-mph maximum.

BOS Start-up Measures

Start-up activities should be tailored to local conditions. In general they should inform riders, stakeholders, and general traffic of the new operations. Riders can be advised by onboard signs, onboard brochures, websites, and regular media news releases. Advising riders in advance will minimize panic when the buses move onto the shoulder and beginning running pass traffic. Ensuring that enforcement, maintenance, and other shoulder stakeholders are alerted in advance is recommended. Most enforcement, maintenance and emergency services agencies have in-house communications means to spread the word. General traffic can be apprised of the new shoulder operations using changeable message signs, on-ramp alert signage, and via general media. The appearance of BOS signs weeks in advance of the start-up should begin alerting for general traffic.

Before the first day of operations, the shoulder should be cleaned of debris and a final checklist or punchlist used to assure that it is ready for BOS operations. It would also be prudent to video the signage and markings along the shoulder to complement the engineering record. The media might have an interest in riding one of the training BOS trips to use in their news report.

On the very first day of operation, the multi-agency team implementing the BOS operations should discuss the need and merits of escort vehicles. It should not be necessary for buses to have an escort, but if bus drivers and other stakeholders believe it is needed, it should be considered for the first day or so.

Most people like ribbon cutting ceremonies, which are a good way to acknowledge politicians and agency staffs that brought the project to opening day.

SECTION 4

Design Considerations and Guidelines

Introduction

Because most BOS operations are retrofits into existing cross sections with little or no geometric modifications, existing design elements and guidelines should be considered, assessed, and possibly modified when considering BOS operations. This section lists some of the more critical design elements and how they may affect particular roadway suitability for BOS operations. It presents and discusses minimum effective shoulder widths, lateral clearances, interchange configurations, pavement cross sections, and drainage considerations. While the factors mentioned are the most commonly encountered, there may be other site-specific issues that must be considered for each deployment and addressed by appropriate agency staff with local knowledge of the facility, its current conditions and future plans, and relation to upstream and downstream conditions.

While BOS operations have been deployed on freeways/expressways and arterials, they involve different considerations in BOS deployment. Functional class may be the most important classification when discussing BOS operations. The amount of mobility versus the amount of access that a particular facility provides will largely determine the type of allowable BOS operation and the governing rules. For example, BOS operations on freeways are subject to more frequent interaction with higher traffic volumes on greater numbers of traffic lanes, with higher amounts of weaving and merging movements with entering and exiting traffic. They will also entail signing and pavement marking requirements that must consider overall driver (both bus and general traffic) workload and expectancy. In contrast, BOS operation on arterial-type roadways must consider operating in typically lower speed environments with more access conflicts (at driveways, bus stops, etc.) and right-of-way conflicts (at intersections) with other vehicles.

BOS operations may occur on arterials or freeways, but the criteria for deployment are fairly consistent. The Minnesota criteria, for example, are as follows:

- Presence of predictable recurring congestion as indicated by the running speed less than 35 mph for general traffic during the peak periods and/or approaches to intersections that have continuous queues during the peak hours,
- Congestion must occur one or more days per week,
- A minimum of six transit buses per day must be likely to use the proposed bus shoulder,
- The expected time savings when using the shoulder must total more than 8 bus-minutes running per mile per week, and
- The proposed shoulder used must be at least 10 feet in width but can include several pinchpoints.

Each community needs to define these criteria for its local conditions. For example, four buses per day might be accepted by other communities considering BOS implementation. Though capital costs for signage tend to be quite minor, the ongoing maintenance efforts and driver training suggests a minimum threshold of transit use to justify BOS implementation.

The shoulder of a roadway is defined as the portion of paved or unpaved surface adjacent to the travel lanes, generally reserved for emergency use and/or stopped vehicles. The shoulder may also provide lateral support for the mainlane base and surface structure (so that the mainlane materials do not "push" outward under load). Most modern roadways and highways are designed and constructed with full-depth shoulders that match the travel lanes section. However, on older facilities the shoulders may have less subbase, base, and/or wearing surface than the adjacent travel lanes. While this material may be adequate for lateral structural support, it is inadequate for long-term exposure to vehicle loading.

BOS operations should be considered on routes with existing shoulders that are judged adequate to accommodate a determined frequency of bus vehicles. Unpaved shoulders should not be considered for BOS operations and surfaced shoulders consisting of gravel, shell, crushed rock, or stabilized soils are not candidates for BOS operation. Only those shoulders deemed adequate or upgradable by a qualified pavements engineer should be considered for BOS use, even then there may be limits on the numbers or types of vehicles allowed on the shoulder. It should be noted that most BOS applications have been low-cost, low-impact means of providing transit preferences and some began as pilot or demonstration projects. As such, BOS shoulders are not always up to ideal pavement design standards, particularly during pilot testing of the concept. A shoulder is designed into the structure of a roadway to achieve the following:

- Provide pavement structural support;
- Provide a safety relief area to make evasive maneuvers to avoid crashes or reduce their severity;
- Give additional lateral clearance to signs, guardrails, and/or barriers, improving driver ease, resulting in more uniform speeds;
- Provide a stopping area for vehicles experiencing mechanical or other emergencies;
- Provide a stopping area for drivers to reference maps or directions (and, more recently, make phone calls);
- Provide additional open space for drivers, reducing stress related to the driving task;
- Provide area for maintenance, snow removal, and/or storage;
- Detour traffic during construction;
- Convey water farther from the primary roadway structure; and
- Pedestrian or bicycle use and bus stops on arterials.

BOS operations may affect the use of the shoulder for some of these functions, but only temporarily, and the impacts can be mitigated with proper operations and planning.

Design Context—Exceptions and the Liability Aspects

To meet the goals of BOS projects while ensuring safe traffic operations, design standards may require exceptions. The design exception process allows for the use of criteria lower than those specified as minimally acceptable values per the AASHTO "Green Book" and/or local design standards. However, for projects on National Highway System routes, FHWA requires that all exceptions from accepted guidelines and policies be justified and documented in some manner. This process requires formal approval for 13 specific controlling criteria (U.S. DOT/FHWA, Flexibility in Highway Design). These criteria are as follows:

- Design speed,
- Lane width,
- Shoulder width,
- Bridge width,
- Structural capacity,
- Horizontal alignment,
- Vertical alignment,
- Grade,
- Stopping sight distance,
- Cross slope,
- Superelevation,
- Vertical clearance, and
- Horizontal clearance.

When evaluating design exceptions, the following three elements should be considered:

- The effect of the variance on the safety and operation of the facility and its resulting compatibility with adjacent sections of the roadway;
- The functional classification of the road, the volume and mix of the traffic, and the crash history of the roadway; and
- The cost of attaining full standards and any resulting impact on scenic, historic, or other environmental considerations.

In addition, the following three questions should be answered:

1. What is the degree to which a guideline is being reduced?
2. Will the exception affect other guidelines?
3. Are there any additional features being introduced that would mitigate the deviation?

The use of roadway geometrics that are of nonstandard designs has the potential for being targeted in court as a result of crashes on modified sections. The transportation agency and/or professional has a strong defense if they have documented the modification process and have shown a positive precedent that was used to support the modification. When defending the modifications, it can be pointed out that current authoritative publications, such as the AASHTO "Green Book" and the *Manual on Uniform Traffic Control Devices* (MUTCD) are not the law, but are a reflection of current professional consensus, but that the publications do not create the consensus (Kuhlman, 1986).

Long before they are published in AASHTO standards, many potential AASHTO standards are published in authoritative journals. Therefore, the most timely and state-of-the-art design practices are accepted among persons in the transportation profession before they are included in any standard publication. Accordingly, agencies can often justify their design exception decisions based on expert testimony and the prior experience of others in the field, even though these views may not yet have been officially adopted. Where states have adopted by statute the AASHTO standards and the MUTCD, some attorneys have argued that deviation from these standards constituted negligence on the part of the government agency. However, most courts have rejected this argument and have concluded that standards adopted by statute are not evidence to determine if there has been a deviance from a standard of care. The court concluded that the standards do not in themselves establish a standard of care (Branch, et al., 1990).

There have been several occasions in which courts have awarded the case to the plaintiff (the motorist involved in an accident) where it is concluded that it was known by the designers that in the design of a roadway segment that the shortcomings of the design or operation might increase the possibility of the plaintiff's accident. It is important to be aware of the previous experience with narrow lane and shoulder use, and to be familiar with the operational and safety experience with these projects.

There have been no litigated cases involving BOS, but there have been cases regarding general purpose or HOV use on the shoulder. There have been several cases in which courts have ruled designs were negligent. An agency should be aware of previous litigation against it and other agencies to develop extended knowledge of the potential pitfalls of shoulder conversion (or use) projects.

It is often too easy for engineers to get overburdened with numbers. However, the transportation engineering profession is linked to the duty to serve the public. Oliver states that "tort liability law did not result from the notions of sympathy or charity towards those injured using the facilities created by the transportation engineer. It resulted from the notions of fair play and justice" (Oliver, 1987). Oliver also points out a four-point test that must be satisfied in establishing negligent conduct:

1. It must be shown that there was a duty to conform to a particular standard of conduct that would have protected the plaintiff from injury.
2. It must be shown that the defendant breached his duty. It has to be shown that something was done wrong or inadequately.
3. It must be shown a harm was caused to the plaintiff.
4. A connection must be made between the plaintiff's injury and the agency or personal conduct. This is referred to as proximate causation and is a concept that has undergone great "judicial liberalization" since the early nineteen-eighties (Oliver, 1987).

Agencies have been taken to court over accidents on shoulder-use facilities. In the 1970s and 1980s, Caltrans saw no hope of freeway reconstruction and widening due to community concerns, environmental concerns, and tight budgeting, so they converted shoulders to mixed-use lanes using these concerns as a basis for their decision. Caltrans had been ruled both for and against in these cases, but the decisions often depended on the amount and detail of engineering decisions documentation and relation to the success and experience of other similar projects (Voigt, 1994). Liability concerns may be lessened with approval from the FHWA when changing the geometrics of a federally-funded project. It is advantageous for a state or local agency to have approval from a "higher-up" when implementing changes in roadway configuration that is not to recognized standards.

In conclusion to the liability aspects of the use of the shoulder for bus operations, there are a few very important tasks on which an agency must concentrate. Maintenance and maintenance records of the roadway must be kept tenaciously, even more than normal when reconfiguration projects are implemented. In the eyes of the court, a maintained roadway is "one maintained within accepted and understood criteria, under promulgated engineering standards." Continuous inspection is necessary because negligence is "predicated on the knowledge or information of the existence of danger" (Oliver, 1987), that on a portion of the roadway there exists a dangerous condition and a failure to subsequently relieve the condition existed. The key is being aware of the condition of the roadway and documenting not only repair and maintenance activities, but operational, safety, and training records as well.

Lane and Shoulder Width

The initial critical engineering-related question when considering BOS operations is whether adequate shoulder width and adjacent lane width are available. Widths of 12 feet for travel lanes and shoulders are certainly desirable, but lane widths less than 12 feet are used in practice. Lane widths of 11 feet are used in urban areas or where right-of-way is limited. Many auxiliary lanes range from 10 to 16 feet. Shoulders may range from no width to more than 12 feet in width and may be adjacent to natural ground, safety barrier, or other physical features (cut slopes, noise barriers, etc.).

Because a typical transit bus is 8.5-feet wide, excluding mirrors, and about 10-feet wide with outside mirrors, there are practical issues that affect whether a 10-foot shoulder is adequate for BOS operations, or if a wider shoulder is necessary. These factors will vary by site and should be subject to assessment by engineers familiar with existing operations on the candidate facility. Widening the shoulder for BOS operations on bridges or adjacent to barriers (jersey barriers, curbs, etc.) is often necessary to give the transit operators some comfortable margin to the lateral obstruction. In these cases, engineers must assess whether it is necessary (and feasible) to narrow one or more adjacent general purpose travel lanes to gain an additional 1.5 to 2 feet for the shoulder. However, if significant truck volumes exist on the route, and they are found to operate in the lane adjacent to the proposed BOS route, the engineer will have to assess whether additional lane width can be taken from other lanes.

Minimum Shoulder Width

For BOS applications, the minimum lane width is governed by the width of the bus and allowance for lateral clearance to both sides. Most agencies have used 10 feet as a minimum operational lane width on straightaways with no lateral obstructions, but with an 11.5 foot minimum width on bridges or adjacent to barriers and curbs. In the Twin Cities, the minimum width for shoulder use is 10 feet, and 90 percent of their BOS lanes are this width. A 10-foot width leaves 9 inches on each side of the bus (which does not account for mirror width, which adds at least six inches).

The desired shoulder width for BOS operations may be 11.5 or 12 feet, but several agencies report that bus operators are comfortable driving on 10 foot lanes with no lateral obstructions (no guardrail, barrier, bridge rail, etc.). Some agencies have questioned whether the shoulder would have to be wider if the BOS operation is on the left should as opposed to the right shoulder, and only qualitative evidence may be used to answer that question. There have been reports that bus drivers feel more comfortable when the shoulder is wider when running on the left shoulder as opposed to the right because of the reliance upon mirrors and indirect sight lines to view adjacent traffic. The left-side shoulder may have to be wider to give the bus operator more comfort in his/her margin for error, because when running on the right shoulder the driver has more immediate access to direct line of sight to the adjacent traffic stream and it is immediately adjacent to him/her, as opposed to opposite the vehicle. The Cincinnati inside-shoulder BOS project uses a 12-foot minimum left-side shoulder and the planned I-55 BOS inside shoulder project in Chicago would use a 12-foot minimum shoulder.

It is certainly plausible that an agency might desire to limit operational speeds (and speed differentials with general flow) on those facilities where shoulder widths are minimal, as has been done in Minnesota, Georgia, Miami, and San Diego. Conversely, agencies may only want to consider operating at speeds less than 35 mph, and only consider increased speeds where the shoulders are 12 feet or more in width, and where general purpose lanes show no evidence of friction with BOS operation during the initial stages of deployment.

While there is no quantitative evidence that shoulders for BOS operations should be wider (or narrower) on arterials as compared to freeways, there is indirect evidence that operating speed and lateral clearance are the two most significant factors in preferred minimum shoulder width, and that is from surveys of bus operators. Some arterials may have allowed BOS operations with speeds greater than those on highways, and in those cases, they may need to have considered wider shoulders—especially if lateral clearances to curbs and other obstructions (landscaping, utility poles, etc.) are present. Conversely, some arterials may have BOS operational speed limits that would provide more comfortable operation for bus operators on narrower shoulder segments. With no conclusive statistical evidence upon which to rely, engineering assessments and test runs with bus operators are needed to determine whether the shoulder widths are appropriate for the given conditions. During the initial period of operations, it may become apparent that a shoulder is too narrow and that mitigating actions should occur. For this reason, it is important that a continuous assessment and improvement process be implemented to monitor operations and make changes as necessary. In addition, safe sight distances at driveways need to be considered. Common practice for motorists exiting poor sight distance driveways is to stick the nose of the car out into the shoulder area to look for traffic gaps. This results in a conflict with BOS operations.

There has been only qualitative evidence that buses running on the shoulder have little impact on adjacent lane speeds or lane keeping. Minneapolis has found that a small percentage of motorists tend to straddle the right edgeline, either unconsciously or purposely, causing the bus to slow and wait until the vehicle moves toward the center of their lane to pass. Minneapolis also reports the occasional "jealous" motorist, or ones that intentionally block the shoulder so that the bus cannot pass, but these events are not common enough to cause a safety or operational issue. Generally, transit operators will honk their horns and the offender will adjust his/her track. In San Diego, onboard video and occasional observation revealed no perceptible impacts on traffic operations when running on narrow shoulders, and no mention of drivers hugging the edgelines was made in the evaluation report.

Observations of the left shoulder BOS application of I-71 in Cincinnati found that motorists in the leftmost general purpose lane tended to favor the left side of the lane during congestion. This probably has more to do with motorists trying to see around the vehicle in front of them rather than blocking the BOS operation. Left-side shoulders might need to be 11-feet wide at minimum to account for this common driving habit. The Cincinnati I-71 inside shoulder BOS project uses shoulders with a minimum 12-foot width.

Alignments with curves should be carefully examined for the impact of vehicle offtracking to determine if the shoulder should be wider in those areas. Offtracking (where the rear wheels do not follow the same path of front wheels) becomes an issue on sharper alignments or on tighter curves with less superelevation. If the bus is traveling on the shoulder in a tight curve, additional pavement width might be necessary to keep the vehicle on the paved surface. Offtracking may not be such a concern on high functional class facilities where original design speeds were high and where the BOS operation will be limited to low speeds, but it may be of issue on turning roadways or at arterial intersections. If it is necessary for a bus to turn on a turning roadway or at an intersection on the shoulder, then checks should be made to ensure that adequate pavement width exists and that clearance from drainage structures, guardrails or barrier, walls, and/or rock cuts is adequate on both sides of the roadway during test runs of the route.

There may be some reasons to accept narrower shoulder widths for limited duration pilot tests. Therefore, agencies should carefully assess whether short segments of narrow shoulder with adjacent lateral obstructions (safety barriers, for example) are acceptable during a pilot test to reduce deployment costs. However, those agencies should also include in their due diligence process some documentation of improvements and/or mitigation necessary if the pilot program is extended after the initial testing period ends, including the costs associated with improvements and which agency or agencies would be responsible for the modifications.

Again, by their nature, BOS deployments are typically an attempt to maximize the ability for a given corridor to move people and goods better. It will likely be necessary to accept less-than-standard conditions for pilot tests, but documenting the exceptions and variances required is an important step in assessing the corridor for continuous BOS operations. It is also advisable to document what events might trigger stopping a pilot deployment until improvements are made to mitigate an unforeseen or unintended consequence of operation.

Increasing Shoulder Width by Decreasing Other Lane Widths

In some cases, the available shoulder is less than 10 feet in width, or a lateral restriction requires that the shoulder be 11 to 12 feet in width, but a BOS operation is still desired. Sometimes, agencies will consider restriping to narrow one or two of the adjacent lanes and reallocating the remaining additional width to the shoulder. This may be done, and may be acceptable, but agencies should check to ensure that unintended consequences do not result. For example, if pavement joints or gaps are currently along the lane lines and become subject to harsher loading by shifting lane locations, pavement damage may result. Sometimes, a small adjustment in parallel lanes will provide the desired shoulder width without adversely affecting the flow in the main travel lanes. Narrowing of general purpose lanes has most commonly been considered to increase shoulder widths across bridge spans. Most BOS projects have initiated operations with the narrow 10-foot wide shoulders, sometimes using pinchpoint signs to alert drivers of segments less than 10-feet wide, but seek more extensive improvements in conjunction with future highway improvements.

The impact of narrowing travel lanes has been well documented over the past three decades, and while there are minor impacts to vehicle capacity (as documented in the *Highway Capacity Manual*), the overall safety impact of these types of modifications has been generally positive when combined with BOS operations where documented (for example, in Minneapolis).

There have been several studies that have documented accident rates resulting from changes in lane width in combination with conversion of the shoulder to a travel lane, either for general traffic or to provide HOV lanes. These studies have documented sites in Houston and California (McCasland, 1978; Urbanik and Bonilla, 1986; and Bauer et al., 2007). While results have been mixed (some stretches of highway experiencing higher crash rates, some lower, and some unchanged), there is a significant difference in operating only buses on the shoulder and allowing passenger vehicles to use the shoulder as well. These crash studies generally found mixed results for most conversions, but higher crash rates with conversion of the shoulder to HOV lanes with mixed-traffic, generally thought to be caused by the speed variances between the HOV traffic and general flow. San Diego modified lane widths with no appreciable impacts to safety or operations on one stretch between Convoy Street and I-805 (about ½ mile).

Planning for Future BOS Operations in New Construction or Major Reconstruction Projects

In design, AASHTO specifies a 10-foot shoulder width along high functional class facilities, with a minimum of 2 feet under less-than-ideal conditions on lower function facilities.

Since most BOS operations are on heavily traveled, higher functional facility corridors experiencing some level of congestion, it is likely that existing shoulders on older highways that are targeted for BOS retrofitting are already fully utilizing available right-of-way widths. If new shoulders are considered for construction to accommodate BOS operations, it is likely that these should be designed to full depth and width as a transit lane. In Minnesota, it is now standard for new shoulders to be 12 feet in new construction, which makes BOS operation easier, and conversion to general purpose (or auxiliary) lanes feasible at a later date. As most road widening projects also involve reconstructing right shoulders, these shoulders are often built to full traffic and pavement standards.

Geometric and Other Features

Aside from the primary concern of BOS operation, shoulder width, several other geometric features could control operations and are subject to checks and mitigation if necessary. Lateral clearance to obstructions (including barriers and guardrail), vertical clearance, curve and superelevation features, ramps and auxiliary lanes, pavement and bridge structures, and drainage and utility concerns all play a role in safe BOS operations.

Lateral Clearance

BOS operations are, by definition, operations that will occur on portions of a cross section that will have less lateral clearance than normal travel lanes. The obstructions may come in the form of curb, barrier, guardrail, bridge piers and abutments, and other roadway features. During a due diligence investigation of a facility's suitability for BOS operations, it is critical to determine if any lateral clearance issues would present themselves as items that require physical mitigation (removal, relocation, etc.) or special attention (e.g., increasing visibility).

Curbs serve many purposes on both highway and arterial facilities: drainage control, roadway edge delineation, barrier, and the like. On some facilities it is difficult for some drivers to see the curbs at night, especially during foggy conditions or when the surface is wet. During the investigation of BOS operation suitability, agencies should particularly examine curbs to see if those curbs require removal, modification, or mitigation. With respect to buses, curbs can cause challenges (particularly with low-floor buses) in that drivers may misjudge their vehicle position relative to the curb, causing a vehicle–roadside collision. There may be instances in which curbs will have to be modified or removed for BOS operations. Some agencies may find that curbs will need additional visibility at critical locations. The use of reflectorized paints or thermoplastic markings may be used to increase visibility on curbs.

Curbs may be combined with gutters as part of longitudinal drainage systems. Inlets along the gutter are also typically provided to provide release for water off of the roadway. Gutters and inlets are of particular importance to check in terms of the affect on BOS operations as older inlets and gutters may not be structurally adequate to carry bus traffic repeatedly.

Without curbs, sideslopes will be the first geometric feature adjacent to the shoulder. Sideslopes serve to stabilize the roadway and provide a path for storm water to drain. The first critical feature of sideslopes that may affect BOS operations is the hinge point, or the point where the paved shoulder meets the earth. The hinge point is critical because this area is where a vehicle leaving the shoulder may go airborne, if only for a brief time.

The other portions of sideslopes, the foreslope and backslope, are less critical for vehicle safety, but provide recovery area for errant vehicles. If a BOS operation is proposed for a facility with sections of shoulder and direct sideslope (no curb or other structures in between), rounding at the hinge point and roadside barriers should be considered to increase the safety of buses on the shoulder. Minnesota has very clear and practical guidelines for sideslopes that may be considered for BOS facilities, though local guidelines may prevail. The Minnesota guidelines state that the bus-only shoulder maximum standard for inslopes is 1:6 (rise:run). Some existing slopes may be 1:4, where not protected by guardrail. For BOS operation, if the inslope is steeper than 1:6, the Minnesota DOT *Road Design Manual* states:

- If inslopes are flatter than 1:6, inslopes may be steepened to 1:6.
- If inslopes are steeper than 1:6, match existing, except:
  - If fill slope is steeper than 1:3 and higher than 2 feet, provide guardrail.
  - If fill slope is steeper than 1:3.5 and higher than 5 feet, provide guardrail unless there is 18 feet between the edge of shoulder and the point where the fill slope becomes steeper than 1:3.5.

Noise barriers may present a combination of issues that are covered in other sections of this report. With respect to BOS operations, noise barriers should be assessed as to their affect on properly placing BOS-specific signing, on allowing adequate sight distance (especially on the inside of horizontal curves), and on specific clearances at merge and diverge points. Some noise barriers incorporate a safety barrier configuration at the base, which may have to be delineated more carefully if lateral clearance for BOS operations is at issue.

Inside Shoulder Versus Outside Shoulder Use

BOS operations may be conducted on either the outside or inside shoulder. Most existing U.S. operations occur on the outside shoulder (Minneapolis, San Diego, Miami, Columbus, Atlanta); however, Cincinnati's BOS operation is on the inside shoulder. The Illinois DOT's planning effort for a new I-55 BOS facility is also considering use of the inside shoulder. There are a few factors that an agency should consider when deciding on which shoulder to select for BOS operations.

The most basic difference in deciding between BOS on the outside or inside shoulder is trip length. The outside (or right) shoulder is most appropriate for BOS operations characterized by shorter trip lengths, especially when entry and exit ramps are to the right, as is typically the case. In contrast, the inside shoulder (or left) may be more appropriate for BOS trips that are more long distance in nature (for example, in the case of express transit or commuter services), or when a trip might begin or terminate at a left entry or exit (to access an HOV facility, for instance).

The right shoulder is typically interrupted by interchanges that may result in more potential conflicts with entering and exiting vehicles. Yielding to entering and exiting traffic at every interchange may reduce operating speeds, resulting in potentially reduced travel time benefits.

The left shoulder may be characterized by fewer interruptions resulting in more uniform speeds and higher travel time savings. Otherwise, if transit trips are short and dispersed, weaving in and out of traffic to use the left shoulder lane will pose more conflicts and might not provide as much travel time savings. Exiting the inside shoulder is also more challenging than merging into traffic from the right side shoulder. The Cincinnati BOS project remerges buses outside of the core congestion bottleneck.

I-394, west of Minneapolis, has a half mile segment that includes BOS on the right side of the general purpose traffic lanes and a high-occupancy managed-lane facility on the left side.

Horizontal Alignment and Superelevation Considerations

Because in most BOS applications, the shoulder is located adjacent to the general purpose travel lanes, the horizontal alignment of the BOS operation will not be significantly different than the general traffic lanes. For those cases in which the BOS operation will be limited to periods of congestion only, and typically held to lower operating speeds, there should be very little issue with horizontal alignment. In some cases, where a lateral obstruction causes the operating agency to restripe adjacent travel lanes to accommodate additional width on the shoulder, the horizontal curvature may increase slightly, but would not typically violate the physics of a bus traversing a given curve.

Superelevation may be most critical horizontal alignment parameter to check on for a proposed BOS route. Most BOS operating agencies specify that the superelevation on the shoulder should be approximately equal to that on the adjacent lanes, with a specified acceptable maximum given local conditions. However, there may be some facilities on which the shoulder slope is not equal to the cross slope on the mainlanes due to drainage or maintenance considerations. This situation may be acceptable, but checks should be made to ensure that superelevation runout on the outside of horizontal curves does not cause undue discomfort for bus operators or passengers. Typically, longitudinal superelevation transitions are kept as short as possible to minimize flat grades for drainage, but some transitions might lead to a "rocking" effect when leaving the curve. This may not be an issue for lower speed operations.

Offtracking may also be a concern on sharper alignments or on those tighter curves with little superelevation. Offtracking occurs when the rear wheels do not follow the same path of the front wheels, and is covered in detail in the AASHTO *A Policy on Geometric Designs of Highways and Streets.* Offtracking might occur on tighter radius curves, or on turning roadways. If the bus is traveling in the normal travel lane, it might use the shoulder if it offtracks, however if it is traveling on the shoulder, additional pavement width might be necessary to keep the vehicle on the roadway. Offtracking may not be such a concern on higher-class functional facilities on which the BOS operation will be limited to low speeds, but it may come into play more on turning roadways or at intersections if the shoulders are to be used.

Offtracking can also occur for steeply sloped shoulders, particularly for articulated buses.

If it is necessary for a bus to turn on a turning roadway or at an intersection on the shoulder, then checks should be made to insure adequate pavement width exists and that clearance from drainage structures, guardrails or barriers, walls, and/or rock cuts is adequate on both sides of the roadway. If turning roadways are critical to the BOS operation, then 2 to 4 feet of lateral clearance should be provided for short lengths (e.g., at a channelized turn at an intersection); from 4 to 10 feet for left shoulders; and from 6 to 12 feet for right shoulders on longer lengths or in areas of cut and fill, although more narrow lateral clearance may be judged to be acceptable. This is in contrast to the minimum 1.5-foot typical lateral clearance for BOS operations on tangents or gentle curves. These distances should always be subject to checks of local conditions.

There may also be issues with shoulder slope transitions from the roadway section to bridge section. Often the slope on a roadway shoulder will be greater than in the general travel lanes in order to accelerate drainage from the roadway. On bridge decks, the shoulder is almost always part of the overall deck crown, which may approximate the slope of the travel lanes. The transition of the shoulder slope from normal cross section to bridge may be abrupt in some cases and should be checked for rideability and comfort during test runs of the route. Mitigation could include easing of the transition by adding pavement material and adding additional signing warning of the "dip" condition ahead.

Highway Interchange and Ramp Interfaces

BOS operations at on-ramps, off-ramps, auxiliary lanes, and interchanges raise some of the most commonly asked questions about BOS deployments. The answers (to date) have been remarkably simple—a majority of the time the transit agency relying on the bus operator (the professional driver) to follow a set of rules that involve, almost exclusively, him or her yielding to other traffic.

The BOS operation at interchanges and ramps is occasionally supplemented with signs and/or pavement markings, but not always. Minnesota uses signing to warn of the presence of buses on the shoulder, but does not use any dedicated pavement markings at ramps or interchanges (see Figure 4-1). Seattle uses signing as well, but uses a HOV/diamond-lane signing scheme (since carpools are also allowed) with pavement markings to delineate the HOV lane and edgelines ("skip stripe") at exit ramps (see Figure 4-2). The San Diego Pilot Demonstration project on SR-52 and I-805 has buses running on shoulders, auxiliary ramps, access ramp lanes, and direct freeway-to-freeway connector ramps. The only pavement markings used in the pilot were "TRANSIT BUSES ONLY" word markings placed in the vicinity of exit and entry ramps—typically after entry ramps and exit ramps. However, the word markings were not used where the shoulder was not to be used by general traffic as part of an exit maneuver (for example, where an auxiliary lane was provided for the exit ahead).

What the Minnesota, Seattle, and San Diego operations have in common is that they typically seek to limit the required bus movement to one merge or weave at any location. Merging

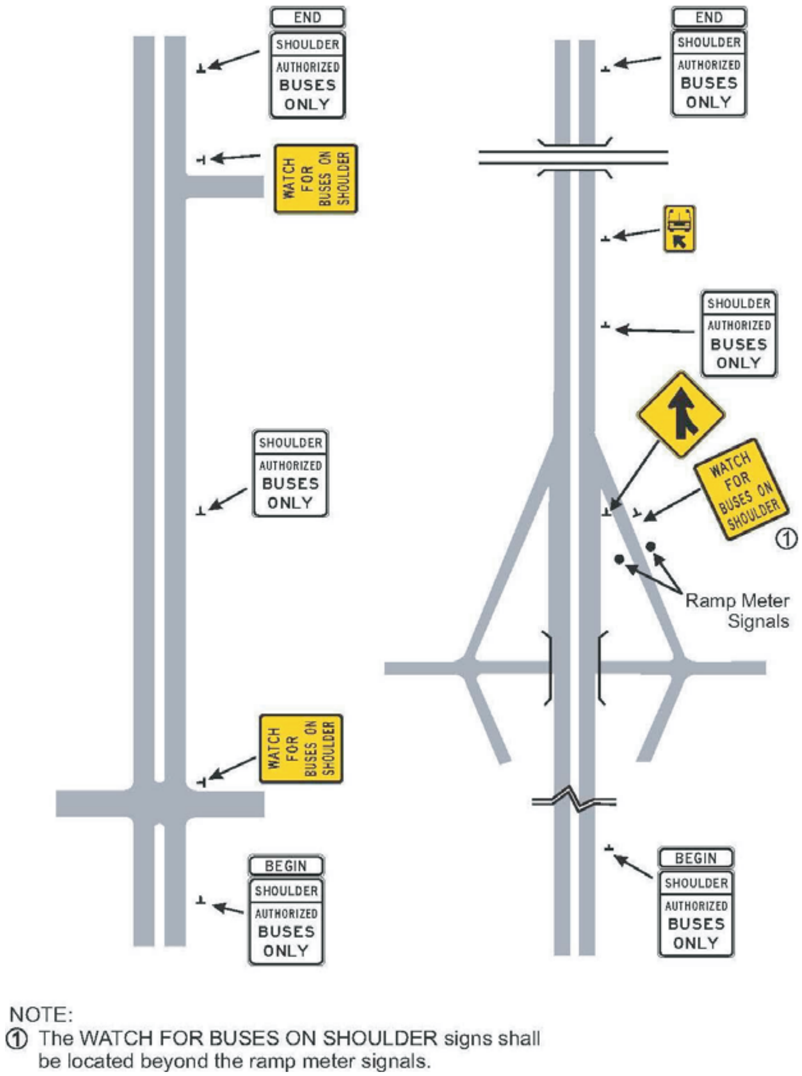


Figure 4-1. Minnesota DOT typical shoulder signing plan for bus on shoulder use (freeway only).

or weaving more than one lane to avoid a ramp or interchange feature may be problematic for buses, especially considering their size and operational characteristics. Operating the BOS in congested conditions, at slower speeds, with limits on the variance between buses and general traffic flow, serves to address many of the concerns of engineers, transit operators, and law enforcement in these situations. As speeds reduce, distances covered during driver's perception and reaction time reduces, contributing to an increased margin of safety during maneuvers through interchanges and ramp areas.

Minnesota also tries to avoid BOS weaving conflicts with on and off-ramps serving 1,000 or more vph during the peak congestion hours. Some ramps serving BOS segments, however, have increased to more than 1,000 vph.

Entry Ramps

Most BOS operating agencies clearly specify that the bus driver is to yield to other vehicles entering the traffic stream from entry ramps or direct connector ramps. This is good policy, not

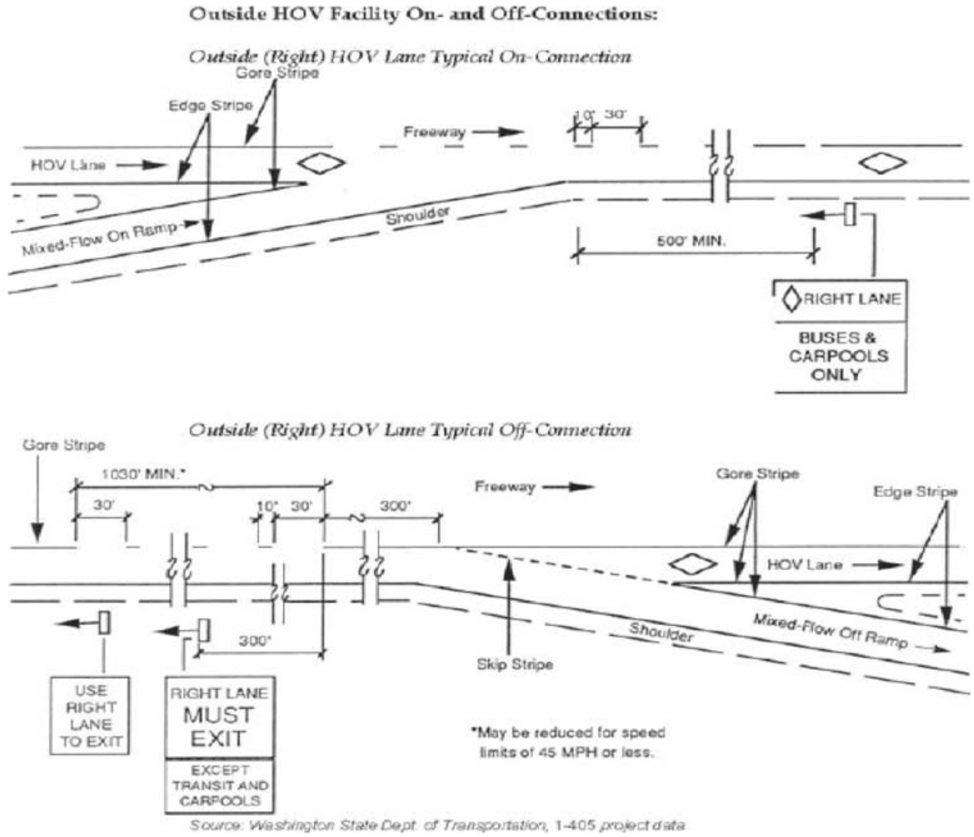


Figure 4-2. Washington State DOT transit/carpool lane signing and pavement marking layouts.

only because the bus driver is in a unique position seated higher above most vehicles (able to view the traffic stream and anticipate the merging and weaving movements of other vehicles), but presents a courteous, non-threatening, and friendly approach by the transit agency when using the shoulders as a privilege.

Some entry ramps may have geometry such that the bus on the shoulder cannot see those vehicles entering the highway on the ramp. Geometric conditions in which the entry ramp is hidden by retaining walls, or is positioned closely to the shoulder, will not allow much advanced warning for the bus driver of a vehicle on the ramp. Unless the entry ramp leads to a lengthy section of acceleration or auxiliary lane, this condition may warrant a reduced speed of buses on the shoulder where adequate stopping sight distance is achieved. If adequate stopping sight distance cannot be achieved for the operating speeds of the BOS, then consideration should be given to merging the bus back to the general purpose lanes in advance of the entry ramp merge to the mainlanes.

Where sight distance is adequate given typical operating speeds, entry ramps should have warning signs posted on the ramp which warn motorists of buses using the highway shoulder. Most typically used is the "WATCH FOR BUSES ON SHOULDER" message, with black text on yellow background on a warning sign. The Minnesota DOT version of the sign is rectangular, but the sign could be a standard diamond shape as well.

During heavy traffic periods, entry ramps may also experience high traffic volumes. The gaps available for a transit vehicle to continue its trip on the shoulder may be very small if ramp volumes are very high and traffic is entering the highway in tight platoons. In these cases, ramp metering may be a viable and effective method to increase the available gaps in traffic so that transit vehicles on the shoulder have a higher probability of meeting an acceptable gap as they approach the entry ramp. Ramp metering has its own set of operational issues; however, and traffic engineers should be consulted to assess the feasibility to meter entry ramps on a case by case basis.

After the entry ramp merges into the general purpose lanes there should be some indication that the shoulder remains useable only for authorized vehicles. Signing and pavement markings are typically used to indicate that the shoulder is for transit or authorized vehicles only from the merge point forward. All implementing agencies have used signing to convey these messages, but some have used word pavement markings to provide supplemental messages. Figure 4-2 shows the Washington State DOT example, but San Diego used signs and word pavement markings ("TRANSIT BUSES ONLY") instead of the diamond beyond where vehicles were supposed to have completed the entry merge to the general purpose lanes.

Auxiliary Lanes and Lane Drops

Auxiliary lanes can provide relief to BOS operations but in some cases can complicate the movements required at ramps to align with downstream shoulders. One of the clearest benefits of auxiliary lanes is at one-lane exit ramps. Providing the auxiliary ramp on the shoulder has the disadvantage that it makes that part of the roadway available for use by all vehicles, but it also provides a specified distance where buses and general traffic can merge together in advance of the gore point—reducing the chances that a late merge at the ramp gore causes a bus/vehicle conflict or collision. For this reason, exit ramp auxiliary lanes are recommended for BOS operations where space and funding permit.

Exit Ramps

Some off-ramps back up onto the main line freeway during peak travel times due to capacity shortfalls at the off-ramp's intersection. These spillback conditions can occur during peak commute times and for special event traffic conditions. When traffic spills back onto the main line, it complicates BOS weaves across the off-ramp. This can either lead to BOS bus delays or BOS weaves farther upstream from the ramp. If possible, the off-ramp capacity should be increased to mitigate this problem. In some cases, this may require adjustment in traffic signal timing.

Dual Exit Lanes

It is almost certain that where the BOS operation approaches a two-lane exit, the bus will be required to re-enter the general purpose lanes when continuing through the junction. The issue is often how far back the bus will have to re-enter the general flow of traffic based on the operational rules set forth by the transit agency. One or two merge/weave movements will be required by the BOS operator when approaching the dual exit, depending on the configuration of the outside exit lane and whether it has an auxiliary lane, or if it directly feeds from a travel lane (a true lane drop):

1. If the outside exit lane originates from an auxiliary lane added at some point upstream of the ramp, this condition causes two required movements of the bus: 1) merge with traffic entering the auxiliary lane, then 2) weave into the general purpose lane that is the optional through-/right-lane ahead. The bus cannot remain in the auxiliary lane and continue past the exit ramp as it will conflict with traffic exiting to the ramp from the rightmost general purpose lane. This conflict forces the bus to weave to the left, into the rightmost general purpose lane.

The bus may then re-enter the shoulder lane once past the dual-lane exit ramp gore point (if not exiting).

2. If the rightmost general purpose lane is the lane drop at the exit, with the next outside lane optional through and right, the bus must merge to the lane that drops, then weave into the shared through/right lane. Once past the exit ramp, the bus can re-enter the shoulder to continue operation.
3. If the two right lanes drop, the bus must maneuver into the leftmost right exit lane if it leads directly to the continued shoulder operation.

Dual Entry Lanes

Where the shoulder lane approaches dual entry ramp lanes, the BOS operation depends greatly on what happens at the next ramp juncture. The basic guidance would be for the bus to consider one of two movements, as follows:

1. Weaving within the entry ramp area to align with the downstream shoulder lane, while minimizing the number of lane changes necessary to do so; or
2. Postponing the weaving movement (continuing in the added entry lane) back onto the shoulder until a point past the entry area in order to minimize the impact on merging and weaving movements.

The choice of which action to take depends largely on the traffic volumes entering on the entry ramps, the ease with which the weaving movements can be made by the bus, the distance to the next ramp or interchange, and the comfort of the bus driver in making the movements. Some drivers may prefer to merge back to the general purpose lanes before a complicated interchange or ramp configuration, and, in most cases, that should remain an option.

Other Interchange and Ramp Considerations

In congestion conditions, late weaving and/or merging movements are not overly problematic. The weaving distances required for these types of movements increase if the buses are allowed to operate at higher speeds. If BOS operations allow for higher speeds (60+ mph) then engineers and transit operators should carefully consider the merging and weaving distances required at the operating design speed and sign for those movements accordingly. At higher speeds, the desired weaving distances may be 800 to 1,200 feet per lane, with preferred minimums of 2,500 feet per lane to minimize the impacts on the general purpose lane. These desired and preferred minimums may vary by site depending on various geometric and operational factors, including bus operational characteristics, heavy vehicle percentages in general traffic, and grade.

BOS operations may cross or incorporate freeway-to-freeway connector ramps in their routes. The San Diego demonstration project used two direct connector ramps in its operation. In these cases, there are operational considerations in play very similar to those at the entry and exit ramps, particularly those of dual-lane ramps. The key consideration is to align the bus through the interchange with as few weaving or merging movements as possible, while eliminating direct conflict points that may arise due to multiple lane entries or exits or by shared through/exit movements. As retrofit deployments, these conflicts may ultimately be eliminated by moving the bus back into the general flow of traffic, which may be the most conservative approach at complicated interchanges. BOS operations may also take advantage of using the shoulder on freeway-to-freeway connector ramps to bypass congestion. There are a few considerations when addressing the use of direct connector ramps for BOS operations. Connector ramps are typically curves, so much more care must be taken by the bus operator in traversing the alignment. The connectors often merge directions of travel together before merging with the mainlanes, and the shoulder may be eliminated at the merge point, or the shoulder may shift one lane, causing a significant disruption in flow. A significant number of connector ramps are elevated, and bus operators and passengers may feel uncomfortable being so close to the edge of the bridge while going around a curve.

Another topic of interest among some operators is the potential differences between overpass and underpass interchanges with respect to BOS operations. When the design of the roadway facility was completed, the decision to take the highway or major roadway over or under the crossing roadway is often based on functional classification, but what most commonly controls the vertical alignment is topography and economics. With respect to BOS operations, overpasses and underpasses have the following considerations:

- Underpasses may or may not impact BOS operations. If lateral clearance is restricted then wider shoulders may be required (11.5 feet instead of 10 feet) to provide more comfort for bus operators. Vertical clearance should also be checked to ensure that structures or attachments will not be subject to a bus collision.
  - Lateral clearance—the minimum clearance at underpasses will vary depending on the original design and what criteria controlled the design. Typically, underpasses will have a rigid barrier on each side of the traveled way and shoulder to accommodate bridge columns for the structure overhead, but some modern underpasses will be crossed with a continuous span with no lateral obstruction to the left. In these cases the lateral obstruction is controlled by the design of the median. On the right, the lateral clearance is typically controlled by a guardrail, barrier, or integral-barrier wall structure. Some agencies place signs in advance of overpasses to warn bus operators of restricted lateral clearance and the need to merge back into the general purpose lanes.
  - Vertical clearance—the vertical clearance is usually governed by policy, with typical minimum clearances of 14.5 to 16.5 feet on major routes. Some arterial routes or parkways with truck restrictions may have limited vertical clearance, down to 12.5 feet in some cases. Pavement resurfacings over time may shorten these clearances, so checks of the clearance on the shoulder should be made prior to bus use on a regular basis. For arterial BOS projects, tree limb obstructions should also be considered.
  - Sight distance from a bus to an entry ramp located after the underpass may be limited due to the separation in grade and any walls or vegetation in the gore area. The maintaining agency may need to take provisions to provide as much sight distance as possible by trimming vegetation or by providing ramp metering to increase available gaps in entering ramp traffic.
- Overpasses typically may only impact BOS operations with restrictions in lateral clearance brought on by proximity to bridge railings. In most cases, BOS operators have prescribed minimum shoulder widths of 11.5 feet on bridges and overpasses to overcome the discomfort that many bus drivers have when driving on these structures. Sight distance is generally not an issue on overpasses as the bus is higher than exiting or entering traffic.

Pavement

The consideration of BOS operations must take into account the condition of the pavement and surface type and suitability for BOS operations. Pavement suitability will depend on many factors, including number of projected bus trips and type of vehicles, existing subgrade, base, and surface depths and materials, pavement age, and drainage characteristics. How well the pavement has been maintained plays an important role as well. This assessment will also depend on how the BOS operation will cross bridges—whether buses will use the shoulders or general purpose lanes for bridge sections.

Pavement Thickness

State and local transportation agencies, either using internal experts or by contracting with consultants, should assess the suitability of a pavement cross section to accommodate the specified amount and weight of bus traffic. Agencies should assess whether the proposed pavement surface will retain its shape, dimensions, and edges with bus traffic, and that any gaps between the mainlane and shoulder are of acceptable width, and if they will have a propensity to widen. Typically, the maintaining agency will have a materials engineer responsible for inspection and assessment of pavement condition, and that individual would be key in the determination of the suitability of the pavement for carrying the anticipated bus traffic on the shoulder.

Experience from other BOS operations, specifically Minneapolis, indicates that occasional use of the shoulder by buses is likely not a cause for concern of most shoulder structures. But as the number of buses increase the potential grows for damage to occur. As of 2007, only one shoulder had been replaced attributable to BOS operations in Minnesota, but others had been repaved, reinforced, or widened. Minnesota now specifies a seven inch shoulder pavement depth to reduce the amount of maintenance required and increase shoulder life. The lower speed operation in Minnesota certainly benefits shoulder pavement longevity. BOS operations that allow higher speeds may see shoulder pavements degrade more rapidly as the pavement structure must absorb more energy.

For bridges to accommodate BOS operations, the shoulder must be checked to ensure that it is structurally adequate. These checks should include whether the structure is capable of carrying legal loads, including buses, and that the bridge is not on any list of structurally inadequate bridges. However, the fact that the bridge is not listed on any list of structurally inadequate bridges does not relieve an agency of checking to ensure that the shoulder of the bridge can accommodate the static and live loading associated with buses using the shoulder.

Pavement Slope Requirements

One key factor in the suitability of shoulders for bus use is in the difference of shoulder slope versus traveled-way slope. This may be a condition found on curves with higher amounts of superelevation. Often a different grade for each is used (with more slope on the shoulder) to drain water away more quickly. Most modern designs will limit this algebraic difference in slope to about six or seven percent maximum. At differences greater than 7 or 8 percent, an agency might consider modifying the grade break to a rounded shape, instead of a hard break.

Pavements with rutting or edge wear should be examined closely for repair and suitability. Weather will also play an important role in determining the suitability of existing pavements for BOS operation. Skid resistance is also of concern on shoulders and should be checked if the engineer feels that the pavement may be deficient in that respect. There is a minimum level of skid resistance required to hold any vehicle on curvature, and the most common impediments to good friction and skid resistance are rutting, polishing, bleeding, and dirty pavements (AASHTO, *A Policy on Geometric Design of Highways and Streets*). Each of these should be checked initially when considering BOS operations and then periodically if BOS operations are deployed. There are very few mitigation measures for skid resistance other than reconstruction or overlay, but this issue is unlikely to occur on the shoulder unless it has been subject to high volumes of traffic previously.

During evaluation of pavement structure some agencies may determine that an existing cross section is suitable for a given duration (1 to 2 years, perhaps) with frequent inspections necessary to ensure that the surface is capable of continuing service. This type of BOS operation may be on a pilot basis, or on a temporary basis, until some repairs take place, but where the transit advantage is important. Some transit and highway agencies may consider minimal patching and repair as "part of the cost of business" until a full repair is programmed, and may decide to share in the cost of maintenance and repair.

Drainage and Utility Considerations

Drainage is a key consideration when assessing and maintaining a BOS operation. Drainage facilities may include a combination of treatments, incorporating culverts, curbs, channels, gutters, and many types of drains. Vehicle operations may also be degraded by water standing in ruts, joints, or uneven pavement.

In some cases there may be drainage or utility structures located on the paved shoulder. During the assessment of the shoulder for use by buses, checks should be made to ensure that conflicts with above-ground drainage and utility structures are mitigated. Drainage is very local in calculation of design capacity. Many operating agencies have their own guidelines, standards, and specifications for drainage capacity and structure.

In many cases, drainage from the roadway occurs by draining flow down vegetated slopes to roadside (or median) drainage channels. Other structures (curbs, flumes, dikes, inlets, chutes, etc.) may also be used to channelize the flow to minimize erosion. In these cases, mitigation for BOS operation is unlikely, but checks should be make for ponding or other disruption in quick and orderly flow of rainwater discharge during feasibility checks. There may be parts of shoulder sections that "dip" toward drainage channels to increase flow. These sections may or may not affect BOS operations, but operators and agencies should be aware of their presence as they may be subject to additional standing water. In these cases, additional edge of pavement delineation may be warranted.

It is more likely that curbed sections along the edge of a highway or arterial become more problematic to BOS operations with respect to drainage. Inlets come in many designs and configurations, with some variations being more suitable to repeated bus loads. Some inlet designs also provide smoother rideability. The Minnesota experience was that buses riding over catch basins provided not only a rough ride for passengers but caused damage to the catch basins themselves. Minnesota DOT subsequently developed a catch basin design specifically for use on BOS routes. The design differed from the old design by incorporating a concrete apron around the catch basin, and bringing the structure flush with the pavement. Minnesota DOT acknowledges that this configuration reduced the capacity of the inlet slightly, but did not indicate that this was a problem.

Rutting may also be problematic for BOS operations. If the shoulder is rutted there is more potential for hydroplaning or splashing vehicles in the adjacent lane. This condition should be considered in the initial assessment of the use of a particular stretch of shoulder and during periodic inspection of the shoulder once it is being used for BOS operations.

If drainage is problematic, many agencies specify that bus drivers should judge whether or not to drive the shoulder during inclement weather or when the potential for flooding along the shoulder is present. For example, San Diego does not allow BOS operations during periods of heavy rain due to the potential for flooding of shoulders.

Utility Considerations and Vertical Clearance

For most cases, utilities within the right-of-way will not have significant impacts on BOS operations. However, any maintenance or construction of utilities may affect BOS operations. There are some cases in which utilities will be attached to existing structures (conduit to bridges, for example) and checks to ensure adequate clearance should be made. If necessary, interference from above-ground utilities should be mitigated prior to BOS operations. Some agencies have placed warning signs in advance of reduced clearance for various roadway features, including the sides of bridge structures or utility conduits attached to the structures themselves.

Structures over the shoulders or mainlanes of interstate or controlled-access highways are designed to meet minimum vertical clearance requirements. The vertical clearance of a truck would typically govern bridge clearance, but in some cases where truck clearance was not accommodated (some bridges and tunnels), the agency would have to ensure that a bus has adequate clearance. The standard of 16.5 feet is typically used for the freeway lanes and most shoulders will clear at this level. However, in situations of restricted vertical clearance, a minimum of 14.5 feet is acceptable per the AASHTO "Green Book," which includes allowance of 6 inches for addition of pavement for future resurfacing (AASHTO, *A Policy on Geometric Design of Highways and*

Table 4-1. Minnesota DOT critical design elements summary table.

Critical Design Element	Minnesota DOT Standard for Shoulder Use by Buses	Reference: Minnesota DOT *Road Design Manual** (and others)
Design Speed	35 mph is the maximum speed for buses traveling on the shoulder	Table 4-4.03A (Minnesota Statutes, Chapter 169, 169.306)
Shoulder Width (Right Shoulder Only)	10 feet minimum 12 feet desirable	Table 4-4.03A
Bridge Shoulder Width (Right Shoulder Only)	11.5 feet minimum 12 feet desirable	Table 4-4.03A
Horizontal Clearance to Obstructions	0 feet	Table 4-4.03A, Section 4-6.05
Bridge Structural Capacity (1)	All new bridges to have HS-25 minimum design load	Chapter 9, Section 9-2.0, Table 4-4.03A
Stopping Sight Distance	250 feet minimum	Table 2-5.09A Table 4-4.03A
Horizontal Alignment, Radius	Match existing roadway	Table 3-4.02A or Table 3-2.03B
Grades, Percent	Match existing roadway	Table 3-4.02A
Inslopes (2)	1:6	Table 4-4.03A
Vertical Alignment, K Value Crest Sag	 Match existing roadway Match existing roadway	 Figure 3-4.04A Figure 3-4.04D
Normal Cross Slope	0.02-0.05	Table 4-3.01A
Superelevation	0.06 maximum	Chapter 3, Section 3-3.0
Vertical Clearance Highway Under Bridge	14 feet	Table 4-4.03A

*http://www.dot.state.mn.us/tecsup/rdm/index.htm

Table Notes:

1. Bridge Structural Capacity—The standards call for an HS-25 design load for new bridges. For existing bridges to allow shoulder use, the shoulder must be structurally adequate (capable of carrying legal loads and does not appear on the inventory of inadequate bridges).
2. Inslopes – Existing inslopes are as steep as 1:4, where not protected by guardrail. The bus-only shoulder standard for inslopes is 1:6 (rise:run). If the inslopes are steeper than 1:6, Minnesota DOT's *Road Design Manual* calls for the following actions: If inslopes are flatter than 1:6, inslopes may be steepened to 1:6. If inslopes are steeper than 1:6, match existing, except: If fill slope is steeper than 1:3 and higher than 2 feet, provide guardrail. If fill slope is steeper than 1:3.5 and higher than 5 feet, provide guardrail unless there is 18 feet between the edge of shoulder and the point where the fill slope becomes steeper than 1:3.5.

Other considerations:

- All existing shoulders proposed for bus use must be of sufficient pavement strength and must be inspected by the District Materials engineer prior to use.
- Concrete bus shoulder design will typically match the mainline pavement and subgrade thickness.
- Bituminous bus shoulder design has a wide range of variability due to subgrade conditions. Required pavement thickness can range from 4 to 12 inches with a gravel base of 8 to 12 inches.
- Embankment cut and fill area excavations can add significantly to the overall project cost if widening and inslope adjustments are needed.
- Drainage structures need to be evaluated for structural integrity before bus use is permitted on shoulders. Oftentimes curb and gutter will need to be replaced with a thicker, reinforced section.

Streets). If an overcrossing road is widened the cross slope on the overpass may result in reduced clearance at the edges of the roadway.

In some cases, utilities or transportation agencies will have pull boxes or utility service lids (manholes) within the shoulder area. These features should be inspected for the ability for buses to travel over them and modified as necessary. It may be necessary to bolt or weld the lids shut to prevent them from opening under load. Storm sewer lids may also need to be bolted or welded shut, especially if they have the potential to lift during heavy rain events.

Checklist for Shoulder Use by Buses: Geometric Design Standards

The Minnesota DOT developed a Critical Design Elements Summary Table for geometric design elements that are most directly and commonly affected by BOS facilities (see Table 4-1). This example checklist is presented for multilane, high-speed divided urban highways. The table includes the design element, Minnesota DOT standard for shoulder use by buses, and reference. Reference is typically to give the table or figure in the Minnesota DOT Road Design Manual with pertinent information. While this table may not contain a comprehensive list of all possible geometric elements possible, it does a very good job at highlighting the most applicable elements that should be considered in a typical BOS implementation on a highway facility. The table provides a good point of departure for developing local design guidelines for BOS implementation. Individual agencies can adapt the table to meet their specific needs. It highlights the key geometric elements that should be considered in developing BOS treatments along freeways and major arterials.

Other potential non-geometric BOS due diligence checklist items include the following:

- Documentation of existing facility/route speeds, allowable bus operating speeds, and estimated transit advantage. Documentation of allowable operational parameters, particularly maximum allowable differential speed.
- Signing and marking plan.
  - Removal or relocation of rumble strips, as necessary.
  - Scheduled assessments of the BOS operations, including signing and marking adequacy.
- Implementation of ramp metering to increase and/or create more consistent gaps on entry ramps (if it does not currently exist).
- Checks of stopping sight distance adequacy, based on maximum bus operating speed, particularly at on-ramps.
- Policy for buses to re-enter the mainlanes if the shoulder is blocked for cause, including disabled vehicle, incident, construction, hazard, weather, law enforcement use, emergency, or any other reason. Buses must typically always move to the travel lanes to pass the obstruction. Minnesota uses a "two light pole rule"—that the bus must move to the general purpose lanes within about 1,000 feet of an obstruction, or about two light poles distance away.
- Bus drivers receive special training for BOS operating rules and always have discretion whether or not to invoke the privilege of using the shoulder for congestion bypass.

SECTION 5

Traffic Operations Guidelines for BOS Operations

Introduction

This chapter discusses the factors related to traffic and incidents during BOS operations. A significant portion of the chapter is focused on the state of the practice and recommendations for signing and pavement markings for BOS operation. Other topics include discussions of safety, incident management, operations in work zones, and the use of intelligent transportation systems (ITS).

Most communities have found that BOS operations are categorical exclusions under National Environmental Policy Act (NEPA) and not in need of extensive environmental studies. While in most cases the BOS operation generally replaces bus operation on adjacent general purpose lanes during peak congestion times, environmental issues should be considered in the due diligence stage. Some states and localities may have more stringent requirements to examine the environmental impacts of changes in operations, and while potentially difficult to quantify, both air pollution and noise pollution would be positively affected by BOS operation since it provides incentive for some drivers to change from single-occupant vehicle (SOV) to the transit mode and reduces braking and accelerating for buses. The amount of noise pollution will vary with the design vehicle, pavement surface, and highway design, but should be considered in BOS planning. BOS projects tend not to be controversial and are largely supported by environmental groups favoring increased transit use. As such, detailed environmental analyses and clearances have not been employed to implement BOS projects.

Most bus drivers are trained to maneuver their vehicles in all types of traffic conditions, but drivers of buses on shoulder should be especially in tune to the control elements of lane placement, speed, steering, and vehicle following. Since some BOS operations will operate on shoulders that may be narrower than a typical travel lane (or with lateral clearances less than normal), bus drivers must use another level of decision making than normal drivers might. For this reason, it is important that during any assessment of the suitability of a shoulder lane for bus operations that bus drivers be advised and their assessments sought as well. This is especially critical with respect to the information systems that are to be provided with BOS operations, including necessary traffic control devices (signing, markings, and delineation) and warning systems in assessments of sight distance, alignment, grade, and lateral clearance.

Most BOS projects to date have successfully used minimal signage and markings. Collaborative use of engineering judgment by partnering agencies has been the norm on most BOS projects to define signage and pavement marking needs tailored to the needs of the BOS operating environment. The information on signs and pavement markings presented in this chapter is intended as background for these collaborative efforts and for projects that are longer term tests or permanent installations. Temporary use of buses on shoulders as a result of major incidents or during construction activity does not allow for extensive signing and markings.

Signs and Pavement Markings

Signs and pavement markings play an important role in BOS operations, since they provide information to both buses and other vehicles sharing the roadway. To date, their use has been very simple to match the retrofit nature of a majority of BOS deployments. In general, signs used have had two purposes, as follows:

1. To regulate: Delineate the distance over which BOS is allowable, and, in some cases, the allowable times of BOS operation and eligible users and
2. To provide warning: Advise about the presence of buses using the shoulder and/or the merging movements associated the BOS use.

Pavement markings are sometimes used to supplement BOS signing, and some pavement markings provide enhanced delineation of the shoulder at entry or exit ramps on highways, or at driveways on arterials. Most BOS applications have not found the need for special pavement markings.

The key issues associated with the signing and marking of BOS operation are typically as follows:

- Whether or not to sign with a "diamond-lane" signing scheme—this is typically done only if high-occupancy vehicles (HOVs) are allowed to use the lane in addition to buses. Such mixed operations are rare for BOS facilities.
- What language to use on the signs to designate the lane:
- To designate the lane as a "SHOULDER."
- To designate the lane as a "TRANSIT LANE."

The designation as a shoulder lane or transit lane is usually tied to the language specified in the enabling legislation.

- What language to use on the signs to designate allowed vehicles:
  – "AUTHORIZED BUSES ONLY."
  – "BUSES & CARPOOLS ONLY."
  – "BUSES & HOV ONLY" OR "BUSES & 3+ HOV ONLY."

Most BOS operations have used "AUTHORIZED BUSES ONLY" as a means to designate that only buses from entities preauthorized and driven by drivers specially trained to use the shoulder lanes are allowed to do so.

- Should warning signs be diamond shaped (mounted on point) or horizontal rectangular signs?

Warning signs generally should be diamond shaped (mounted on point).

As mentioned above, both regulatory and warning signs are typically used for BOS facilities. Regulatory signs instruct road users of what they are to do (or not to do) under certain conditions. In the U.S., regulatory signs are generally rectangular shaped, with black text on a white background. Warning signs indicate hazards ahead that may not be immediately apparent to drivers. In the U.S., warning signs are typically diamond shaped signs with black text on yellow backgrounds. While there are examples of signs and markings used in other BOS projects, deploying agencies should ensure that signing and markings comply with the font and text requirements of the latest version of the MUTCD in effect at the time of the project design.

The MUTCD, issued by the Federal Highway Administration, specifies the standards whereby signs and pavement markings are designed and installed. However, readers will not find signs and pavement markings used in BOS deployments in the 2009 MUTCD. These signs are not standard signs and are subject to approval by the FHWA through the experimentation process (with details available on the FHWA website or through technical assistance from a FHWA Division Office).

The approval of the signing and pavement marking plans as part of a BOS deployment will likely be part of an overall review and approval process by FHWA and FTA. The experimentation process requires an evaluation of the traffic control devices to be tested, and the evaluation of the BOS deployment may include an evaluation of the signs and markings as a subsection.

In general there is no difference in the signing and pavement markings needed to support BOS operation, whether the lane is to the left or right of the general purpose lanes. Compliance to the MUTCD and/or engineering judgment is critical to the correct application of the signing and markings to convey the necessary messages to both drivers of buses and other vehicles. The only difference is that facilities to the left of general purpose lanes may need less signing and markings because fewer conflict points may be present.

Signing used by implementing agencies has been developed for use for BOS operations outside of the existing MUTCD and approved on an experimental basis, but use the MUCTD guiding principles for warning and regulatory signing. Some of the applicable sections from the 2009 Edition of MUTCD are as follows.

Regulatory Signs for Preferential Lanes

This section of the MUTCD provides information about signing for preferential lanes, including lanes designated for special traffic uses, including HOV and buses, among others. Preferential-only lane assignments may be made on a full-time or part-time basis. The preferential lane sign spacing should be determined by engineering judgment based on "prevailing speed, block length, distances from adjacent intersections, and other considerations." These are signs along the route that are typically intended to reinforce the use of the shoulder lane for buses only.

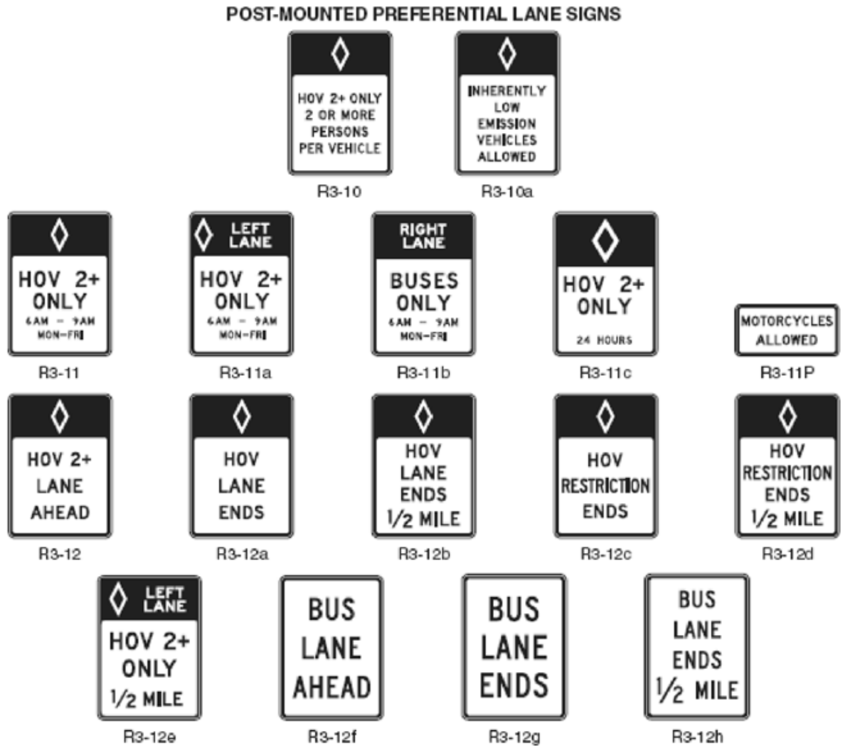
Figure 5-1 shows examples of both ground-mounted and overhead preferential lane signs as shown in Figure 2B-7 in the MUTCD. Sign R3-11b might be applicable to BOS use, if modified to read "SHOULDER" instead of "RIGHT LANE". The text on the R3-11b might also be modified to include "AUTHORIZED BUSES ONLY" text to satisfy legal requirements. The time and day of operation shown on the R3-11b would be optional as well in some cases.

The MUTCD states that "the symbol and word message that appears on a particular Preferential-Only Lane sign will vary based on the specific type of allowed traffic and on other related operational constraints that have been established for a particular lane, such as an HOV lane, a bus lane, or a taxi lane."

Section 2G.01 of the MUTCD restricts the use of the diamond symbol to HOV lanes only. Unless a BOS operation is mixed with carpools, the requirements for guide and regulatory signs in advance of all preferential-only lanes on freeways may not apply. Section 2G.01 of the 2009 MUTCD (Preferential Only Lanes for High-Occupancy Vehicles) does not apply to BOS-only operations, but may apply for combined HOV and bus operations on the shoulder (rare). This section also contains guidance on the legend text and supplemental use of changeable message signs (CMSs) to support the preferential-lane only signs if an agency deploys CMS in support of BOS operations.

Signing to Start and End BOS Operation

Signing to designate the beginning and end of authorized BOS use is deployed as a means not only to provide information to motorists that buses will use the shoulder along a designated route, but also to legally define the allowable portion of a highway on which authorized buses are allowed to travel. Agencies have typically designated the start and conclusion of allowable BOS use by using supplemental "BEGIN" and "END" plaques placed with their standard regulatory signing. These signs are regulatory, not warning signs, and are black text on white background.



Manual for Uniform Traffic Control Devices for Streets and Highways – 2009 Edition by American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

Figure 5-1. Examples of preferential-only lane signs (2009 MUTCD).

Signing Along the Route

Signing along the BOS route consists of both regulatory and warning signs. The regulatory signs are generally used to 1) provide confirmation of the allowable shoulder use by buses along the stretch of roadway and 2) to indicate a control condition on approach to a BOS facility. The confirmation signs are usually the same signs used to designate the beginning and end of the BOS lane, but without the supplemental “BEGIN” and “END” plaques. These signs are placed 300 to 1000 feet beyond entry ramp merge points, then, at minimum, ½-mile intervals or at least once between signalized intersections on arterials. Operating speeds do not necessary dictate spacing of these regulatory signs, but more often access points (entry ramps on freeways or driveways/cross streets on arterials) determine how often to place these regulatory signs.

Most commonly “YIELD TO BUSES ON SHOULDER” or “STOP FOR BUSES ON SHOULDER” supplemental plaques are added to yield or stop signs on the cross-street approaches (streets or driveways) on non-access, controlled facilities. Agencies may consider the use of a supplemental plaque with the name of street containing the BOS facility as needed.

Warning signs are also used to warn drivers of the potential for buses to be operating on the shoulders. In addition to the standard W4-1 (MERGE AHEAD) sign placed on the mainlanes before on-ramps, some agencies use a warning sign, with black text on yellow background, stating “WATCH FOR BUSES ON SHOULDER” on the on-ramp itself. This sign is typically placed on on-ramps in advance of the merge point, with the placement distance dependant on operating speeds on the on-ramp.

Optional “bus-only” warning signs may be used to inform bus drivers of points along BOS segments where they may need to be aware of restricted lateral clearance or locations where they need to merge back to mainlane traffic, such as near the end of the lane or approaching complicated interchanges. In Minnesota, these signs are small, black on yellow signs with bus graphics. They may be supplemented with arrows (indicating the need to merge back to general traffic) or other messages (e.g., warning of clearance) as necessary.

Washington State uses signing for shoulder use for HOV and buses, but these signs could be modified for BOS use. In the case of Washington State, the exiting traffic from the general purpose lanes must mix with transit and HOV lane traffic to access the exit ramp. "USE RIGHT LANE TO EXIT" signs are posted more than 1000 feet in advance of the exit ramp, with "RIGHT LANE MUST EXIT—EXCEPT TRANSIT AND CARPOOLS" signs posted about 300 feet before the exit ramp gore point. This type of sign could also be used for bus on shoulder-only operation (e.g., RIGHT LANE MUST EXIT—EXCEPT TRANSIT BUSES).

Allowable hours of operation for BOS use may be included on the regulatory signs as necessary (or if required by law). There is some thought that the hours of operation should not be included on signing in order to allow maximum flexibility to run buses on the shoulder for special events or incidents, or as congested conditions dictate. Posting hours of operation for BOS use may be more useful on arterials where there may be more frequent mixing of traffic on the shoulder when it is used for turn lanes at intersections or where buses may use the shoulder during only one peak period. The New Jersey DOT posts hours of operation on Route 22 (e.g., "BUSES MAY USE SHOULDER 4PM–8PM MON–FRI"), and also posts signs with messages about the mixing of right turns with bus on shoulder traffic on Route 9: "ALL TURNS FROM RIGHT LANE" and "RIGHT TURNS PERMITTED AT ALL TIMES."

Some agencies have used posting the hours of operation as a surrogate message to infer when the use of the shoulder for emergencies is allowable, but most agencies advise that the use of the shoulder for emergencies is always allowable and that their operations will be modified (e.g., buses will move out of the shoulder) in this case. Public education about the use of buses on the shoulder and how emergency use is modified or allowed is a key to a successful implementation. For example, Maryland uses the message "SHOULDER USE, BUSES ONLY 6–9 AM MON–FRI EMERGENCY PARKING ONLY AT ALL TIMES" to convey that emergency use is allowed on the shoulder anytime.

Pavement Markings

The use of pavement markings to supplement BOS signing or to convey other messages has been used in only a few cases. Many agencies that have deployed BOS operations have done so on a test basis and have generally refrained from the use of pavement markings to save the cost of installation (and removal, if the test was ultimately deemed unsuccessful).

However, those agencies that have employed BOS use for many years have generally used some type of pavement markings as part of the operations. New Jersey used "BUS ONLY" markings on its arterial BOS operation on US Route 9 and San Diego used "TRANSIT BUSES ONLY" word markings on the shoulders of State Route 52 and I-805 during its pilot project. The Washington DOT uses "TRANSIT ONLY" word markings on State Route 522 (an arterial roadway).

Lateral lane line treatments vary for freeway and arterial BOS deployments. On freeways, there have typically been very few modifications to shoulder edgelines, with most agencies retaining their standard white, solid, continuous 4 (or 6) inch edgelines. On freeways, agencies that have used word markings used "BUS ONLY" or "TRANSIT ONLY" within 500 feet after exit and entry ramps, and at ¼- to ½-mile spacing thereafter.

On arterials, however, agencies have varied the lateral lane lines based generally on two requirements, as follows:

1. Allowing access to driveways and minor cross streets and
2. Allowing access to right-turn deceleration lanes striped from the approach to some intersections.

Figure 5-2. SR-522 at 63rd avenue, arterial BOS pavement markings at minor intersection (Kenmore, Washington—Image via Google Earth).

The Washington State DOT and the New Jersey DOT take two different approaches based on the characteristics of the arterial segments on which they have employed BOS. On SR-522 in Washington, the Washington State DOT uses broken "dot-" type markings to delineate the edgeline of the shoulder where very dense driveway concentrations exist (see Figure 5-2). This treatment is meant to convey to drivers that the shoulder is available to merge onto the shoulder to make a right turn to a driveway. Once past the area where driveways are present, the Washington State DOT transitions back to the solid edgeline marking to delineate the shoulder. Along the shoulder lane, the Washingtion State DOT supplements roadside signing by placing the "TRANSIT ONLY" word markings on the shoulder pavement. At intersections with no driveways present, where the shoulder is used for a right-turn deceleration lane by all vehicles, the Washingtion State DOT uses the "dot" markings to open the shoulder up to merge for all right-turning vehicles, then using turn arrow markings to denote the right-turn lane. On egress from a driveway, the Washingtion State DOT uses transverse white markings for about 50 feet (markings about 12 inches in width, spaced at 10 feet) followed by the "TRANSIT ONLY" markings to convey that the shoulder use is reserved for transit vehicle through movements.

On US-9 in New Jersey (in the town of Old Bridge), the New Jersey DOT uses the shoulder for bus use on a major arterial facility that differs in character from SR-522 in Washington in that it has many fewer driveway and side-street access points, the result being a more traditional pavement marking delineation of the shoulder (a solid white continuous marking). "BUS ONLY" word markings are placed at 600 to 1000 foot intervals along the length of the shoulder. Figure 5-3 shows the typical use of pavement markings along the shoulder on US-9 in support of BOS operation. The New Jersey DOT used continuous white edgeline to delineate the shoulder, "dot" type markings to delineate the transitions where vehicles other than buses may merge into or from the shoulder area, and "BUS ONLY" markings past channelized right turns and on egress from major intersections.

The 2009 MUTCD (Section 3D.03) specifies that single normal solid white lines are acceptable standard edgeline lane markings for preferential lanes, such as BOS lanes. An edgeline should always be used for a BOS application. Where crossing the edgeline is permitted, the single broken wide white or single dotted normal white line is specified (MUCTD, Figure 3D-03). Double solid wide white lines may be used where crossing is prohibited, and a single solid wide white line is used where crossing the edgeline is discouraged.

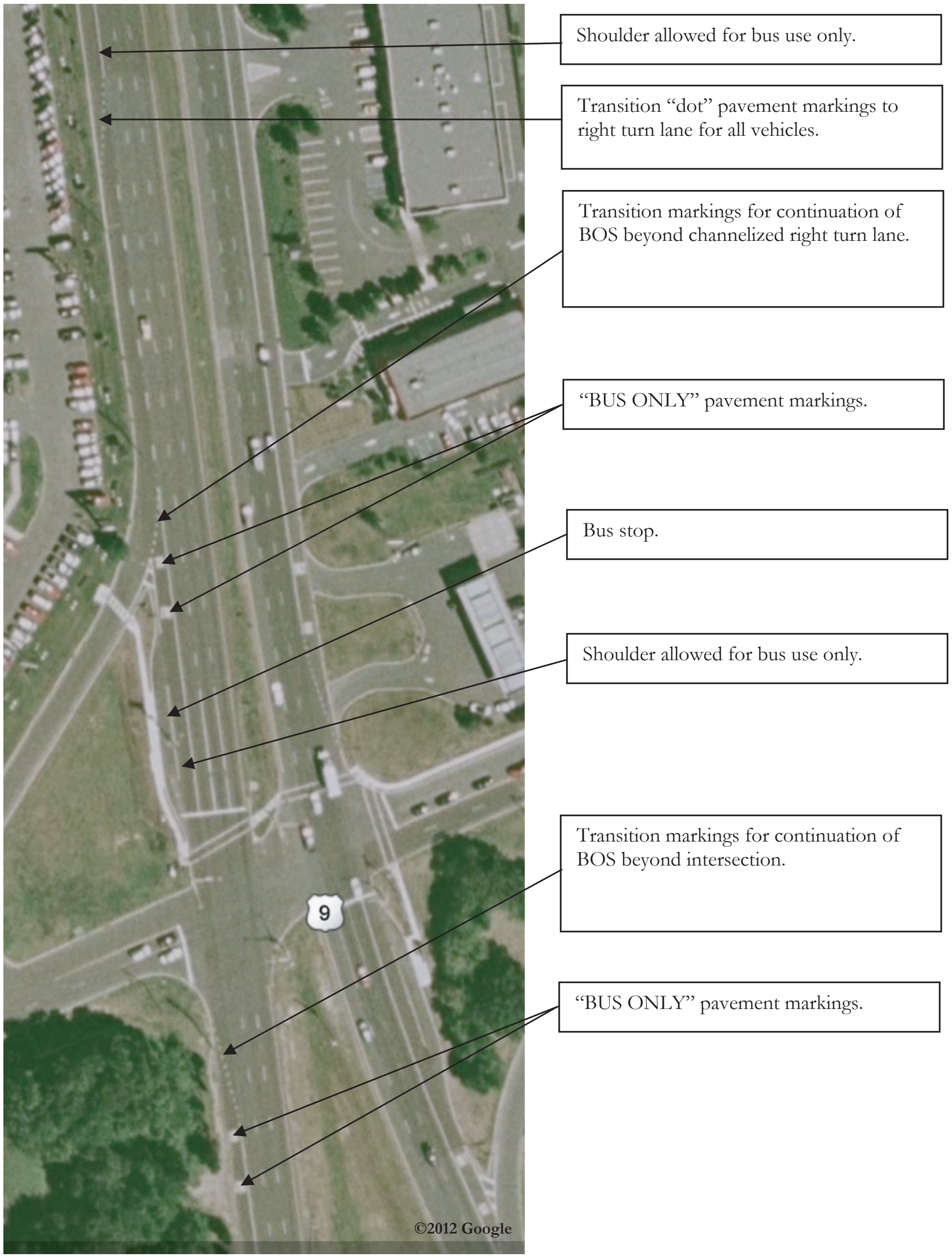


Figure 5-3. Example of arterial BOS pavement marking scheme. US-9 at Spring Valley Road, Old Bridge, New Jersey.

Delineators and Object Markers

Delineators and object markers have not traditionally been especially deployed for use on BOS projects. However, there may be occasions for which an agency needs to supplement signing and pavement markings with additional positive guidance using delineators or mark objects that might not have been marked when traffic was not using the shoulder.

Delineators are typically used to emphasize separation or provide guidance where alignment or lane changes take place (at lane reductions or on curves). They have become used more in recent years in the practice of access management to provide visible separation of direction of lanes or to prevent turns. One example of a delineators application potential is to use the device to delineate lane lines at an intersection approach in order to provide separation near intersections with channelized right turns that occur before the intersection. This application could help prevent turns of vehicles from the right general purpose lane across the shoulder in front of buses if violations of lane use becomes an issue.

Per the MUTCD, object markers are used to mark obstructions within or adjacent to the roadway. During the due diligence phase of predeployment, it is critical that the responsible agency have qualified engineering staff check the presence of object markers at all obstructions along the route, including checks not only of presence but of retroreflectivity as well. The appropriate placement of object markers is critical to BOS operations since the shoulders are typically narrow and bring the vehicle into closer than normal proximity to obstructions on the side of the roadway. Underpass piers, bridge abutments, guardrails, handrails, barriers, and culvert headwalls are all typically roadside features that should be checked for the need to place object markers before BOS operation is allowed. The MUTCD gives very clear guidance on the application of object markers, and many states and local agencies supply supplemental guidance relating to placement.

Rumble Strips and Stripes

If a facility is equipped with rumble strips, rumble stripes, or other raised pavement marking materials, additional noise could occur with buses crossing or riding over those types of treatments, making some mitigation necessary if noise is a concern. It is almost certain that rumble strips should not be used on BOS deployments with shoulder lanes narrow enough so that the bus is forced to ride the rumble strip. The rumble strip could be relocated to the center of the shoulder, but that reduces the time for a motorist to react to crossing the strip before leaving the roadway or striking a roadside object.

While it is not known as to the effectiveness of rumble stripes in reducing the potential for sideswipe crashes between vehicles in the lane adjacent to the BOS lane and buses running on the shoulder, the tactile response that rumble stripes offer may replace the function that rumble strips provide on existing facilities. Rumble stripes contain a grooved pattern in the pavement within the painted edgeline, or within the marking itself.

Texture and Color

Shoulder construction using contrasting textures and colors may be beneficial in better delineating the mainlanes from shoulders, but this case is the exception rather than the norm. The use of edgelines as prescribed in the MUTCD will suffice in lieu of any contrasting color or texture of shoulder pavement. BOS projects that will incorporate mill and overlay or reconstruction may consider whether a contrasting texture or color for the shoulder is appropriate; however, this should not be a significant factor in the BOS project design.

Lighting

Most BOS implementations have not found the need to strengthen lighting. In some cases, though, additional or modified roadway lighting may be needed to improve the margin of low-light driving safety and increase the ease of BOS operation. During the investigation phase of BOS operation, agencies should examine the adequacy of existing roadway lighting to ensure that 1) enough illumination and 2) illumination in the proper place (on the shoulder for BOS operation) is provided. Additional lighting may be needed at bridges (at least at the start of bridge structures), overpasses, and underpasses. Stretches of roadway on which shoulder operation may share pedestrian or bicycle traffic might be candidates for additional lighting.

While lighting is typically present at urban highway interchanges and intersections, additional lighting may be necessary to illuminate the highway shoulder, ramps, and weaving sections. Additional lighting may be supplemented with reflective delineation of roadway features that should be avoided by motorists and bus drivers on the shoulder such as curbs, bridges, piers, and abutments. There may also be the need to place guardrail or other barrier if operations on the shoulder bring those elements within the 30-foot clear zone. Those features may be attenuated, and may typically need breakaway features to for his purpose. Lighting installed under bridges and above the roadway should also be checked for clearance and moved as necessary. Lighting enhancements generally have not been found to be required for BOS projects.

Traffic Operations

Typically, the primary issues with BOS operations are defining the acceptable speed variance between the bus and adjacent traffic stream and ensuring that motorists and bus operators clearly understand the rules for yielding. However, evaluating the impacts of BOS operations on traffic operations presents challenges. In most of the pilot studies that have been conversions of existing shoulders, questions have been asked about how freeway level of service is impacted by the BOS operation, or about bus transitions to and from the transit lanes causing noticeable disruptions in mainlane traffic. Attempts at quantifying these measures are difficult because of the micro-level nature of their impacts and relatively low frequency of incidence, but qualitatively the impacts are believed to be minimal. For example, the San Diego Association of Government (SANDAG) referenced the use of "visual-based survey" by traffic management operators and observation of traffic through the use of transit vehicle on-board video. Both revealed no traffic operations issues of note (SANDAG 2007). Evaluation and monitoring of the BOS operations is valuable to identify benefits of the program and identify issues as they arise so that they may be mitigated before becoming negative impacts to the BOS operation.

Testing the route with a bus should occur before passenger service starts using the shoulder. This should be done in the peak hours, under different lighting conditions, and in conjunction with vehicles running adjacent to the bus in the near regular traffic lane. Repeated test runs will likely reveal potential travel time savings, conflict points along the route, needs for signing, pavement markings or delineation, or the need for modifications to drainage or other structures.

Operational Speed Criteria

Bus movements on the shoulder should be slower than the posted speed of general purpose traffic lanes for several reasons. Two of most obvious reasons to be cautious are to 1) take care when driving on the narrow travel lane, increasing the ability to maneuver safely and 2) avoid the perception of being a hazard to both transit passengers and motorists on adjacent lanes. These two reasons are the most often cited statements when agencies refer to why they place limits on when they allow BOS operations and why they limit the speed difference between general traffic flow and the transit vehicle. Minnesota set one example of limiting the bus speed to a 35-mph maximum with a 15-mph maximum greater speed than adjacent traffic. Other operators have closely followed the Minnesota example (Miami, Columbus, San Diego, etc.), but there are some exceptions. In Washington State, buses and carpools use a bus bypass on the shoulder with no limits on speed or speed variance (other than facility speed limit) on SR-520, a highway facility, and on SR-522, an arterial facility. BOS operations in Ontario, Canada, features operating speeds of 62 mph.

The case may certainly be different where the BOS operation has been carefully planned and designed into the roadway cross section. Where wider lanes exist, and even where some level of buffer between traffic flows have been provided, agencies may feel they can provide a higher level of service to transit passengers by allowing a higher speed differential while maintaining an acceptable margin of safety. These decisions should be made on a case by case basis given the geometry of the facility, condition of the shoulder, nature and duration of congested conditions, characteristics of ramps and weaving areas, and other issues as noted in this guidebook. More importantly, implementing and operating agencies should monitor BOS operations and make adjustments in policy and procedures when conditions merit.

BOS operations have several advantages over HOV or peak-hour general purpose traffic use of the shoulder. First, bus volumes tend to be much lower than HOV or general purpose traffic use of the shoulder. This, along with communications with dispatchers, allows buses to remerge into general traffic more easily than HOV general use of shoulder motorists. Emergency responders are therefore not impeded and disabled vehicles using the shoulder cause less of an impact on traffic conditions. The lower volume of buses also simplifies weaving conflicts at interchange ramps. Second, buses operate at lower speeds than HOV and general use traffic, so speed differentials are minimized, helping to enhance safety. Third, BOS drivers are professional drivers with special training on the use of shoulders. These reasons allow BOS buses to safely operate on relatively narrow 10-foot wide shoulders that could be imprudent for general traffic to use.

Merging To and From BOS Lanes

Merging to BOS lanes is typically a straightforward movement by the transit bus. Based on the operational conditions upon which the bus operator can move to the shoulder to operate (congested conditions, for example) and where signing indicates that the authorized use of the shoulder begins, the bus simply merges over to the shoulder and proceeds at a prudent speed.

In most of the previous instances of BOS operations, bus operators are required to yield to other vehicles when entering or exiting, or when a vehicle is present on the shoulder (for an emergency or otherwise). Buses are also typically instructed to stay behind a vehicle that is traveling on the shoulder or straddling the edgeline until it moves out of the way. Bus drivers may use their horns as a warning to the driver to move over, but cannot take any other action to move the driver out of the shoulder lane.

At slower speeds, merging from the shoulder lane to the general purpose lane is generally done about 1,000 feet or more before an obstacle or where the lane ends. In Minnesota, the rule of thumb is 1,000 feet before an obstacle where the BOS operational speed limit is 35 mph. Minneapolis has since translated this rule of thumb distance to the equivalent of two highway light poles for easier bus driver understanding. For agencies considering operations at higher speed limits, merging distances before obstructions should be more generous to allow a similar margin of safety.

Operational Considerations for Motorists

In general there are very few operational considerations for motorists in the general purpose lanes adjacent to shoulders with bus operations. Some motorists who drive in the outside lanes of highways or roadways naturally tend to use the edges of those lanes to provide more space between them and the adjacent inside lanes. Most drivers use the edges unconsciously or to increase their level of comfort, but some “jealous” drivers do so to block the bus from passing on the shoulder. Experience in Minnesota has shown that these drivers can cause minor slowdowns in bus speed, but that these instances are infrequent and cause no issue with safety or operations otherwise.

Experience to date has not shown any negative impact on flow rates/conditions of general traffic lanes. Removing buses from the general purpose lanes might possibly improve conditions in the general purpose lanes. Copycat motorists using the shoulders have not proven to be a problem.

Many roadway agencies use rumble strips on the outside of the edgeline, within the shoulder, to alert drivers that they are leaving the travel lane. While the rumble strip provides an important warning to motorists, the rumble strips may be in the bus wheel path and causes noise, vibration, and discomfort to bus operators and patrons. An option is to replace the rumble strip with a rumble stripe—which can be either a reduced-width indention in the pavement along the edgeline or a thermoplastic marking with raised elements that cause vibration and sound when a vehicle crosses them.

Ramp Metering and BOS Operations

Ramp metering can provide a significant operational advantage to BOS operations from two perspectives. The first is from the perspective of the bus operating on the shoulder of the highway on approach to an entry ramp. Ramp metering restricts the total flow entering the highway by increasing the gaps in traffic. It does this by breaking up the platooning effect caused by the release of vehicles at upstream signals, often located at the cross-street and ramp interchange. With the larger gaps, buses traveling on the shoulder have a greater opportunity to merge into the entry ramp auxiliary lane/shoulder without restriction or delay.

The second method by which ramp metering may assist BOS operations is by offering priority entry on those ramps with bus traffic that enter the highway and use the shoulder.

Arterial Operations

There are many potential concerns with providing BOS operations on an arterial facility. Arterials incorporate traffic signal control (which might provide transit signal priority), deceleration lanes, and turn lanes, which can provide for transit bypass of traffic signal queues, more bus stop locations, school zones, multimodal concerns (vehicles, transit, bicycles, pedestrians, etc.), parking, and other roadside features. The New Jersey DOT dealt with many of these issues on US-9 in Middlesex County when improving the roadway to accommodate 400+ buses per day. Improvements included new sidewalks, pedestrian refuge islands, full-depth shoulders for bus use, reducing cross slopes from 4 percent to 2.5 percent, and significantly increasing the number of drainage inlets to improve drainage.

School Zones

BOS operations may occasionally take place within school zones. In these cases, implementing agencies should study the area around the school to assess the presence of pedestrians and/or bicyclists, crosswalks, intersection operations, as well as the existing parking conditions near the site. If an agency proceeds with planning for BOS operation once an initial assessment is made, it may be necessary to mitigate for school issues with respect to BOS operation. These assessments will be site specific.

Pedestrian and Bicycle Activity

BOS operations should not typically be deployed on arterial roadways with dedicated lanes for bicycles or along a bike route. If a BOS operation is being considered on a facility with an existing bike route or with bicycle traffic, careful analysis should be performed as to the impacts of the operation and how these vehicle types would mix. Mixing of the two modes (bike and bus) is not advisable, and other options should be explored, including moving the bike route, widening the shoulder to add dedicated width for a bike lane, or limiting bicycle use through regulation during potential BOS operational hours.

Other Roadside Features

Other roadside features, especially on arterials, may factor into the design and operation of a BOS deployment. Driveways, mailboxes, bus facilities (stops), and on-street parking may have to be accounted for in the plans for operating a BOS route on an arterial. Driveways increase the number of potential conflict points along the route, and turning movements to and from them may interfere with the bus through movements. Mailboxes placed at the edge of pavement for convenient delivery of mail should be checked to ensure that they are located beyond the edge of the pavement to reduce the potential for collision. Decisions to provide BOS along arterial roadways should be closely coordinated with existing bus operations where bus stops are frequent and/or close to the edge of the pavement. Similarly, there should be no curb parking during hours of BOS operation.

Access Management and Control

One of the most important aspects of investigating suitability of a route for BOS operations is access control. For highway facilities with limited access, the operations around ramp merging and weaving areas are critical. For arterial-type facilities, the number of cross streets and driveways can have significant affects on overall mobility and the effectiveness of BOS operations.

Since BOS operations are usually retrofit deployments, the opportunity to restrict access with BOS in mind may be limited. However, after a BOS operation is installed, and it is viewed as a permanent operation, then some consideration to managing (and limiting) access should be considered. Many states and localities have access management guidelines in place, and those that do not should consider access management on any routes that may be candidates for BOS operations.

Considering that most BOS operations will be on highways and high functional class arterials, there will already be a preference given to prioritize through movement to some degree. On most freeways and highway facilities, full access control is the rule and access at ramps and associated weaving areas will be a key to safe and effective BOS operation. On arterials, however, limiting private driveway access and minimizing cross-street access once BOS operations are underway is often difficult.

Access management should be considered in BOS operations to preserve the throughput function of major corridors where BOS operations become necessary or preferred. Local and state governments should consider using existing guidelines or establish new ones to enforce policies and decisions to limit access on BOS operating facilities. Through the use of appropriate design parameters (even if they are exceptions to standard practice) and access management, a systematic and supportable process can be invoked to be used in balancing both public and private needs and priorities.

Safety

All transportation operating agencies emphasize safety as a core responsibility. BOS operations may at first glance be counter to the notion of providing a safer transportation facility and/or traveler experience. The buses are driven by professional drivers, familiar with the capabilities of their vehicles and the routes on which they drive. Safety experience to date has been good over a wide range of operating environments.

AASHTO's *Geometric Design of Highways and Streets* has a good summary on the emphasis of safety and the foundational research that guides good design and operations. Some points on safety that have applicability to BOS operations include the following:

- Speed may be a contributing factor in crashes, but it is speed variance that may be more critical. This is why most BOS operating agencies limit the speed variance between the general purpose lanes and shoulder to a specified amount (typically 15 mph).
- BOS crashes generally increase on sections of roadway with curvature, so it is critical that suitability assessments and driver training account for curvature and how it might affect BOS operation, especially considering sight distance, operations on grade, and lane tracking.
- Mitigation of roadside obstacles is important. When agencies are analyzing the suitability of a facility for BOS operations they should assess whether additional treatments are necessary to remove or relocate obstacles or objects on the roadside, treat obstacles with breakaway devices, shield the obstacle with barrier or cushion, or delineate the object to increase awareness. Examples of roadside obstacles include poles, bridges, sign structures, utilities, as well as guardrails and barriers themselves (which may benefit from additional delineation).
- Driver information should be provided uniformly. Consistency among traffic control devices is stressed, but the national MUTCD to which the guide refers does not specifically address BOS-specific signing. The 2009 MUTCD does discuss the use of word-type pavement markings, such as "BUS ONLY" where some agencies have traditionally used "TRANSIT BUS ONLY" within the area of BOS operations.
- Highways should be designed to minimize driver decisions and potential for driver expectancy violation—planning for BOS operations should take this into account.
- The number of access points that BOS operations must cross should be minimized; for those they do cross, mitigated geometrics should be applied where necessary and bus drivers should be trained in the appropriate actions when traversing these areas.
- At intersections, assessments should include gathering of operational data, including traffic volumes, signal timings, preemption capability (if necessary and desired), sight distance, and bicycle and pedestrian facilities (including bus stops). Assessments should also include the need for channelization of turning movements, refuge sidewalks for pedestrians or bus patrons, and other lighting and signing improvements for safety.
- It is vital that training and retraining of bus operators who operate on the shoulder lanes take place.
- It is also necessary to undertake public information campaigns explaining the BOS operation and the benefits to the traveling public.

The good safety record of BOS operations is likely attributable to good multi-agency coordination, planning, training, and execution of operations. The safety record is also attributable to the limits placed on the operation, including when allowed (only when congested conditions exist on general purpose lanes), and maximum speed differential (typically the BOS operation is allowed to go only 15 mph more than general purpose lane traffic flow). In addition, bus operators must yield to any vehicle entering, merging within, or exiting through the shoulder (or auxiliary lane), and they must re-enter the mainlane for any shoulder obstruction. The bus itself is a very visible vehicle to other motorists, and it offers the bus operator a high vantage point from which to view the traffic flow.

Crash History

There have been no reported statistically significant findings with respect to crash analysis for BOS pilot projects. However, the Minnesota DOT completed a general accident study (referenced in the 2007 Minnesota BOS evaluation) that found that between 1991 and 2001 there were only 20 accidents on the shoulder involving a bus in their system, all property—damage–only incidents. Most accidents appeared to be minor scrapes or mirror clips, with Metro Transit reserving only $7,000 per year for damages resulting from BOS operations. Since 2001, there has been one injury crash, a fatality, resulting from a BOS related crash, but the transit operator was not found to be at fault (Humphrey Institute, 2007).

SANDAG's evaluation of the Transit Lane Demonstration Pilot in San Diego included a safety evaluation. According to the evaluation, during the 12 month study period, there were no transit-related accidents and there were no accidents involving vehicles stopped for emergency issues in the transit lane. Bus operators did not report any "near-miss" conflicts during transitions to and from the bus lanes. The California Department of Transportation (Caltrans), the California Highway Patrol, and freeway patrol crews reported no safety or operational issues associated with the demonstration project. While no statistical analysis of the crash data was reported, the crash rates appeared to decrease on the sections of highway with the transit lanes during the study period. The SANDAG evaluation also included a survey of bus operators, passengers, and other users who all indicated a positive reaction and perception toward public safety with respect to BOS operations for the demonstration project (SANDAG, 2007).

Studies that have shown mixed results when converting shoulders to general purpose use or to high-occupancy vehicle (HOV) lanes. Recently, these types of studies have shown a propensity for increased crash rates associated with shoulder conversions to HOV lanes. The studies noted that the speed differentials associated with HOV lanes, when compared to general purpose lanes, have the potential to increase sideswipe and lane-changing crashes; however, these results have not been noted with the BOS pilot projects.

To enhance safety and make drivers more aware that buses are (or could be) running on the shoulder, agencies should consider the use of on-vehicle flashers (either hazard beacons or other types of flashing lights) when the bus is traveling on the shoulder, illuminated signs on the bus indicating that the bus is using the shoulder, static signs indicating that motorists should not follow the bus when it is using the shoulder, and roadside dynamic message signs (DMSs) indicating that the shoulder is in use by transit vehicles.

Weather-Related Operational Issues

Weather conditions, including fog, rain, snow, and high winds may affect driver capabilities, vehicle performance, and pavement characteristics. These factors may impact traffic flow, resulting in lower travel speeds, increased travel times, and increased potentials for crashes.

It has been reported that 24 percent of all crashes are weather related or result from slick pavement. Weather-related crashes also account for about 17 percent of fatal crashes, 22 percent of injury crashes and 25 percent of property-damage–only crashes (U.S.DOT/FHWA, Road Weather Program web page). BOS operations during adverse or abnormal weather conditions should be based on predetermined policy, but adjusted based on actual "real-time" conditions. Some of the weather-related considerations that may impact BOS operations are as follows:

- Adverse weather conditions are typically associated with increased congestion and delay, and potentially more incidents. With travel times in the general purpose lanes adversely affected, the transit advantage offered by BOS operation is increased.
- Most freeway lanes are designed to drain toward the shoulders, increasing the amount of water on the shoulder during heavy rains. Driving on shoulder in heavy rain conditions may pose risks for hydroplaning—in-field supervisors and bus operators should be relied upon to gauge whether conditions are safe to use the shoulder, and at what speed.

- The presence of snow or water on the shoulder combined with narrow shoulder width reduces the margin of safety and may increase the possibility for a crash while driving on the shoulder. It is critical that bus operators be trained to recognize this reduced margin of safety and be prepared to stay in, or move back to, the general purpose lanes to avoid potential safety issues.
- Caution should be exercised in allowing BOS operations during bad weather conditions. Existing BOS operations limit access to the shoulder during bad weather. The use of shoulders during bad weather is either not allowed (as is the case in San Diego) or is left to the judgment of bus operator (as is the case in Minneapolis).

Roles for ITS

A wide range of ITS technologies may be appropriate for use with bus-only shoulder facilities. ITS may enhance the operation and enforcement of bus-only shoulder projects and adjacent freeway lanes, improve the convenience and ease of use of transit, and provide real-time information to motorists and transit agencies. Some level of ITS deployment likely will be present in corridors that are candidates for BOS operations. Candidate highway corridors will typically have some amount of congestion, and the operating agency may have some combination of closed-circuit television (CCTV) monitoring, vehicle detection, and dynamic message sign capability on the facility. Arterials may have traffic signal interconnect, transit signal priority, and CCTV capability that might enhance BOS operations.

The use of ITS is not a requirement to deploy BOS operations, but it may fill a role in providing operators and the public with more information about its operations and capabilities. In the future, BOS facilities may provide a testing ground for new technologies, like driver-assistive technology, virtual mirror and virtual bumper systems, and lane-keeping assistance based on (GPS).

Some of the immediately available ITS capabilities (as defined by ITS National Architecture market packages) that can assist operations of BOS project include the following:

- Network and Traffic Probe Surveillance—includes traffic detectors, surveillance equipment (CCTV, for example), and communications to transmit data back to the Traffic Management Center. The data generated enables traffic managers to monitor traffic and road conditions, and identify and verify incidents. Speed data on the traffic stream can be used to determine optimal times and duration for BOS operation, and the benefits of use. Surveillance may also be key in identifying incidents blocking the shoulder and in responding as quickly as possible to clear them so that operations may continue.
- Transit Vehicle Tracking—monitor transit vehicle location using Automated Vehicle Location Systems (typically GPS or radio/beacon based). Real-time tracking is used to determine real-time schedule adherence and/or use of the shoulder for congestion bypass in combination with traffic management systems.
- Broadcast, Interactive and Transit Traveler Information—provides transit users with ready access to transit information, and could include the status of a route's use of the shoulder.
- Surface Street Control and Transit Signal Priority–provides the control and monitoring, communication, and the signal control equipment for local surface street control and/or arterial traffic management. Signal priority can occur between the transit vehicle and the individual intersection or may result from coordination between transit and traffic management centers.
- DMSs—provide information about BOS operation times to bus operators as well as to the motorists in general purpose lanes. They can also be used to supply public information about BOS operations and reminders about their operation in the corridor.
- Maintenance and Construction—these ITS systems may be used to coordinate multi-agency construction and maintenance activity and alert transit operators of activity that might affect BOS operations. This could include roadway weather information systems (snow, flood, etc.) that would affect use of the shoulder.

- Future deployments of ITS could include lane keeping and driver-assistive systems. These systems may be based on in-pavement sensors that automatically guide the bus vehicle track to facilitate bus tracking on narrow shoulder sections. Longitudinal, lateral, and intersection safety warning systems may also have future applicability to BOS operations. Further into the future, advanced longitudinal and lateral control systems may be developed to assist BOS operation.

Dynamic Message Signs

DMS may be used to provide supplemental messages to drivers about the bus use of the shoulder. These messages may be of a marketing nature or may serve to warn the driving public that buses are driving on the shoulder. For example, in Cincinnati, the Advanced Regional Interactive Management and Information System (ARTIMIS) Center has posted DMS messages stating "METRO BUS PERMITTED TO DRIVE ON SHOULDER" (see Figure 5-4). DMSs might be used to convey BOS operating time-of-day or operating conditions (e.g., BOS operations when congested). DMSs might also be used in real-time by posting BOS operational messages when other sensors indicate conditions in which BOS operations are allowed—this could conceivably be done automatically without transportation management center operator intervention through software capabilities.

Ramp Metering

Many freeway facilities that might be considered candidates for BOS operations include freeway entry ramp metering. Ramp meters are used if controlling the flow of vehicles entering the freeway can reduce delay on a facility. Their application is governed by chapter 4H of the 2009 MUTCD. The presence of ramp metering does not in itself hamper potential BOS operations. The ramp meter can operate without modification since the bus driver must yield to oncoming vehicles. However, if an agency is operating "active" ramp meter systems (those that use vehicle detection to identify adequate gaps in upstream traffic), these systems may be configured to sense the presence of a bus traveling on the shoulder and reduce metering rates or hold traffic until the bus passes the entry ramp. Interviews with agencies that have deployed BOS operations did not reveal any modified ramp metering in conjunction with BOS deployment. However, ramp meter operation modification is typically feasible to accommodate BOS operation if necessary.

Figure 5-4. DMS Message for BOS operations (Cincinnati, Ohio).

Lane-Use Control Signals

Lane-use control signals are often used by operating agencies to denote lanes that are open, closed, or closed ahead. Lane-use control signals are addressed in the 2009 MUTCD, chapter 4M. Lane-use control signals have reportedly not been used for BOS operations; however, they may hold potential to address driver information requirements about whether the shoulder is open for bus and emergency use, or emergency use only. These types of systems could conceivably be used to indicate the progress of a bus along the shoulder and provide warning to drivers in the adjacent lane to the shoulder that a bus is approaching.

In-Roadway Lights

In-roadway lights (also known as lighted pavement markers) have been used for crosswalk applications, but they also have been applied in other instances to guide, warn, illuminate, and/or regulate. No known existing BOS operations use in-pavement lights in their operations, but they have been used overseas to provide delineation for temporary shoulder lanes around entry and exit ramps. In-roadway lights may be a technical solution at complicated entry/exit ramps if there is a need to delineate lanes on a time-of-day basis. Information on in-roadway lights may be found in 2009 MUTCD chapter 4N, additional background is found in *NCHRP Synthesis 380: Applications of Illuminated, Active, In-Pavement Marker Systems.*

Roadway Weather Information Systems (RWIS)

RWIS are typically environmental sensor stations along the roadway that communicate data to central systems for reporting and alarms. Three types of roadway weather information are primarily used by traffic management centers: atmospheric data, pavement data, and water level data. Atmospheric data commonly include air temperature and humidity, precipitation type and rate, and wind speed and direction. Pavement data may typically include pavement temperature and condition (e.g., wet, flooded, icy). Water level data may include water levels near or on roads. These systems can be valuable to monitor problem locations that may be subject to frequent flooding, helping supervisors make operational decisions to use or not use the shoulders for bus travel. That information can be conveyed to bus operators in the field.

Incident Management, Law Enforcement, and Emergency Services

Enforcement practices for law enforcement agencies may change once BOS facilities are operational. If the shoulders have been converted for transit use, dedicated areas for enforcement or emergency use may need to be constructed, or law enforcement activities moved to take place off of the facility (on inside or ramp shoulders, or to cross streets). However, if there is law enforcement or emergency activity on the shoulders, the transit vehicle merges back onto the general purpose lanes to bypass the obstruction. Because the speeds at this point will typically be slow, the transit vehicle will likely not have difficulty merging back into the flow of traffic.

Enforcement issues should be considered early in the planning process to ensure that legislation is in place to provide agencies with the necessary enforcement authority of shoulder use, that enforcement elements are incorporated into the design of a facility, and that operational guidelines for enforcement are in place when a project opens. Enforcement should be a topic at stakeholder coordination meetings. Where space permits, provisions for law enforcement can be located on the far side of the BOS operations. The Georgia 400 BOS project has pullouts for law enforcement use and for disabled vehicles along its length.

Emergency use by motorists with mechanical trouble or emergency medical situations may be allowed (and will occur) on the BOS facility. Bus drivers should be trained to recognize these situations, take evasive maneuvers, and notify supervisors of the situation. The participating agency with primary incident management responsibility should then be notified to respond according to existing protocols, or ones created as part of the BOS program development. The timely removal of disabled vehicles and strategies to quick-clear incidents should be used on BOS facilities. Law enforcement, transit agencies, and transportation departments should team up to contact each other about known disabled vehicles or incidents that are within BOS operational areas as coordination is key.

Highway Maintenance

Agencies should strive to provide the same level of maintenance on the shoulders that is provided on the general purpose lanes. There should be a regular check for debris and disabled vehicles on BOS routes. During inclement weather, there should also be checks for high water or snow blocking the lane.

Agencies should coordinate maintenance activities (public or private/permitted maintenance activity) to minimize the impact of shoulder blockage during potential BOS operational hours. Multi-agency coordination is most effective, with information distributed to drivers at the route level via checkout or dispatch procedures. If a work zone will be present within a BOS operational area for any length of time, the placement of construction signing that considers the additional time needed for buses to merge back into the general traffic stream may be necessary. Sign placement will often have to be further from the work area than typically specified and engineers may consider bus-specific signing warning of the shoulder being closed ahead.

Snow Storage and Removal

Snow storms provide maintenance issues for general purpose lanes and shoulders. Before storms, agencies should include treating the shoulder containing BOS operations similarly to treatments for the mainlanes. After storms, the shoulders may provide temporary snow storage for clearance of the general purpose lanes, making BOS operations secondary and eliminating the transit advantage in situations where it may be needed the most. Maintenance staff and or contractors may be evaluated on criteria based solely on clearance of lane-miles of general purpose lanes. Areas with BOS operations that are subject to snow removal issues should consider implementing policy to put clearance of snow on the shoulders with BOS operations equal to clearance of the adjacent mainlanes. This may require that alternative areas for snow storage be identified (use of the shoulder without BOS operation, use of right-of-way outside the shoulder, etc.).

In addition, transit agencies may need to instruct operators to use judgment in determining whether a shoulder that is partially covered with snow is appropriate to use for congestion bypass. Operators who are in doubt should merge back into the mainlanes or consult supervisors for advice or assistance.

Summary

Traffic operations and management for BOS facilities is a straightforward pragmatic process. It calls for a sensible application of signs, pavement markings, roadway delineation techniques, and emerging ITS. Careful analysis of existing operating practices and accident information is essential.

SECTION 6

Recommended Decision-Making Framework

Introduction

BOS experience has shown that the concept does work. It saves bus passenger travel time without increasing accidents or congestion to the general purpose travel lanes. Bringing these benefits to other communities requires (1) locations where buses encounter congestion; (2) continuous shoulder of at least 10 feet (preferably more) and (3) close cooperation amongst transit agencies, highway agencies, and corridor communities. Section 6 is organized into the following four elements:

- Identification of BOS stakeholders and issues,
- Reasons for implementing BOS,
- Overview of current BOS decision-making process, and
- Recommended BOS decision-making process.

Most BOS projects are low cost, and relatively easy to implement transportation system management (TSM) measures. The decision-making process needs to incorporate the careful design of a project to ensure safety, but it also often needs to balance ideal highway standards with other mobility objectives. Keeping projects simple and low cost using good engineering judgment is important.

Decision Stakeholders and Issues

The decision-making processes that have been employed to implement BOS projects have involved partnership efforts among transit service operators, state DOTs, other highway agencies, metropolitan planning organization (MPOs), and often the police. It is difficult to isolate the decisions of transit service operators from those of other team members. It is also difficult to generalize the processes that they have followed, as BOS issues and institutional frameworks for transportation decisions very much influence how decisions are made.

MPOs typically are key agencies in BOS project development and implementation. Most transit agencies do not have in-house traffic engineering or highway design resources. As such, transit agencies often do not fully appreciate the traffic engineering and highway design challenges associated with implementing BOS projects. Conversely, many state DOTs do not have bus transit operating skills in-house and, therefore, do not fully understand the perspectives of transit operators. MPOs tend to have both skills in-house and often function as a bridge between transit providers and DOTs. Involvement of the FHWA is sometimes direct and other times coordinated through state DOTs.

Transit Agency Issues

Transit agencies differ in their size, types of operations, institutional makeup, and many other aspects. Many metropolitan areas also have more than one public transit operator providing service on its freeways. Some transit agencies are part of multimodal transportation agencies and some cover multiple jurisdictions rather than being confined to a city service area. These features influence how decisions are made on many issues including BOS.

Transit agencies are usually the first proponent in communities for BOS operations. This is because they understand their operating problems and their passengers' needs more than other agencies. They are the first to appreciate congestion affects on their running times and schedule reliability. They understand their competitive position in the regional travel marketplace and are most aggressive at seeking measures to be more competitive. For those transit agencies with buses operating along congested highway segments, the basic question tends to be "why can't we do it here?".

Eleven objectives and issues have been identified for transit operators. These are in addition to the definition of the corridor and its termini.

Objectives

1. Added satisfaction benefits to existing riders and the potential for increased ridership;
2. Operating cost savings resulting from reduced labor time, reduced vehicle operating costs, and the ability to schedule a second peak direction peak trip per bus;
3. Running time savings for average trips and for worst case trips (bad weather or accident delays);
4. Schedule reliability improvements;
5. Ride quality for passengers;

Issues and Concerns

6. Safety for vehicles and passengers;
7. Capital costs required to make physical, traffic control, and other BOS improvements;
8. Priority policy for clearing debris, disabled cars, snow, and other blockages of the shoulder;
9. Effort required for driver training;
10. Legal and code changes required to authorize BOS and allow its enforcement; and
11. Definition of operating protocols for the shoulder–times, speeds, eligibility, use of flashers, and maximum differential speed.

Department of Transportation Issues

State DOTs are organized in variety of ways. Often they have sections responsible for geographic districts as well as headquarters' functions, and they generally have sections for engineering design, traffic operations, maintenance, and the like. Most have multimodal sections either at the headquarters level or integrated into each local district office. Thus there are many decision makers within a DOT, and each decision maker or group tends to have its own objectives. Because most DOT resources are focused on highways, vehicle traffic capacity and safety tend to be the primary concerns.

Freeways and expressways have proven successful at moving high volumes of traffic rapidly and safely. Speed, capacity, and safety changes to freeway and expressway facilities, therefore, are cautiously approached by DOTs. This holds true even for non-multimodal changes like closely spaced interchanges. DOTs invest considerable resources in the development, operation, and maintenance of the freeways and expressways, and they are generally reluctant to depart from established design and operating standards. BOS facilities in some respects are a departure from established practice. Wide lanes, absence of surprises (uniformity) and minimal speed differentials, and design continuity are all features that favor traffic safety. The success of the Twin Cities area BOS, however, proves that BOS can work when done correctly by retaining safe design factors and by preserving highway capacity and safety.

For turnpike or toll facilities, the issue of revenue is also a concern related to BOS operations.

A number of basic issues and concerns related to highway operations, design, and safety were identified for DOTs.

Need—A fundamental concern is determining the benefit of implementing BOS projects. Will the project increase person carrying throughput of the corridor? Will it reduce person delay? Will it increase transit usage? Essentially, what are the benefits that justify departures from conventional shoulder use and design?

Traffic Safety—The most common concerns that were identified by the *TCRP Synthesis 64* survey respondents dealt with traffic safety. The following 11 traffic safety concerns were identified:

- Conflicts at on- and off-ramps,
- Sight distance adequacy, particularly at on-ramps,
- Conflicts for motorists pulling onto the shoulder,
- Loss of safe evasive movement shelter area,
- Need for bus driver training,
- Speed differential,
- Impact on adjacent lane motorists,
- Return merge distance adequacy,
- Shoulder area debris hazards,
- Reduced clearance for buses at bridge abutments, and
- Drainage and hydroplaning.

Shoulder Functions—Roadway shoulders provide a range of important functions. The following five shoulder-use functional categories were identified as concerns by the *TCRP Synthesis 64* survey respondents:

- Removal/storage of disabled vehicles and accidents,
- Emergency vehicle use,
- Stormwater drainage,
- Staging area for maintenance work, and
- Snow storage.

Use of the shoulder facilities at times when the highway is congested and moving very slowly, therefore, could affect these functions, even if limited to bus use.

Physical Design—Design practices and operating environments vary by jurisdiction. The following seven concerns were identified in *TCRP Synthesis 64* for physical design:

- Shoulder width adequacy,
- Shoulder pavement strength,
- Signage needs,
- Lateral obstruction adjacent to shoulder,
- Need to narrow general purpose lanes,
- Modifications to drainage inlets compromise function, and
- Conflicts with pavement edge rumble strips.

Reasons for Implementing BOS

Reasons cited for implementing BOS operations have included the following:

1. Pilot testing of the concept;
2. Temporary construction impact mitigation needs or emergency response needs;
3. Interim measure until ultimate transitway, managed mane, or freeway widening project can be funded and constructed;
4. Long-term ultimate transit solution for the corridor/network; and
5. Support for new express bus service strategy in the corridor.

Of the seven case-study communities:

- Ottawa initiated its first BOS segment in coordination with a construction project and has extended and added to the initial application as interim solutions until their transitway network can be expanded in the future.
- The Twin Cities BOS project began as a long-term solution to an expressway bus operating problem and was substantially expanded after a major flood. Its continuing expansion is part of the region's multimodal strategy for transit priority and is considered a long-term investment.
- The BOS project in Miami is seen as an interim solution, until addition of managed lanes or addition of more general purpose lanes can be implemented.
- The New Jersey Transit Old Bridge Township BOS project is viewed as a long-term solution to congestion problems.
- The San Diego BOS operation is seen as an interim improvement until managed lanes can be funded and constructed.

The Miami, San Diego, and Columbus BOS applications are "pilot/demonstration" projects. The recent Atlanta BOS project is also considered an interim solution for its corridor. In the BOS implementation communities, the transit operators have not seen the need for a pilot having seen the success in the Twin Cities area. The need for a pilot or demonstration project has generally related to satisfying state and local traffic engineers that the concept works.

Overview of Current Decision-Making Process

TCRP investigations did not discover any formal decision and implementation process. There were no rigidly defined "alternatives analysis" processes and often there were not even detailed National Environmental Policy Act (NEPA) processes, since most BOS projects were NEPA categorical exclusion projects. Rather, agencies tended to work through decisions and issues in a team process. Decision making was more a cooperative and pragmatic process of identifying needs and opportunities and of addressing various agency concerns. The decision process tended to include eight steps, some of which were accomplished together, particularly if dictated by urgent needs. The eight steps, shown in Figure 6-1, generally included the following:

1. Identify problem/need,
2. Develop concept plan,
3. Establish a multi-agency BOS team,
4. Perform feasibility assessment,
5. Develop project definition,
6. Plan implementation,
7. Project start-up, and
8. Monitor performance.

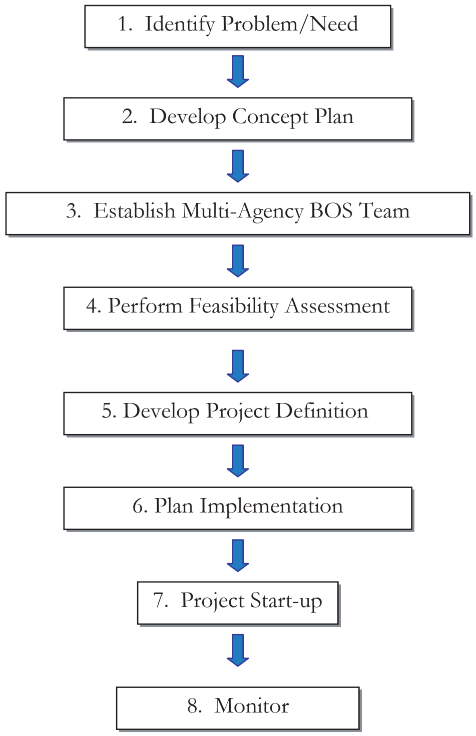


Figure 6-1. Key BOS Decision Steps.

1. Identify Problem/Need

Transit agencies and metropolitan planning organizations (MPOs) have typically led this phase of project development.

Transit agencies regularly monitor their services, including running times and schedule reliability for planning and scheduling purposes. They also develop near-term and long-term service and infrastructure plans often with transit priority elements. These in-house efforts can help to identify a freeway service operating problem. Transit agencies see the travel time, reliability and passenger attraction benefits as well as potential cost savings associated with BOS operations.

A number of non-transit agency planning efforts sometime "flag" arising congestion problems. MPOs also have ongoing updates to their multimodal Regional Transportation Plans. These Regional Transportation Plans are another potential source for identifying near-term and long-term BOS applications. Lastly, state DOTs coordinate highway improvement planning with the MPOs and sometimes with transit agencies. Some state DOTs have ongoing freeway/highway performance monitoring systems that can provide useful information.

Once freeway/highway bus service problems are identified, the search for solutions should include consideration of BOS measures. Unless the transit agency advocates its consideration, it is unlikely that BOS solutions will be considered. It should be noted that non-transit stakeholders often believe that a minimum volume of buses are required to warrant priority measures like BOS. As such, education of other stakeholders is sometimes required on the subject of priority measures for low-volume bus services (less than 20 buses an hour).

The initial expansion of the Twin Cities' BOS arterial highway projects to freeway applications involved an emergency response collaboration between the Minnesota DOT, Metro Transit, and the MPO.

2. Develop Concept Plan

Based on an understanding of current and future congestion on bus operating performance in terms of location and intensity, the next step has been to define a vision for the potential BOS application. In essence, a "purpose and need" reason is useful for recruiting other non-transit agencies to get involved and support transit improvements in the corridor(s). This general project description might include the desired termini of the BOS segments, bus operation strategy, and potential project benefits: running time savings, schedule reliability improvements, benefits to existing ridership, potential patronage increases.

DOTs have generally not been involved in this phase of project development. As the concept becomes better known, however, some DOTs may suggest BOS as a potential solution to corridor congestion. The BOS concept seems like a reasonable concept for consideration in comprehensive corridor NEPA Environmental Impact Statement (EIS) studies as a TSM option. None of the implemented BOS projects were the TSM alternative of a major corridor improvement study. BOS projects would seem to be a very logical TSM treatment or alternative.

3. Establish Multi-Agency BOS Team

If an established multi-agency committee is not in place to coordinate transit priority projects, it should be quickly established at the outset of the BOS decision-making process. All five of the case-study communities employed a multi-agency committee to implement BOS projects.

Minneapolis-St. Paul Twin Cities—Team Transit was established and continues to function. Team Transit consists of the Minnesota DOT, Metro Transit, suburban bus operators, Metro Council of Governments, local counties, and the Minnesota State Patrol.

Ottawa, Ontario—A Transit Priority Task Force has been established to coordinate transit priority in the region. The intent was to strengthen the dialogue between transit staff (who identify problems and propose solutions) and traffic operations staff (who assess trade-offs and implement solutions). The Task Force has helped each group understand the other's world and facilitated "outside-the-box" thinking and that has helped to overcome resistance to new ideas.

Miami-Dade, Florida—The BOS effort arose from a Miami-Dade MPO planning effort, which involved Dade County, Miami-Dade Transit, the Miami-Dade Expressway Authority, and the Florida DOT, Miami-Dade Public Works and the Turnpike Enterprise. The General Manager for Miami-Dade Transit became a strong advocate or champion for the BOS concept implementation.

Columbus, Ohio—The transit operator, the Central Ohio Transit Authority (COTA), proposed the BOS project on I-70 and in partnership with the Ohio DOT, the City of Columbus, the Ohio Highway Patrol, FHWA, City of Columbus Police, and the MPO (Mid-Ohio Regional Planning Commission), implemented the pilot project. This group is called the Transit Advantage Group.

San Diego, California—The BOS concept was proposed by the MPO (SANDAG) and a team was established, including the transit operator (Metropolitan Transit System), Caltrans, the Highway Patrol, and the MPO. Caltrans ultimately became the lead agency responsible for implementing the BOS project. The partnership sign (see Figure 6-2) is displayed on the back of BOS service buses.

Atlanta, Georgia—The Georgia Regional Transportation Authority (GRTA) proposed the BOS concept and worked closely with the Georgia DOT to implement it. Another transit operator, MARTA, also operates buses on Georgia 400 and the state patrol assists with enforcement.

Source: Courtesy of San Diego Association of Governments.

Figure 6-2. BOS Project Partnership Signage, San Diego.

DOTs have been involved in the multi-agency teams that have successfully implemented BOS projects. They often have taken the lead for phases that follow planning—design and construction. As the BOS shoulder is their facility, it is logical that the DOTs have control of these critical phases of BOS implementation. While the Twin Cities initial BOS segments were implemented without FHWA involvement, current BOS projects in the Twin Cities area are coordinated with the FHWA. The most recent projects in the United States have included the FHWA as a partner. In some locales, FHWA has been a direct participant in the project planning, while in other locales coordination with FHWA has been accomplished through the DOTs. Involvement of police is desirable. Participation by the police tends to decline once the BOS operation is up and running and has proven not to be an enforcement or safety problem.

4. Perform Feasibility Assessment

The feasibility assessment is primarily a DOT activity. From a transit operator perspective, the key coordination input is how the operator might use the BOS facilities. Which bus routes might benefit and what features of BOS might the transit operator exploit for improved passenger service? For example, would the corridor market lend itself to a "station stopping" express bus service (form of bus rapid transit)? Ottawa operates some of its buses in a station stopping mode. Buses exit the shoulder onto the off-ramp, cross the intersecting street and make a passenger stop, re-enter the highway using the on-ramp and flow back onto the shoulder lane. Early input regarding new bus operations would allow highway and traffic engineers to consider minor improvements to interchanges in response to transit service needs. Columbus, Ohio, is considering rerouting the path buses use from the BOS segment into downtown to minimize bus traffic conflicts at the dual-lane I-70/I-71 interchange.

For DOTs, this phase essentially seeks to identify physical or operational reasons that would permit or preclude BOS implementation or influence priority ranking of BOS corridors, including terminals. Key issues include the width of shoulders, pavement strength of the shoulders, worrisome weaving conflicts, overall traffic safety, and coordination with planned improvement construction. It also addresses how these features might be mitigated. Recent BOS planning in Kansas and Illinois have included field demo BOS trips with stakeholders invited to observe feasibility.

Minneapolis-St. Paul Twin Cities—In the Twin Cities area, most of the "low hanging fruit" BOS projects have been implemented. Substantial effort is now directed at maintenance and preservation of the current BOS network. Initial criteria for BOS implementation included regularly occurring congestion, a minimum of six buses per week must use the proposed shoulder, the expected time savings must be greater than eight minutes/mile/week, and the proposed shoulder must have a minimum 10-feet width.

Ottawa—BOS segments have been implemented as interim transit priority measures until a full transitway extension can be funded and constructed.

Miami—In Miami, the Phase II Special Use Lanes Study: Transit Use of Shoulder Bypass Lanes listed the following five criteria for BOS consideration:

1. Roadway characteristics (interchange spacing, traffic volumes/congestion, shoulder width, accidents and merge distances),
2. Programmed corridor improvements,
3. Proposed express bus service,
4. Potential for park-and-ride locations, and
5. Usable shoulder segments.

The Miami BOS project is documented in terms of freeway corridor characteristics and the screening process. For each candidate corridor, interchange spacings, segment traffic volumes, 3-year accident history, weaving distances, identification of needed near-term construction, identification of bus services, assessment of park-and-ride lot potentials, assessment of reoccurring and non-reoccurring congestion, and shoulder widths and conditions were inventoried.

San Diego—In San Diego. the pilot BOS project was selected for presence of congestion, adequate shoulder width, absence of near-term construction, and safe traffic operations features. The assessment of the SR-52/I-805 BOS project considered ridership need, potential time savings, multimodal connectivity, viable alternatives, pavement strength, drainage modifications, shoulder width, enforcement/maintenance/emergency pullout needs, sign and striping, grade breaks and super elevation, lateral obstructions in the "clear recovery zone," guardrail and dike modifications, and required "design exceptions."

Columbus, Ohio—In Columbus, the planning effort primarily looked for freeway segments with congestion, express bus service operations, and minimum-width shoulders. Field reviews were conducted of shoulder widths and conditions.

Atlanta—In Atlanta, the Georgia 400 corridor was selected for BOS implementation to address severe congestion, high volumes of bus service, and available shoulder width. Shoulder features were reviewed, along with accident history and a CORSIM based weaving analysis.

5. Develop Project Definition

During the project development definition phase of implementation, the following four important issues typically are addressed:

1. Benefits of restructuring/modifying corridor bus service to fully exploit the BOS opportunities and strengthen the arguments for the project (focus more buses along the BOS corridor);
2. The physical improvements to the shoulders in terms of width, strength and cross slope;
3. The protocols for BOS operations; and
4. The legal basis for operating buses on the shoulder.

A basic strength of the BOS concept is that it is low in cost and easy to implement. There are trade-offs regarding width, cross slope and pavement strength improvements. A number of BOS projects have been implemented with minimal physical improvements. In fact, some BOS projects result from the difficulty of sufficiently widening the highway to accommodate a full width additional traffic lane. The key for transit operators is to minimize the cost and implementation time for the BOS improvements so that they remain attractive options. In Miami, Columbus, San Diego, and Minneapolis, acceptance of suboptimal shoulder widths for some segments helped to get the projects on the ground. This is particularly true for pilot BOS projects. The pilot

BOS projects in San Diego, Miami, Columbus, and Cincinnati decided it was not necessary to strengthen shoulder pavements or improve drainage inlets and utilities.

Defining operating protocols for speed, eligibility, speed differentials, times of use, and use of four-way flashers seem straightforward to transit operators. These issues, however, need to be worked out with highway engineers. The Minneapolis experience has been used as a template for successful cooperation. The maximum speed definition is critical only to long-distance BOS application. Except in Canada, most communities have adopted the Minneapolis 35-mph maximum speed (Atlanta and Miami are 25 mph). The Minneapolis maximum speed was defined with input from its bus operators. The most cautious approach for shoulder-use eligibility is to limit use only to trained drivers. This is how most BOS projects start. Most communities have also adopted the Minneapolis-St. Paul Twin Cities maximum speed differential with general traffic (15 mph).

From a bus operator's viewpoint, the most critical aspect of the legal issue is the change required to legally operate on the shoulder. This varies by state. In San Diego, Miami, and the Twin Cities start-ups, the DOTs were able to authorize the demonstration projects without the need for special legislation.

Once potential BOS corridors have been identified, key physical improvements, transit operating protocols for buses, maintenance and enforcement needs, traffic engineering, and legal authority must be defined. These efforts are done in team meetings with respective staffs leading certain issue definition. Sign placement for BOS projects has typically occurred in the field, rather than via formal engineering signage and striping plans. Recent planning for BOS projects in Illinois and Kansas City have included demo BOS runs with DOT and other stakeholder staffs to provide a real on-the-road appreciation for the physical and operational features of the BOS. These trial runs included special escort vehicles and both allayed many concerns as well as helped to define implementation needs.

Minneapolis-St. Paul Twin Cities area—In the Twin Cities area, Team Transit's expansion of the BOS network builds upon its proven history with respect to operating protocols, maintenance and enforcement, traffic engineering, and its legal basis. Key needs in this phase are engineering determinations of shoulder improvements and bus service planning coordination. As most new highways are built with full strength shoulders, the engineering tends to be modest. In the early days of developing the network, Team Transit used inputs from bus drivers to help define operating protocols. Physical improvement needs were developed based on field experience.

Ottawa, Ontario—Signage, striping, and other traffic engineering features are defined in Canadian manuals. As the shoulder operates as a full-time transit lane, normal shoulder functions are provided on an adjacent graveled shoulder. The operating protocols are also well established. To accommodate buses stopping at off-line stations, some refinements were made to interchanges along the BOS segments to facilitate through bus movements. Design of some of the bus on-ramp movements have attempted to place the buses on the right side of the on-ramp traffic to eliminate the need for weaving. The Transit Priority Task Force coordinates these decisions.

Miami, Florida—Miami-Dade reviewed the Twin Cities template for BOS facilities and operations and adapted them to the local area. For the pilot project, minimal physical improvements were implemented and the transit operating protocols were generally copied. The key exception was the adoption of a 25-mph threshold for buses to use the shoulder versus the 35-mph threshold that is used in the Twin Cities area. Signage also was modified to reflect the Florida DOT's desire to emphasize the normal functions of shoulders as the primary use (with authorized buses allowed to use the shoulders).

Columbus, Ohio—The Columbus Transit Advantage Group largely adopted the Twin Cities signage and markings template and did not make physical improvements to the shoulders for their demonstration project. They used a diamond shaped warning sign rather than a horizontal shaped warning sign for the on-ramps. They adopted the Twin Cities BOS operating protocol based on its proven history.

San Diego, California—The BOS pilot project in San Diego is largely patterned after the Twin Cities system. Its principal difference is that it is technically a transit lane and not a shoulder. This definition reflects restrictions in the California Vehicle Code.

Atlanta, Georgia—The Atlanta BOS project is also patterned after the Twin Cities success. Bus operating protocols and most other features were borrowed from the Minneapolis-St. Paul system. The Georgia DOT, however, wanted to use a regulatory sign for the on-ramps rather than a warning sign and felt that adding raised buttons on the BOS shoulders would help to discourage copycat motorists using the shoulders. They also favored adding accident investigation–site paved pockets periodically along the shoulder.

6. Plan Implementation

This phase of project development usually involves environmental clearance, FHWA approvals, and the like. Environmentally, the BOS projects are generally exempt since they involve little if any new construction and whatever construction is needed is within current rights-of-way and therefore basically an operating and maintenance improvement. FHWA is usually involved in approvals. These approvals are sometimes coordinated by DOTs (Florida and California). Atlanta, Columbus, and Cincinnati involved the FHWA offices in the early planning process. San Diego field tested running buses on shoulders several months before operations began. The test bus was escorted by a police vehicle.

Training BOS bus drivers occurs during this phase of implementation once environmental and FHWA approvals have been obtained. Metro Transit in the Twin Cities area has recently developed an excellent video training tool for drivers. Most classroom training tends to use popular presentation software. San Diego, Columbus, the Twin Cities, and Cincinnati employed both classroom and on-the-road training.

FHWA Approvals—All of the recent BOS projects have been implemented with input and approvals by FHWA. In Florida and California, this was coordinated through the DOTs, but elsewhere the FHWA has been involved in the team project development meetings.

Environmental Clearances—San Diego, Columbus, Cincinnati, Atlanta, the Twin Cities, and Miami all cleared their projects through NEPA with categorical exclusions. San Diego also cleared their project through the state environmental process—the California Environmental Quality Act (CEQA)—with a categorical exemption. Caltrans led the NEPA effort and SANDAG led the CEQA efforts.

Funding—The Minnesota DOT provides for BOS development and maintenance funding in its normal budget. Some maintenance funds are also provided using FTA 5307 fixed guideway funds. FHWA requirements for eligibility need to be addressed. For example, formal signage and striping plans are typically required.

Constructability—Most of the BOS projects involve minor signing improvements to the highway right-of-way. Restriping, pavement strengthening, and drainage inlet improvements all require coordination to minimize impacts on traffic flow. The pilot programs have avoided these improvements for constructability as well as cost reasons.

Legal—Vehicle codes in most states do not allow vehicles to use shoulders for congestion bypass purposes and, without enforcement, abuses are inevitable. The Minnesota State Patrol indicates that the incidents of abuses are no higher on BOS segments than on other shoulder segments. Florida drafted legislation but ultimately approved their pilot BOS project using an Interlocal Agreement rather than special legislation. Discussion of nomenclature regarding bus lane or BOS should also occur in this phase of project development.

The California Vehicle Code does not allow part-time use of shoulders by buses. To address this restriction for the pilot project, the shoulders along the BOS segments of SR-52 and I-805 were redefined to be transit lanes. This nomenclature distinction preserves restrictions for travel on shoulders in California but does allow buses to use the "transit-lane shoulder." As a demonstration project, the district office of Caltrans had the authority to approve the BOS project via a Memorandum of Understanding (MOU)-type of agreement (Decision Document).

Texas has drafted legislation that would permit BOS operations.

Driver Training—As noted, Metro Transit in the Twin Cities area developed a new video in 2010 for their driver training program. Most BOS sites use a combination of classroom and on-the-road training.

Marketing and Public Information—For the start-up of the Cincinnati BOS project, a media ride was planned one week in advance of passenger service. Metro Transit in the Twin Cities area has staged races between their BOS bus and a sports car in general traffic.

7. Project Start-up

Transit agency efforts for the start-up tend to focus on marketing. Buses running on the shoulder, bypassing congestion, quickly becomes a self-marketing effort. These marketing efforts are aimed at promoting ridership of the new priority corridor service as well as to acquaint motorists using the general purpose lanes of the reasons that buses should be given priority. Other start-up activities generally include coordination with enforcement efforts and with traffic-advisory efforts that alert motorists to a change in operating use of the shoulder. In Miami, the start-up included a rehearsal. It also included use of variable message signs to alert motorists of the new operations on the shoulder. San Diego used radio spots, print media, web page, and on-the-bus "take-one brochures" to market their BOS. They also made a special outreach effort one month before BOS start-up with fire, police, and other emergency service agencies. Atlanta produced a video for its BOS project and posted it on their web page.

The Ohio DOT used variable message signs 1 week in advance of BOS operations in Columbus to alert motorists of the new shoulder use. The Ohio DOT is planning the same 1 week advance messaging for the Cincinnati BOS project. Miami also employed variable message signs prior to BOS start-up.

8. Monitor Performance

Once the BOS service is up and running, transit efforts should shift to supervision, enforcement, and monitoring ridership/schedule changes. In San Diego, a need was identified for more pavement markings. Debriefing bus drivers is very helpful. A recent modification for the Twin Cities BOS operating protocol was the addition of a guideline to exit the shoulder at least two light poles in advance of an obstruction on the shoulder. The light pole–based guideline is easier than a 300-foot guideline, which requires some estimation by bus drivers.

Performance and safety are major concerns related to BOS projects. The more established Twin Cities area and Ottawa BOS projects monitor schedule performance on an ongoing basis and they both track accident histories. The more recent pilot projects in San Diego, Columbus, and Miami are planning on performance analysis reports in the near future. The same is true for the new Cincinnati BOS project.

Model Decision-Making Framework and Checklist

The eight-step process that transit agencies, MPOs, DOTs, and other stakeholders have generally used to implement BOS projects provides a sound framework and is a model for other agencies. This framework should be flexible as most BOS projects have been implemented using a loose structure. The relatively low-cost BOS projects also can be quickly implemented to address immediate needs. The low cost and ease of implementation along with their attractiveness to passengers are the key strengths of the BOS concept. As such, the amount of effort and the process for implementing BOS projects should be tailored to the needs of each community and the specific issues related to the project. Undue complexity should be avoided.

A checklist for the eight steps is provided to facilitate comprehensive and efficient decision making for BOS projects.

1. Identify Problem/Need

Typical problems include the following:

- ☐ Congestion-related delays to bus operations,
- ☐ Congestion impacts on bus operating schedule reliability,
- ☐ Congestion impacts on bus operating costs, and
- ☐ Congestion impacts on market competitiveness.

These problems could be existing or projected. The latter might be related to planned capacity increases elsewhere on the highway network that would further congest critical bus segments of the network.

2. Develop Concept Plan

Suggested steps are the following:

- ☐ Draft a BOS Purpose and Need Statement;
- ☐ Define BOS corridor(s) and termini;
- ☐ Describe bus operating plan for project;
- ☐ Make preliminary estimates of travel time, reliability, patronage, and bus operating benefits;
- ☐ Estimate person-trip capacity throughput benefits for the corridor; and
- ☐ Provide information on successful BOS operations elsewhere.

This effort essentially outlines the desired project and provides a description of its potential merits as a means of engaging non transit stakeholders and interest groups. It focuses on addressing the observed problems/needs.

3. Establish Multi-Agency BOS Team

This team should include the following:

- ☐ DOT concerned departments and policy lead,
- ☐ Transit operator(s) key staff,
- ☐ MPO staff,

- FHWA,
- State and local police, and
- Local jurisdiction(s) staff.

Recognizing that departmental staffs often have specific missions, it is suggested that this step identify and engage a policy-level manager from the DOT to broaden the discussion to increase multimodal transportation objectives. It is important to address the BOS issue from both a why do it and a why can't it be done perspective. Most departmental staffs will find a way to do projects, if challenged to do so. If the problem highway segment is controlled by local governments or toll road/bridge authorities, these agencies should also be involved in the BOS team.

4. Perform Feasibility Study

The feasibility study should assess the strengths and weaknesses of the potential BOS concept plan in terms of traffic operations and safety, ease of enforcement, physical features of the shoulders, likely cost and benefits, and opportunities to strengthen the concept for the corridor. This is a planning-level assessment, rather than an engineering-level analysis. Essentially it determines if there are any "fatal flaws" or major constraints that would prohibit BOS implementation or dictate direction for its design and implementation including legal authority for BOS operations. Typical subjects for a checklist of issues are as follows:

- Inventory shoulder widths including identification of pinch points,
- Assess pavement strength of the shoulders,
- Assess drainage inlet and other utility suitability for BOS operations,
- Assess interchange weave suitability for BOS,
- Identify other traffic sight distance or safety concerns,
- Identify any conflicting BOS near-term improvement/maintenance plans,
- Identify legal restrictions associated with BOS operations, and
- Determine the benefits of a pilot/demonstration approach.

This step identifies potential difficulties in implementing BOS and suggests means to overcome these difficulties.

5. Develop Project Definition

This step should provide a more detailed project description and design. Key steps include the following:

- Refine, as appropriate, the BOS project termini;
- Identify improvements to shoulder widths or lane restripings;
- Identify shoulder pavement and edge strengthenings;
- Identify need and opportunity for complementary paved pockets for disabled vehicles/enforcement and accident investigation;
- Identify need for cross-slope improvements;
- Identify drainage inlet and other utility relocation/improvements;
- Identify, as appropriate, changes to shoulder rumble strips;
- Define BOS speed policies, including general traffic, maximum shoulder speed, and maximum speed differences with general traffic;
- Define hours, direction, or driver-discretion policy regarding when shoulders can be used;
- Define eligible users of the BOS (e.g., transit only);
- Establish bus operating policies concerning use of four-way flashers;
- Define criteria for traversing interchanges—continuous BOS operation versus remerge into general traffic lane;
- Identify protocols at other critical entry/exit and weaving BOS locations;
- Define plan to minimize blockage of the BOS shoulder (disabled vehicles, debris, snow, etc.);

- ☐ Develop signage and striping plan;
- ☐ Identify complementary upgrades to ramps (e.g., ramp metering);
- ☐ Identify upgrades/policies regarding potential ponding;
- ☐ Identify required legal changes;
- ☐ Estimate BOS facility improvement costs;
- ☐ Refine estimates of project benefits;
- ☐ Determine need and develop (as appropriate) formal signage, striping, and shoulder design plans; and
- ☐ Define, as appropriate, possible changes to bus routes and services.

Many details need to be refined in this work effort. They include physical improvements to the shoulders, operating protocols for buses, traffic engineering, maintenance and enforcement protocols, legal authority, refinements of project costs and estimated benefits, and project design (as appropriate). A field trial run with the BOS team on-board a bus often is useful.

6. Plan Implementation

Implementation planning steps are as follows:

- ☐ Execute as appropriate an interagency MOU,
- ☐ Obtain required FHWA approvals,
- ☐ Establish required legal authority,
- ☐ Perform necessary environmental studies,
- ☐ Obtain funding for the project,
- ☐ Develop a construction strategy that minimizes traffic impacts,
- ☐ Develop and implement a bus driver training program, and
- ☐ Develop marketing and public information plans.

These implementation items should be identified prior to start-up. They should be considered throughout the entire planning process and not left to the end.

7. Project Start-up

Key efforts should include the following:

- ☐ Implement a motorist advisory program for motorists using the corridor, possibly using variable message signs;
- ☐ Outreach to the media—good potential for “photo op” for project champion(s);
- ☐ Coordinate with enforcement agencies; and
- ☐ Market benefits to bus riders.

This step provides a good opportunity for photo opportunities for project “champions.”

8. Monitor Performance

The performance of the project should be monitored in a continuing basis, as follows:

- ☐ Monitor with BOS driver and police input the adequacy of signs and markings;
- ☐ Monitor wear and ride quality of shoulders;
- ☐ Debrief drivers to identify improvement potentials;
- ☐ Assess the benefits—patronage, run time, reliability, and so forth of the project; and
- ☐ Identify desired changes.

Typically, minor improvements are identified that will correct unforeseen problems or improve performance.

SECTION 7

Conclusions

BOS projects have proven to be popular with bus passengers and communities that have implemented them, and the bus drivers that operate on the shoulders feel that they are good projects. Typically, they are not the ideal bus priority or corridor capacity enhancement option, but because they utilize current right-of-way, they are low cost and relatively easy to implement. Following is a number of conclusions that can be drawn from current BOS operations:

1. Bus priority treatments on freeways and arterials have operated successfully for about 50 years. They have increased the person capacity of highway corridors and saved bus passengers time without adversely affecting vehicle flow.
2. The concept of BOS has emerged in the past two decades. It has been applied where bus volumes are too low and/or roadway geometry does not permit dedicated bus lanes.
3. With BOS, authorized buses are allowed to use the roadway shoulders (typically, but not exclusively, the right-side shoulder) during peak hours only when the main freeway lanes are congested.
4. BOS has proven successful in many communities including metropolitan regions of Minneapolis-St Paul, San Diego, Miami, Cleveland, Columbus, Cincinnati, Washington D.C., Seattle, Atlanta, New Jersey, Wilmington, Ottawa, and Toronto.
5. Bus passengers save time while highway service levels remain unchanged.
6. Safety experience has been excellent even running on narrow 10-feet wide shoulders.
7. The basic requirements for a successful BOS include the following:
   - Presence of buses—usually at least four buses per hour.
   - Congested freeways—speeds of less than 35 mph.
   - Minimum 10-foot continuous shoulder of sufficient strength to support buses. Ideally, the shoulder should be at least 12 feet to better protect protruding bus mirrors.
   - Avoidance of multilane entrance and exit ramps and ramps with very high traffic volumes (more than 1,000 vph).
   - Willingness of transit and roadway agencies (along with the MPO) to work together.
   - Ability to obtain needed "design exceptions" from the FHWA.
8. BOS operations should be installed only after a careful analysis of physical and operational feasibility. Buses should be able to safely enter and leave the lanes. Shoulders should be wide and strong. There should be no nearby obstacles or protrusions.
9. Complementary corridor improvements like park-and-ride lots are desirable.
10. The key analysis steps include identifying the problems and needs, developing concept plans, establishing a multi-agency BOS team, assessing feasibility, clearly defining (and refining) the project plan, starting-up the project, and monitoring performance.
11. The overall study effort should be clearly focused. It should be pragmatic. In many respects, it should produce a transit sensitive TSM-type treatment rather than a major facility design.

The research effort found relatively little documentation of benefits, costs, and safety impacts. A greater emphasis on data assembly and analysis will prove helpful in assessing performance, identifying possible problems, and better quantifying effectiveness. The apparent reason for the absence of performance data is that no problems have arisen and the BOS concept appears intuitively beneficial. Passengers love it and bus drivers think it is a good concept. Quantification of the benefits is also complicated by the widely fluctuating traffic conditions in congested corridors and by difficulty isolating BOS benefits from the numerous other factors that influence patronage (e.g., service and fare changes).

References

AASHTO. *A Policy on Geometric Design of Highways and Streets,* 6th Edition. Washington, D.C., 2011.

Bauer, K. M., D. W. Harwood, W. E. Hughes, and K. R. Richard. Safety Effects of Narrow Lanes and Shoulder-Use Lanes to Increase Capacity of Urban Freeways. *Transportation Research Record: Journal of the Transportation Research Board, No. 1897,* Transportation Research Board of the National Academies, Washington, D.C., 2004, 71–90.

Branch, J. A., C. A. Fry, and M. E. Lebeck. *Litigating Hazardous Highway Claims.* John Wiley and Sons, New York, New York, 1990.

Carson, J. L., J. Tydlacka, L. Stevens Gray, and A. P. Voigt. *NCHRP Synthesis 380: Applications of Illuminated, Active, In-Pavement Marker Systems,* Transportation Research Board of the National Academies, Washington, D.C., 2008.

Corradino Group. *Special Use Lane Study: Transit Use of Shoulders By-Pass Lanes.* Miami-Dade Metropolitan Planning Organization, August 2005.

Douma, Frank, Poindexter, Gavin, and Frooman, Steven. Bus-Only Shoulders in the Twin Cities Metropolitan Area, Minnesota. *Transportation Research Record: Journal of the Transportation Research Board, No. 2072,* Transportation Research Board of the National Academies, Washington, D.C. 2008, pp. 41–48.

Federal Highway Administration. *Manual on Uniform Traffic Control Devices.* 2009.

Hubert Humphrey Institute of Public Affairs, University of Minnesota. *Bus-Only Shoulders in the Twin Cities.* Federal Transit Administration. Washington D.C. June 2007.

Kuhlman, R. S. *Killer Roads: From Crash to Verdict.* The Mitchie Company, Charlottesville, Virginia, 1986.

MARTA/GRTA. *Improving Transit Reliability Using Shoulder On 400* (DVD), 2006.

McCasland, W. R. The Use of Freeway Shoulders to Increase Capacity. *Transportation Research Record 666,* TRB, National Research Council, Washington, D.C., 1978, 46–51.

Metaxatos, Paul, and Thakuriah, Piyyushimita. Planning for Bus-on-Shoulders Operations in Northeastern Illinois: A Survey of Stakeholders. *Transportation Research Record: Journal of the Transportation Research Board, No. 2111,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 10–17.

Minnesota Department of Transportation, *Minnesota Road Design Manual,* September 2004.

Oliver, D. C. The Impact of Tort Liability on the Provision of Transportation Services. *ITE Journal.* October 1987.

Parsons. *Bus On Shoulders Service Evaluation.* Miami-Dade Metropolitan Planning Organization, Sept. 2008.

Regional Transportation Authority. *Categorical Exclusion Group I. I-55 Bus on Shoulders Demonstration.* Illinois Department of Highways, District 1, Chicago. January 2011.

Schumacher, D., Williamson, J., and Menes, R.. Internal Memo—Minneapolis Trip to View Transit Use of Shoulder Lane Operations. San Diego County Association of Governments, November 4, 2003.

SORTA. *I-71 Bus On Shoulder Project Passenger Survey Results.* 2007.

SRF Consulting Group, Inc. *Study of Bus-Only Shoulders.* Minnesota Department of Transportation. 1998.

Thakuriah, Piyushimata; *Bus Riding On Shoulders.* Illinois Center for Transportation, University of Illinois, Urbana, Champaign. August 2010.

Transportation Research Board of the National Academies, *Highway Capacity Manual 2010.* Washington, D.C., 2010.

U.S. Department of Transportation, Federal Highway Administration. “Flexibility in Highway Design,” http://ttap.colostate.edu/Library/FHWA/FHWA-PD-97-062.pdf.

U.S. Department of Transportation, Federal Highway Administration, Road Weather Management Program Webpage, Accessed Feb 10, 2008. http://ops.fhwa.dot.gov/weather/q1_roadimpact.htm.

Urbanik, T., and C. R. Bonilla. Safety and Operational Evaluation of Shoulders on Urban Freeways. Report Number 395-1, Texas Transportation Institute, August 1986.

Varas, Jesus, Santos, Ray, Emerson, Barrow, Vesh, Danny, and Stadeck, Scott. *Technical Report Draft: Transit Lane Demonstration Pilot.* California Department of Transportation and San Diego Association of Governments, June 2007.

Voigt, A. P. *Operational, Safety, and Liability Issues of Converting Freeway Shoulders to Travel Lanes.* Southwest Region University Transportation Center, Texas Transportation Institute, Texas A&M University System, SWUTC/94/72194-2, August 1994.

Wilbur Smith Associates. *TCRP Synthesis 64: Bus Use of Shoulders: A Synthesis of Transit Practice.* TRB, National Research Council, Washington D.C., 2006.

Abbreviations and acronyms used without definitions in TRB publications:

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