Efficient Use of Highway Capacity Summary

Report to Congress

November 2010

Foreword

This report was developed to summarize the implementation of safety shoulders as travel lanes as a method to increase the efficient use of highway capacity. Its purpose is to provide a succinct overview of efforts to use left or right shoulder lanes as temporary or interim travel lanes. As part of this summary, information related to the impact of that shoulder usage on highway safety and/or accidents during operations was reviewed as well. The intent of the report is to provide critical information that the Federal Highway Administration (FHWA) can use to formulate guidance for transportation agencies on providing temporary shoulder use as a means of increasing roadway capacity.   The study that generated this product was conducted at the request of Congress through the Safe, Accountable, Flexible, Efficient Transportation Equity Act, A Legacy for Users Technical Corrections Act of 2008 (2008 Technical Corrections Act). Those issues that need to be considered include design, traffic control devices, performance measures, potential safety benefits, maintenance concerns, enforcement roles and processes, incident response, training for personnel, costs, liability and legal issues, and public outreach and education. Careful consideration of these issues can help ensure a shoulder use deployment is effective without having negative impacts on safety and operations.

Notice

Quality Assurance Statement

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Technical Report Documentation Page

1. Report No. FHWA-HOP-10-023	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EFFICIENT USE OF HIGHWAY CAPACITY SUMMARY		5. Report Date May 2010 6. Performing Organization Code HOP
7. Author(s) Beverly Kuhn		8. Performing Organization Report No. Report
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project No. DTFH61-06-D-00007
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Highway Administration Office of Operations (HOP) Mail Stop: E86-205 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Covered Technical 14. Sponsoring Agency Code FHWA
15. Supplementary Notes Project performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration. Project Title: Efficient Use of Highway Capacity Summary		

16. Abstract

This report was developed to summarize the implementation of safety shoulders as travel lanes as a method to increase the efficient use of highway capacity. Its purpose is to provide a succinct overview of efforts to use left or right shoulder lanes as temporary or interim travel lanes. As part of this summary, information related to the impact of that shoulder usage on highway safety and/or accidents during operations was reviewed as well. The intent of the report is to provide critical information that the Federal Highway Administration (FHWA) can use to formulate guidance for agencies on providing temporary shoulder use as a means of increasing roadway capacity. The study that generated this product was conducted at the request of Congress through the 2008 Technical Corrections Act. Those issues that need to be considered include design, traffic control devices, performance measures, potential safety benefits, maintenance concerns, enforcement roles and processes, incident response, training for personnel, costs, liability and legal issues, and public outreach and education. Careful consideration of these issues can help ensure a shoulder use deployment is effective without having negative impacts on safety and operations.

17. Key Words Highway capacity, safety shoulder, temporary shoulder use, safety, operations, managed lanes, HOT lanes, HOV lanes, geometric design, active traffic management		18. Distribution Statement No restrictions. This document is available to the public through the FHWA Freeway Management Program website: http://ops.fhwa.dot.gov/freewaymgmt/mngd_lns_hov.htm	
19. Security Classif.(of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 96	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

List of Figures

List of Tables

Executive Summary

Chapter 1: Background

This report was developed to summarize the implementation of safety shoulders as travel lanes as a method to increase the efficient use of highway capacity. Its purpose is to provide a succinct overview of efforts to use left or right shoulder lanes as temporary or interim travel lanes. As part of this summary, information related to the impact of that shoulder usage on highway safety and/or accidents during operations was reviewed as well. The intent of the report is to provide critical information that the Federal Highway Administration (FHWA) can use to formulate guidance for transportation agencies on providing temporary shoulder use as a means of increasing roadway capacity. The study that resulted in this report was conducted at the request of Congress in the 2008 Technical Corrections Act. The issues that need to be considered include design, traffic control devices, performance measures, potential safety benefits, maintenance concerns, enforcement roles and processes, incident response, training for personnel, costs, liability and legal issues, and public outreach and education. Careful consideration of these issues can help ensure a shoulder use deployment is effective without having negative impacts on safety and operations.

Document Overview

This document is divided into five chapters that discuss in detail the results of the study and the critical issues and findings related to the use of shoulders for increasing capacity during congested travel periods. The titles of each chapter and major topics covered are highlighted below.

- **Chapter One—Background:** Provides an overview of the document including its scope and purpose, intended audiences and uses, and background information on the roles that planning and project development play in the decision to use a shoulder as a travel way to increase capacity and enhance mobility.
- **Chapter Two—Context and Findings:** Discusses the concept of shoulder use within the context of active traffic management (ATM) and summarizes the domestic and foreign experience with this operational strategy and those that are complementary to its deployment.
- **Chapter Three—Critical Issues:** Gives a brief overview of the critical issues that need to be addressed when considering the use of shoulders for temporary capacity increase on congested freeways.
- **Chapter Four—Case Studies:** Provides case studies of European and domestic applications of shoulder use.
- **Chapter Five—Final Remarks:** Includes final remarks related to the document and its use and provides a complete list of references used in the development of this document.

Chapter 2: Context and Findings

The report documents usage of shoulders as travel lanes in both the United States and three European countries.

Shoulder Lanes—The American Experience

In the United States, the primary use of shoulders has been as a safety refuge area. The limited shoulder use as a travel lane has been primarily reserved for special users of the roadway system, most often transit vehicles. Some shoulder use dates back to the 1970s, and many installations have been in operation for more than 10 years to address congestion on urban corridors. Agencies have seen bus use of shoulders as a low-cost and quick strategy to improve bus operations and reliability without having to acquire additional right-of-way and invest additional large sums of money into the infrastructure. The length of these deployments varies depending on location, ranging from a more than 290-mile comprehensive network in the Minneapolis-St. Paul metropolitan area to deployments less than 1 mile in length used to serve as a queue jump for transit in Delaware. The operational strategies often depend on the congestion on the general purpose lanes and often require speed restrictions of the transit vehicles using the shoulders. Overall, experience using shoulders for interim use has been positive in the United States, and more agencies are considering the strategy to address growing congestion on their urban freeway networks. In fact, several States have deployed temporary shoulder use for all vehicles on congested corridors with success. Another application that is much more difficult to research and document is the number of locations where an existing shoulder has been narrowed or taken away to allow for widening with an extra permanent travel lane. This method is more commonly used in roadway work zones to maintain the existing number of travel lanes during construction. However, it has been applied in some permanent forms as well. In the United States, usage can be broken out into the following categories:

- Bus-only use on shoulders
- Converted shoulders used as permanent lanes
- Temporary use of shoulders for either general purpose traffic or managed lanes
- Emergency (Hurricane) Evacuation Routes

Shoulder Use—The European Experience

In Europe, part-time shoulder use is a congestion management strategy typically deployed in conjunction with complementary traffic management strategies – such as variable speed limits (speed harmonization) and/or ramp metering – to address capacity bottlenecks on the freeway network. European implementers include The Netherlands, Germany, and Great Britain. The strategy provides additional vehicle-moving capacity during times of congestion and reduced travel speeds. The use of the exterior shoulder during peak travel periods has been used in Germany since the 1990s. When travel speeds are reduced, dynamic signs over or next to the shoulder indicate that travel on the shoulder is permitted.

A complete series of traffic signs indicate operations related to temporary shoulder use, including one with a supplemental speed limit indication (used when overhead gantries are not present).

These signs and the overhead lane messages are blank when travel on the shoulder is not permitted. Temporary shoulder use is permitted only when speed harmonization is active and speed limits are reduced, thus providing an operating environment only when speeds are managed below posted levels.

Generally, implementation of temporary shoulder use is at the discretion of the traffic management center operator, although traffic volumes help determine the need for the strategy. A typical installation in Europe incorporates a number of unique roadway features, which can include:

- Lightweight gantries.
- Lane control signals.
- Dynamic speed limit signals.
- Dynamic message signs.
- Automated enforcement technology.
- Closed-circuit television cameras.
- Enhanced lighting.
- Roadway sensors.
- Emergency roadside telephones.
- Advanced incident detection.
- Intensified incident management.
- Emergency refuge areas or pull-outs beyond the shoulder.

Operation of the system is handled by the regional control center, with operators on hand to monitor the system and initiate the modified operations as necessary. Specifically, operators use closed-circuit television cameras (CCTVs) mounted on lightweight sign gantries or separately to check for incidents and stalled vehicles in the shoulder before activating the system.

Chapter 3: Critical Issues

The primary concern related to shoulder use involves its impact on operations and safety. The purpose of this project was to assess the deployments of shoulder use in the United States and determine the impacts on, the experience with, and the addressing of the following safety issues:

- Conflicts at access ramps.
- Sight distance.
- Conflicts with motorists pulling onto the shoulder for emergency purposes.
- Loss of use of the shoulder for emergency refuge.
- Need for bus driver training.
- Speed differential between the general purpose lanes and the shoulder.
- Effect on general purpose lane users.
- Return merge distance adequacy.
- Debris hazards on shoulder.

- Reduced bridge clearance.
- Drainage.
- Operational efficiency.
- Crash experience.

By providing a summary of this information and data related to shoulder use experience, it is expected that the project can assist FHWA with developing guidance on the subject and identifying what, if any, research needs to be conducted to address unknowns related to the operational strategy and its potential long-term and widespread use in the United States.

Agencies need to consider a wide range of issues when determining whether shoulder use is appropriate for a particular corridor or region. Experience both overseas and domestically provides a wealth of experience from which agencies can learn to make informed decisions. From the European perspective, part-time shoulder use is only used during congested periods when queues begin to build at bottlenecks in the system. Moreover, this treatment is almost always deployed in conjunction with speed harmonization. The intent is to reduce the speeds along the corridor and smooth out driver performance and reduce the likelihood of collisions. (1) Furthermore, European agencies have realized both safety and mobility benefits as a result of these projects. While American deployments have been limited, the experience has generally been positive. However, safety benefits have not been conclusive. The issues that need to be considered include design, traffic control devices, performance measures, potential safety benefits, maintenance concerns, enforcement roles and processes, incident response, training for personnel, costs, liability and legal issues, and public outreach and education. Careful consideration of these issues can help ensure a shoulder use deployment is effective without having negative impacts on safety and operations.

Another area needing further analysis is the topic of left shoulder use versus right shoulder use. Domestically, almost all applications of part-time shoulder use have occurred on the right side, while shoulder conversions to permanent lanes have tended to be more prominent on the left side. Each application has a different subset of design and operational considerations to analyze.

Chapter 4: Case Studies

Detailed Case Study reviews were made of the following locations:

- The Netherlands
- Germany
- Great Britain
- Virginia
- Minnesota
- Massachusetts
- Washington

Chapter 5: Final Remarks

This report was developed to summarize the implementation of safety shoulders as travel lanes as a method to increase the efficient use of highway capacity. Its purpose is to provide a succinct overview of efforts to use left or right shoulder lanes as temporary or interim travel lanes. As part of this summary, information related to the impact of shoulder usage on highway safety and/or accidents during operations was reviewed as well. The report provides critical information that the FHWA can use to formulate guidance for agencies on providing temporary shoulder use as a means of increasing roadway capacity. The study that resulted in this report was conducted at the request of Congress in the 2008 Technical Corrections Act.

Agencies need to consider a wide range of issues when determining whether shoulder use is appropriate for a particular corridor or region. Experience both overseas and domestically provides a wealth of experience from which agencies can learn to make informed decisions. From the European perspective, temporary shoulder use is only used during congested periods when queues begin to build at bottlenecks in the system. Moreover, this treatment is almost always deployed in conjunction with dynamic lane control signing and speed harmonization. Furthermore, European agencies have realized both safety and mobility benefits as a result of these projects. While American deployments have been limited, experience has been positive, though safety benefits have not been conclusive. The issues that need to be considered include design—such as the treatment at interchanges and auxiliary lanes, drainage, emergency refuge areas, rumble strips, and Intelligent Transportation Systems (ITS) components; traffic control devices; and operational and safety performance measures. In addition, maintenance concerns, enforcement roles and responsibilities, incident response procedures, personnel training, costs, liability and legal issues, and public outreach and education are issues that should be examined. Careful consideration of these issues can help ensure that a shoulder use deployment is effective without having negative impacts on safety and operations.

The following results can be taken away from this summary:

- The use of buses on shoulders has generally significantly benefited transit trip time reliability in those corridors where it has been implemented.
- There have been shoulder use projects that have shown bottleneck relief at spot locations.
- Incident data provided from the U.S. seems to be inconclusive at this point. There are safety benefits provided from the European applications. However, the shoulder use is only a part of a much larger investment in ATM technology and resources to manage them.
- There have been longer incident clearance times in areas that don’t have shoulders available to move incidents off the highway. Also, responders don’t have the benefit of traveling the shoulder to reach the incident scene.
- European usage of hard shoulder running has always been accompanied by additional ATM strategies such as dynamic lane control signals and variable speed limits. These additional support strategies have generally been lacking in U.S. applications.

As a result of the information gained from this study, consideration should be given to the following:

- The FHWA should consider developing clearer agency guidance on the use of shoulders. This would need to be a joint effort from the Offices of Infrastructure (Design), Safety, and Operations (including how the Manual on Uniform Traffic Control Devices (MUTCD) relates to shoulder use lanes). The lack of existing U.S. performance data would also point to the need for more research in this area.
- Hard shoulder running was one of the ATM strategies recommended for implementation in the U.S. from a recent international scan. As FHWA and American Association of State Highway and Transportation (AASHTO) develop guidance on ATM, they should clarify guidance on temporary shoulder usage. This would include comparing the differences in current U.S. usage to that of the European countries.
- Research and modeling for temporary shoulder use is lacking at this time. This could be covered in research being developed for the ATM program.
- The results of the NCHRP/AASHTO/FHWA Domestic Scan on Maximizing Flow on Existing Highway Facilities should be considered in the development of shoulder use guidance

Chapter 1: Background

Scope and Purpose

This report was developed to summarize the implementation of safety shoulders as travel lanes as a method to more effectively use existing highway capacity. Its purpose is to provide a succinct overview of efforts to use left or right shoulder lanes as temporary or interim travel lanes. As part of this summary, information related to the impact of that shoulder usage on highway safety and/or accidents during operations was reviewed as well. The intent of the report is to provide critical information that the Federal Highway Administration (FHWA) can use to formulate guidance for agencies on providing temporary shoulder use as a means of increasing roadway capacity. The study that resulted in this report was conducted at the request of Congress through the 2008 Technical Corrections Act.

Document Overview

This document is divided into five chapters that discuss in detail the results of the study and the critical issues and findings related to the use of shoulders for increasing capacity during congested travel periods. The titles of each chapter and major topics covered are highlighted below.

- **Chapter One—Background:** Provides an overview of the document including its scope and purpose, intended audiences and uses, and background information on the roles that planning and project development play in the decision to use a shoulder as a travel way to increase capacity and enhance mobility.
- **Chapter Two—Context and Findings:** Discusses the concept of shoulder use within the context of active traffic management (ATM) and summarizes the domestic and foreign experience with this operational strategy and those that are complementary to its deployment.
- **Chapter Three—Critical Issues:** Gives a brief overview of the critical issues that need to be addressed when considering the use of shoulders for temporary capacity increase on congested freeways.
- **Chapter Four—Case Studies:** Provides case studies of European and domestic applications of shoulder use.
- **Chapter Five—Final Remarks:** Includes final remarks related to the document and its use and provides a complete list of references used in the development of this document.

Intended Audiences and Uses

The intended audience for this report is transportation professionals and agencies at the State, regional, and local levels involved in transportation planning, project development, and operations who may be considering the temporary use of a highway shoulder to increase capacity on a congested facility, be it for special users or general purpose traffic. It is anticipated that the information provided in this document will offer valuable insight for professionals and ensure that they carefully consider all aspects of shoulder use from the planning, design, operational, and safety perspectives prior to implementation. Moreover, agencies might factor potential shoulder use into the planning process as a potential operational strategy where capacity increases are limited. The report will also lay the groundwork for supporting project development efforts once the planning process is complete.

The Planning Framework and Shoulder Use

As modified and enhanced by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), the modern transportation planning process works to improve the transportation system and investment decision making associated with transportation projects. (2) Based on the paradigm shift from construction to system preservation, ISTEA identified critical issues related to transportation planning, including but not limited to:

- Linking transportation to the economic, mobility, and accessibility needs of the country.
- Emphasizing the participation of key stakeholders in the transportation planning process.
- Recognizing the constraints limiting expansion.
- Protecting the human and natural environments while providing accessibility to transportation services.
- Linking transportation planning to the air quality objectives in the Clean Air Act amendments and State air quality plans. (3)

The Transportation Plan

The transportation plan (also known as the long-range transportation plan, metropolitan transportation plan, regional transportation plan, etc.) is a statement of the way in which the region plans to invest in the transportation system. (4) This 20-year document, which must be updated on a periodic basis (typically every 5 years, but every 3 years for nonattainment and maintenance areas), sets the stage for transportation investment in the region by mapping general strategies for improving the safe and efficient movement of people and goods throughout the area. Operational strategies, which might include temporary use of shoulders during peak periods or measures such as managed lanes, can be part of this plan.

The Transportation Improvement Program

The transportation improvement program (TIP) is a short-range document related to the transportation plan. Covering a minimum 3-year period of investment, this fiscally constrained document identifies the immediate high-priority projects and strategies as outlined in the transportation plan and advances them for implementation. (4) In short, the Metropolitan Planning Organization (MPO) takes those projects in the transportation plan and lays out which of them can realistically be undertaken with the limited resources available over the next several years. The TIP is incorporated into the statewide transportation improvement program (STIP) and must conform to the state implementation plan (SIP) for improving air quality for projects to move forward to implementation.

Planning Process Elements

The elements of the metropolitan transportation planning process include public involvement, planning factors, management systems input, major investment studies (MIS), the air quality conformity process, and the financial plan. Ways in which temporary shoulder use for capacity increases and other operational strategies may impact these elements are as follows:

- Public involvement when planning operational improvements helps ensure that all of the social, economic, and environmental consequences of investment decisions are considered and that the MPO has the broad support of the community.
- The goals and objectives of various operational strategies easily fit within the general planning factors in the transportation planning process.
- Congestion management systems might consider shoulder operational strategies, whose goals and objectives work in concert with the system, to maximize the efficiency potential for the transportation network.
- Incorporating shoulder use operational strategies as potential solutions in the major investment study can help address the factors influencing project solutions while efficiently and effectively meeting the needs of the community.
- Shoulder use strategies that involve pricing may present transportation agencies with an opportunity to capitalize on innovative techniques to balance financing with regional goals.

Developing the Transportation Plan with Shoulder Use in Mind

Figure 1 and 2 outline the basic steps in the general planning process and the Transportation Improvement Plan process. These figures indicate where the critical consideration of operational strategies such as temporary shoulder use fits into the process. Regional planning and corridor- and facility-level planning through the MIS process are all part of developing the 20-year regional transportation plan. Once projects get placed on the TIP and the STIP, they move to implementation. It is important to note that the MPO, FHWA, and the Federal Transit Administration (FTA) check for conformity with the SIP at the plan, TIP, and project levels. Once again, public involvement throughout the entire planning process cannot be overlooked. It helps an MPO develop a comprehensive plan for transportation improvements that is responsive to the community and its needs.

Incorporating shoulder use for capacity increases into the planning process requires agencies to consider various planning-related issues from a slightly different perspective. While all of the planning considerations listed below are general transportation factors that can apply to virtually any mode, they are listed here within the shoulder use context. Throughout the entire planning process, the MPO should consider these issues when assessing shoulder use strategies as potential solutions to the region’s transportation needs and when formulating the plan and TIP. The typical shoulder use planning considerations include but are not limited to the following:

- Geometric design and cross-section.
- Decision making needs and traffic-control devices.

- Enforcement.
- Environmental justice.
- Evaluation and monitoring.
- Funding and financing.
- Incident management.
- Maintenance.
- Interoperability and technology components.
- Public outreach and education.
- Legal and institutional challenges.
- Operational flexibility.
- Pricing as an option.

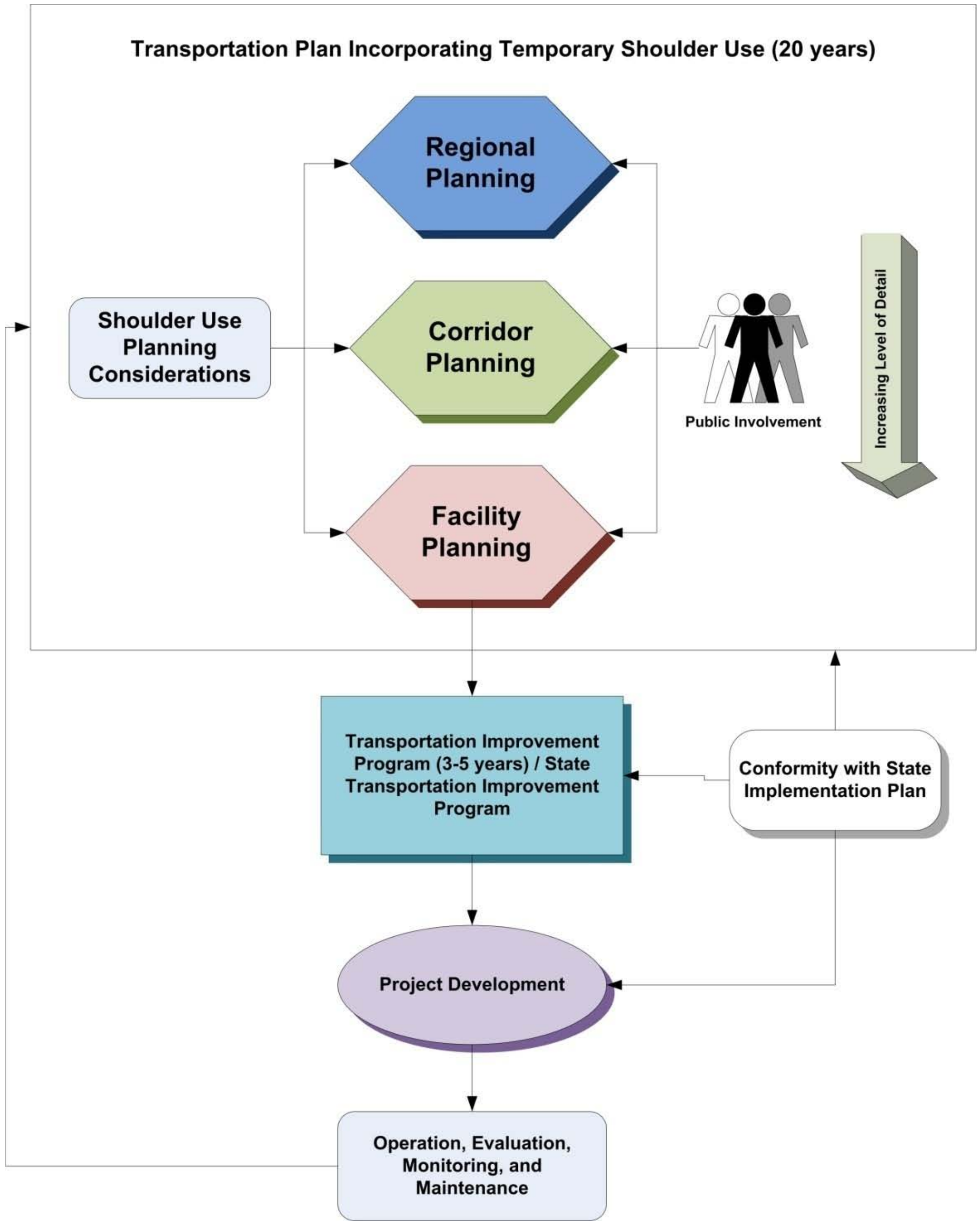

Figure 1. Flowchart. Developing the Transportation Plan [4]

In many areas temporary use of shoulders has been implemented as a low-cost interim solution. Whereas the ultimate plan is a much more costly widening project or reconstruction, given the need to develop transportation plans that are fiscally constrained, there might be more opportunities for operational-based, lower-cost projects in the near term.

One area that is lacking is historical data for use in traditional planning models. To that extent, additional modeling and research efforts are needed to fill this gap in data.

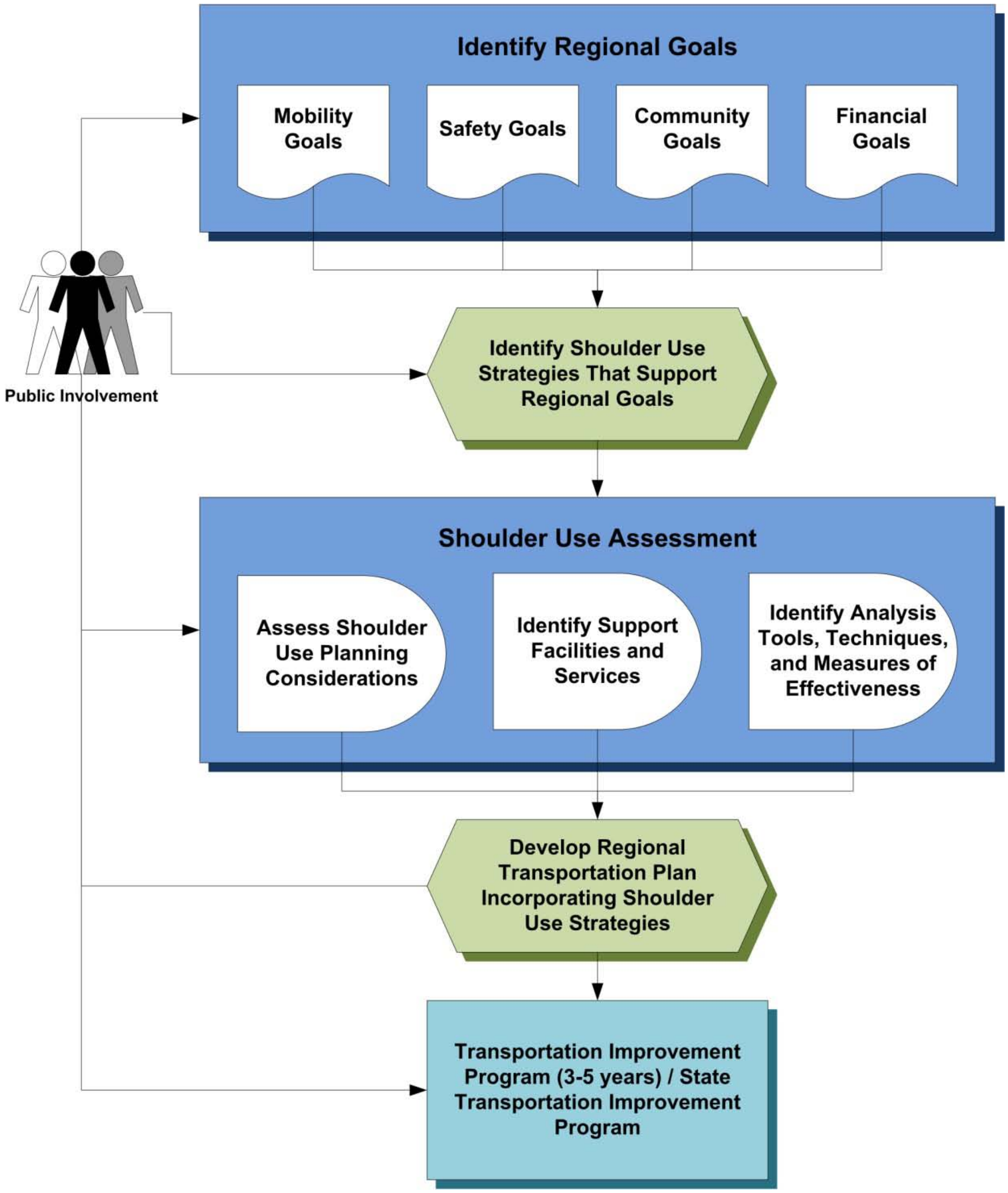

Figure 2. Flowchart. The Regional Context and Shoulder Use.

Project Design

During project design, agencies must engage in even more detailed planning and design to ensure that all aspects of shoulder use operational strategies are considered and assessed for a particular facility. Design standards dictate project design. By their very nature, temporary shoulder usage projects run contrary to most design standards for highways since they have a requirement for shoulders. Therefore, almost any project proposing to use the shoulder as a travel lane is going to involve a design exception. These design exceptions will need to be analyzed on a case-by-case basis with particular emphasis given to the safety elements of the roadway. This will involve geometric design elements of the roadway, traffic volumes and congestion, and crash history. Careful consideration of these issues at the facility level can help ensure that the shoulder use operational strategy is effective in meeting the goals and objectives for the corridor, enhance operational flexibility, and optimize use over the life of the project. These parameters include but are not limited to the following:

- Design vehicle.
- Design speed.
- Access control, design, and spacing.
- Signing and pavement markings.
- Driver information.
- Safety.
- Acceleration and deceleration distance.
- Vertical clearance.
- Lateral clearance.
- Drainage.
- Toll collection.
- Interoperability.
- Incident management.
- Design flexibility for future needs.

The careful consideration of the parameters shown above are important factors when planning a facility and should be considered in project's development.

After identifying and assessing the design parameters and additional shoulder use considerations for a facility, the MPO and stakeholder groups need to assess the specific operating strategy(ies) for a facility. The factors to consider in this assessment include but are not limited to the pricing approach, time period variations and their impact on hours of operation, enforcement issues, incident management, evaluation and monitoring, marketing, and operations during construction. After careful assessment of all of these issues, the agencies can identify the most appropriate strategy or combination of strategies for a facility.

Chapter Summary

This document summarizes the implementation of safety shoulders as travel lanes as a method to increase the performance of the existing highway's capacity. Its purpose is to provide a succinct overview of efforts to use left or right shoulder lanes as temporary or interim travel lanes.

This chapter presents an introduction to the report, outlines the basic steps of the general planning process and where the critical consideration of shoulder use operational strategies fits into that process, and discusses design considerations. The reader should also have an appreciation of the shoulder use planning considerations that should be specifically addressed at the regional, corridor, or facility level in the process. Additionally, this chapter discusses the project development process as impacted by the consideration of shoulder use operational strategies. It presents the general steps in this process and offers insight into how an agency might incorporate shoulder use operational strategies to best meet the needs of the community at the corridor and facility levels. The reader should understand the importance of public and agency input, project identification and shoulder use assessment and project design.

Chapter 2: Context and Findings

Congestion in urban areas in the United States is increasing. It occurs on more roads during longer parts of the day, delaying more travelers every year. (6) The "rush hour" grows longer and costs Americans dearly in the form of delay, increased fuel consumption, lost productivity, and related crashes. Congestion interferes with daily life, and any method to alleviate it, such as managed lanes projects, can help reduce its impact on productivity. Another reality of improving the transportation infrastructure today is that agencies must function within environmental constraints. Agencies must consider the environment in the planning of transportation projects, minimize the negative impacts of construction, and work to reduce transportation-related pollution in the process. They must demonstrate environmental stewardship and improve the environmental quality of their transportation decision making. (7)

Congestion Management and Mitigation

Congestion management is a primary operational strategy that U.S. agencies use to operate their facilities. As illustrated in Figure 3, a variety of factors, both recurring and non-recurring in nature, cause congestion for American travelers. Thus, FHWA has designated congestion mitigation as one of its top priorities and is targeting resources on developing and sustaining regional partnerships to address all aspects of congestion. (8)

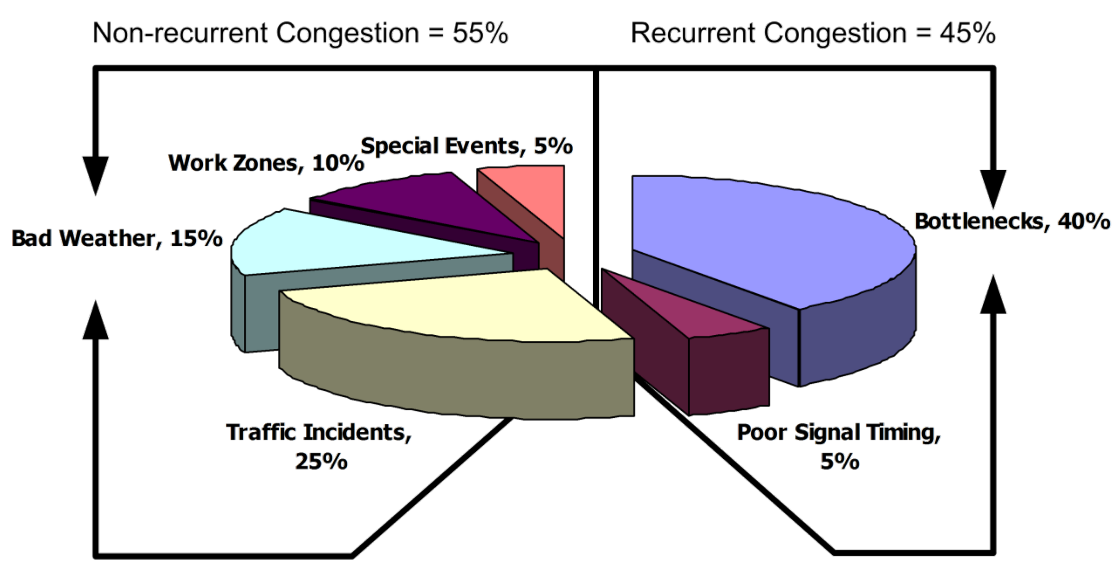

Figure 3. Graph. Causes of Congestion in the United States. (8)

Various operational and management strategies and methods exist for mitigating congestion and its impact on roadway users. For example, to combat recurring congestion in the highway environment, which accounts for approximately 45 percent of all congestion in the United States, agencies undertake freeway management and traffic operations through policies, strategies, and actions to enhance mobility on highway and freeway facilities. (8) These strategies include but are not limited to roadway improvements such as widening and bottleneck removal, operational improvements, ramp management and control, managed lanes, and ATM. Mitigation techniques for non-recurring congestion include incident management, work zone management, road weather management, and planned special events management. [8] All of these strategies center around the theme of increasing the efficient use of existing facilities. The following sections highlight two major categories of operational strategies that can be considered for deployment in shoulder use situations where capacity increases are not possible: managed lanes and ATM.

Managed Lanes

The term "managed lanes" refers to an array of lane management strategies. These lanes are managed through the application of pricing, vehicle eligibility, or access control to expedite the flow in that lane. Figure 4 illustrates the potential lane management strategies that fall into this broad definition of managed lanes. On the left of the diagram are the applications of a single managed lanes operational strategy—pricing, vehicle eligibility, or access control. In the middle of the diagram are the more complicated managed lanes facilities that combine more than one of the strategies. The multifaceted facilities on the far right of the diagram are those that incorporate or combine multiple lane management strategies.

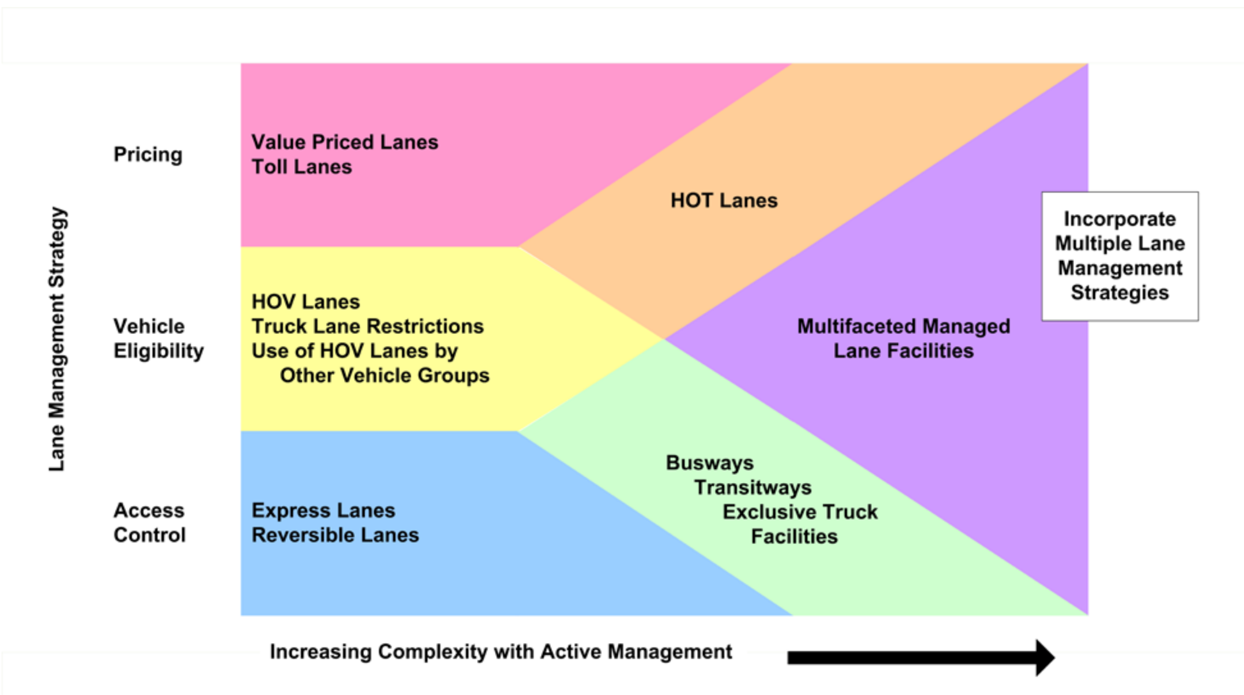

Figure 4. Graph. Lane Management Operational Strategies. [9]

According to FHWA, the distinction between managed lanes and other traditional forms of freeway lane management is the operating philosophy of "active management," where the operating agency proactively manages demand and available capacity on the facility by applying new strategies or modifying existing strategies to meet pre-defined performance thresholds. [10] It is important to note that this definition does not preclude active management on other lanes in the roadway network.

Active Traffic Management

A 2006 FHWA-sponsored International Scan Tour of Europe (FHWA Scan Tour) examined the congestion management programs, policies, and experiences of other countries that are either in the planning stages, have been implemented, or are operating on freeway facilities. This scan sought information on how agencies approach highway congestion and how they are planning for and designing managed lanes at the system, corridor, and project or facility level. The FHWA Scan Tour revealed a complete package of strategies that make up the broader concept of active traffic management. This approach to congestion management is a more holistic approach and is considered the next step in congestion management of freeway corridors.

The FHWA Scan Tour defined ATM as the ability to dynamically manage recurrent and non-recurrent congestion based on prevailing traffic conditions. (1) Similarly, the Transportation Research Board Joint Subcommittee on ATM defines it as the ability to dynamically manage traffic flow based on prevailing traffic conditions. (11) Focusing on trip reliability, the goal is to maximize the effectiveness and efficiency of the facility under both recurring and non-recurring congestion as well as during capacity reductions involving incidents or road work. Through the flexible use of the roadway, ATM aims to increase system performance as well as traveler throughput and safety through the use of strategies that actively regulate the flow of traffic on a facility. (11) ATM strategies can be automated, combined, and integrated to fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public. Typical ATM strategies within the freeway context include bus operation on roadway shoulders, temporary shoulder use on freeways by general traffic or high occupancy vehicle s (HOV), speed harmonization, queue warning, dynamic rerouting, ramp metering, and interchange junction control. This report focuses on the first two of these strategies.

Shoulder Use—The European Experience

In Europe, part-time shoulder use is a congestion management strategy typically deployed in conjunction with complementary traffic management strategies – such as variable speed limits (speed harmonization) and/or ramp metering – to address capacity bottlenecks on the freeway network. European implementers include The Netherlands, Germany, and Great Britain. The strategy provides additional vehicle-moving capacity during times of congestion and reduced travel speeds. The use of the exterior shoulder during peak travel periods has been used in Germany since the 1990s as illustrated in Figure 5. (12) When travel speeds are reduced, dynamic signs over or next to the shoulder indicate that travel on the shoulder is permitted.

A complete series of traffic signs indicate operations related to temporary shoulder use, including one with a supplemental speed limit indication (used when overhead gantries are not present). These signs and the overhead lane messages are blank when travel on the shoulder is not permitted. Temporary shoulder use is permitted only when speed harmonization is active and speed limits are reduced, thus providing an operating environment only when speeds are managed below posted levels.

Figure 5. Photo. Temporary Shoulder Use—Germany (13).

Generally, implementation of temporary shoulder use is at the discretion of the traffic management center operator, although traffic volumes help determine the need for the strategy. A typical installation in Europe incorporates a number of unique roadway features, which can include:

- Lightweight gantries.
- Lane control signals.
- Dynamic speed limit signals.
- Dynamic message signs.
- Automated enforcement technology.
- Closed-circuit television cameras.
- Enhanced lighting.
- Roadway sensors.
- Emergency roadside telephones.
- Advanced incident detection.
- Intensified incident management.
- Emergency refuge areas or pull-outs beyond the shoulder. (1)

Operation of the system is handled by the regional control center, with operators on hand to monitor the system and initiate the modified operations as necessary. Specifically, operators use closed-circuit television cameras (CCTVs) mounted on lightweight sign gantries or separately to check for incidents and stalled vehicles in the shoulder before activating the system.

In Great Britain, the first deployment of temporary shoulder use was part of a comprehensive traffic management system that also involved speed harmonization. Figure 6 shows the installation of the temporary shoulder use including a critical component, which is the installation of emergency refuge areas at 500-meter (m) intervals along the shoulder, each equipped with an emergency call box.

Figure 6. Photo. Shoulder Use with Emergency Refuge Area—Great Britain. (1)

Plus Lane

The Netherlands, in addition to allowing temporary use of the right shoulder, also deploys temporary use of the left shoulder under congested conditions, as shown in Figure 7. The left lane, or plus lane, is opened for travel use when traffic volumes reach levels that indicate congestion is growing. As in Germany, temporary use of the left lane is allowed only when speed harmonization is in effect. Additional facilities implemented to mitigate any adverse safety consequences of temporary shoulder use include overhead lane signs, emergency refuge areas with automatic vehicle detection, speed reduction, variable route signs at junctions, advanced incident detection, CCTV surveillance, incident management, and public lighting. (14)

Figure 7. Photo. Plus Lane—The Netherlands. [(1)]

Junction Control

A variation of temporary shoulder use deployed in Germany is junction control, a combination of ramp metering and lane control at on-ramps. [(15)] Typically, the concept is applied at entrance ramps or merge points where the number of downstream lanes is fewer than upstream lanes. A graphic illustrating the concept is shown in
Figure 8.

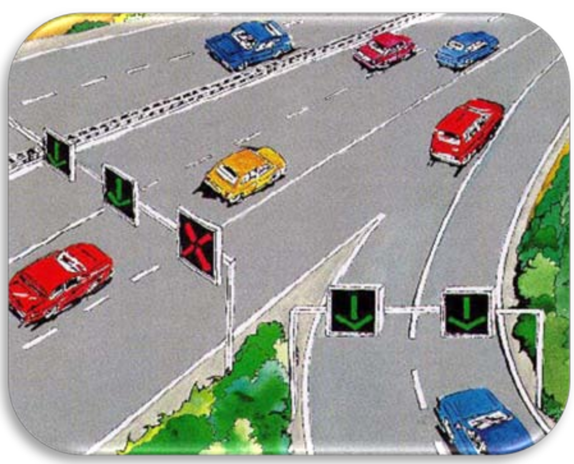

Figure 8. Graphic. Junction Control Schematic in Germany. [(16)]

In Europe, these strategies for managing recurrent congestion work to improve traffic flow and safety. The following is a summary of the three countries that are the main users of this strategy in Europe.

The Netherlands

The Netherlands implemented temporary right shoulder use—also known as hard shoulder running or the rush hour lane—in 2003 as part of a larger program to improve use of the existing infrastructure. Operated by the National Traffic Control Center (NTCC) and regional control centers since 1981, temporary shoulder use is utilized on more than 1,000 km (620 mi) across The Netherlands. Typically, a gantry with lane control signals indicates when the shoulder is available for use. Where a shoulder lane passes through a junction and at the end of a hard shoulder running section, guidance information will change according to lane use. (14) In addition to allowing temporary use of the right shoulder, the Dutch also deploy the use of traveling on a dynamic lane on the median side of the roadway. This treatment—also known as the plus lane—is a narrowed extra lane provided by reconstructing the existing roadway while keeping the hard shoulder and is opened for travel use when traffic volumes reach levels that indicate congestion is growing. Deployment is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator. It only operates during time periods of congestion or when incidents occur along instrumented roadways.

Germany

Since 1996, Germany has deployed temporary shoulder use—also known as hard shoulder use—to provide additional capacity during times of congestion and reduced travel speeds. Operated by the Federal Ministry of Transport and regional traffic management center on more than 200 km of roadways across the country, temporary shoulder use is only deployed in conjunction with speed harmonization (also known as line control) when maximum allowable speeds are 100 km/hr (62 mph) and if dynamic message signs are used for lane control. The deployment of the variable speed limits is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator.

Great Britain

Temporary shoulder use in Great Britain is deployed as part of an overall operational ATM scheme. Operated by the Highways Agency since 2006, temporary shoulder use is only deployed in conjunction with variable speed limits and when speeds are reduced (initially to 50 mph). Deployment of variable speed limits is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator. It only operates during time periods of congestion or when incidents occur along instrumented roadways, and between junctions, requiring users to exit at each junction and reenter the roadway beyond.

Shoulder Lanes—The American Experience

In the United States, the primary use of shoulders has been as a safety refuge area. The limited shoulder use as a travel lane has been primarily reserved for special users of the roadway system, most often transit vehicles. Some shoulder use dates back to the 1970s, and many installations have been in operation for more than 10 years to address congestion on urban corridors. (17) Agencies have seen bus use of shoulders as a low-cost and quick strategy to improve bus operations and reliability without having to acquire additional right-of-way and invest additional large sums of money into the infrastructure. The length of these deployments varies depending on location, ranging from a more than 290-mi comprehensive network in the Minneapolis-St. Paul metropolitan area to deployments less than 1 mi in length used to serve as a queue jump for transit in Delaware. The operational strategies often depend on the congestion on the general purpose lanes and often require speed restrictions of the transit vehicles using the shoulders. (17) Overall, experience using shoulders for interim use has been positive in the United States, and more agencies are considering the strategy to address growing congestion on their urban freeway networks. In fact, several States have deployed temporary shoulder use for all vehicles on congested corridors with success. Another application that is much more difficult to research and document is the number of locations where an existing shoulder has been narrowed or taken away to allow for widening with an extra permanent travel lane. This method is more commonly used in roadway work zones to maintain the existing number of travel lanes during construction. However, it has been applied in some permanent forms as well. The following sections briefly describe the shoulder use treatments deployed in the United States and provide summary details about the deployments of those treatments in specific States.

Bus on Shoulders

Bus on shoulders (BOS) programs, generally considered special-use applications of dedicated shoulder lanes, are most often implemented as a means of increasing the reliability of transit service in congested corridors in order to encourage increased use by the public. The BOS programs are operational on over 290 mi of freeways and arterials in the Minneapolis metropolitan area. Shown in Figure 9, this operational strategy is generally a low-cost and quickly implemented solution that does not require costly expansion of highway right-of-way. It may be implemented on both highway and arterial corridors, but arterial BOS applications must often rely on additional operational treatments such as signal prioritization in order to maintain a time advantage over automobile travel. In addition to Minneapolis, BOS programs are operational in the States of Virginia, Maryland, Washington, New Jersey, Georgia, Delaware, Florida, and California; in Canada (Vancouver, Toronto, and Ottawa); and in Ireland and New Zealand. (17)

Besides stand-alone BOS operations, BOS may also be implemented in conjunction with a separated managed lane facility. Bus lines running a station-stopping operation along a median HOV or high occupancy/toll (HOT) lane may benefit greatly from the implementation of a BOS program. Such routes often make frequent stops at intervals of less than a mile between successive stops, which can pose significant problems with regards to weaving into and out of the HOV or HOT lane facility they access. This weaving can cause backups and disruptions on both the interior managed lane facility as well as the adjacent general purpose lanes. A BOS program ensures that buses can achieve significant travel time savings without the need to enter the interior managed lane facility and weave through general purpose traffic to enter or exit an interior managed lane. The following sections summarize the deployments of BOS in operation across the United States.

Figure 9. Photo. Bus on Shoulders—Mn/DOT (Photo courtesy of Mn/DOT).

California

In San Diego along I-805/SR 52, transit vehicles may use the freeway shoulder during congested periods. Initiated in 2005, this application was intended to increase transit speeds and to improve schedule reliability. Operating agencies are the California Department of Transportation (CALTRANS) and the San Diego Association of Governments. Transit vehicles may use the shoulder when general purpose lane traffic slows to 30 mph or lower. They may travel no more than 10 mph faster than traffic in general traffic lanes. The cross-section of the shoulder is at least 10-ft wide throughout the deployment area. Pavement markings to indicate the operational strategy include text indicating “Transit Lane Authorized Buses Only.” (17)

Delaware

Along US 202 in Wilmington, Delaware, buses are allowed to use an arterial shoulder. Operational for many years, this treatment is intended to provide a southbound queue jump along a 1,500-ft-long section of the facility, which includes an intermediate signal. The application provides priority for transit vehicles bound for I-95. Operational 24/7, the treatment is denoted with the diamond symbol on the pavement and lane control signals over the shoulder. (17)

Florida

The Florida Department of Transportation, Miami Dade Transit, and the Miami Dade Expressway Authority operate several shoulder use applications in the Miami region. Along the Florida

Turnpike, SR 826, and SR 836, buses are allowed to use the shoulder when the freeway is congested. Implemented in 2005, the program stipulates that buses may travel no faster than 35 mph on the shoulder when open to transit. The typical cross-section is a minimum 10-ft width with a 12-ft width in high volume areas and cross slopes of 2 percent to 6 percent. Pavement markings indicate "Watch for Buses on Shoulder." (17)

Georgia

Alpharetta, Georgia (suburban Atlanta), is another location where shoulder use is available to transit. On GA 400, buses are allowed to use the freeway shoulder in an effort to provide access between a Metropolitan Atlanta Rapid Transit Authority rail station at North Springs and a park-and-ride lot at Mansell Road. In operation since 2005, the 12-mi facility allows transit vehicles to save between 5 and 25 minutes during heavily congested periods. The Georgia Regional Transportation Authority and Georgia Department of Transportation operate the facility, which is functional whenever traffic slows to 35 mph or slower. Buses can travel no more than 15 mph faster than general purpose lane traffic and are required to reenter general traffic lanes before interchanges. The installation cost 2.8 million dollars in order to widen the shoulder by 2 ft and to provide reinforcement of the shoulder pavement. (17)

Maryland

Two shoulder use applications are in operation in Maryland. The first, along US 29 in Burtonsville, is an arterial shoulder application in both the southbound and northbound directions of the corridor. The 4-mi arterial highway segment provides shoulder use queue jumps at several signalized junctions for transit users. Operational for years, the treatment operates Monday–Friday from 6:00 a.m. until 9:00 a.m. in the southbound direction and from 3:00 p.m. until 8:00 p.m. in the northbound direction. The second treatment, in Bethesda, provides buses with a shoulder queue jump in the northbound direction of I-495 at the I-270 interchange. This queue jump is about 3 mi in length and has been operational for years. The intent of the treatment is to allow transit vehicles to bypass congestion at the I-270 interchange. Hours of operation are Monday–Friday, 6:00 a.m.–9:00 a.m. and 3:00 p.m.–7:00 p.m. The maximum allowed speed on the shoulder is 55 mph. (17)

Minnesota

The Minneapolis-St. Paul region has a comprehensive network consisting of over 290 mi of BOS operations on freeways and arterials, on sections with ramp meters, and in rural and urban areas. The BOS deployments are along segments as small as 0.3 mi to up to 9 mi in length. Initially deployed in 1992 and still being expanded, these deployments are intended to encourage transit use and to fully utilize the capacity of the metropolitan highway system. The operational partners of these facilities include the Minnesota Department of Transportation (Mn/DOT), Metro Transit and other transit agencies in the region, charter bus companies, Minnesota State Patrol, and local police departments. The operational strategy is considered interim, and some deployments have been removed since their inception. When operational, buses must yield to any vehicle entering, merging, or exiting through the shoulder. Buses must reenter the main lanes when the shoulder is obstructed. Typically, buses may use the shoulder any time that traffic in the adjacent mainlines is moving at less than 35 mph. Buses may travel no more than 15 mph faster than mainline traffic with a 35 mph maximum allowed speed on the shoulder. The typical cross-section is 10-ft minimum, 11.5-ft minimum at bridges, and 12-ft minimum on new construction. Typically, buses travel through the entrance and exit ramps; where queues are long at ramps with metering, buses typically merge with traffic on the ramp and return to the shoulder after the ramp. (18)

New Jersey

In Mountainside, New Jersey, along Route 22, buses are allowed to use the shoulder of the arterial in the eastbound direction during congested periods. Operational for years, this shoulder use treatment was intended to allow transit vehicles to save travel time along the corridor toward Perth Amboy for about 1 mi. The facility is operated by the New Jersey Department of Transportation, and pavement markings indicate "Buses May Use Shoulder." (17)

Virginia

The Dulles Access Highway (Route 267) in Falls Church, Virginia, provides buses with an eastbound queue jump along a 1.3-mi segment. Operational for years, the treatment helps ease congestion for buses during the evening commute and facilitates bus access to the West Falls Church Metrorail station. Operated by the Virginia State Police, the Metropolitan Washington Airports Authority, and the Virginia Department of Transportation (VDOT), the shoulder treatment is available Monday–Friday from 4:00 p.m. until 8:00 p.m. The maximum allowed speed for buses on the shoulder is 25 mph. (17)

Washington

Along SR 520 in the Seattle, Washington, region, buses and carpools of at least three people may use the freeway shoulder in the westbound direction from I-405 to the Evergreen Bridge over Lake Washington. Operational since the 1970s, this 2.7-mi application operates 24 hours a day, 7 days a week. Buses can travel at the same speed as other general purpose lanes, but must merge with regular traffic at interchanges. The typical cross-section of the shoulder is 13-14 ft. (17)

Dedicated Shoulder Lanes

Since the 1950 publication of the Highway Capacity Manual and 1957 AASHTO Red Book, 12-ft shoulders have been the interstate design standard for urban freeways. (19) Furthermore, a minimum of 4.5-ft lateral clearance is required, with 6–8 ft recommended in the vicinity of pier structures. However, by the 1980s, in response to rising levels of congestion and a lack of right-of-way for contemporary expansion of capacity, many States adopted the use of dedicated shoulder lanes, sometimes in conjunction with or instead of narrowed lane widths. (20) By the 1990s, only four States had chosen to extensively use shoulders and/or narrow lanes on freeways: California (Los Angeles and Bay Area), Texas (Houston), Virginia (Fairfax County), and Washington (Seattle). Figure 10 shows a converted shoulder lane in California.

Figure 10. Photo. Converted Shoulders on I-5—California (Photo Courtesy of CALTRANS).

In dedicated shoulder-lane operations, either general purpose or HOV-specific capacity has been added through the permanent conversion of shoulders. Most HOV applications use the interior lane for HOV operations, while the exterior shoulder is used for general purpose traffic so as to maintain the same number of general purpose lanes that existed prior to implementation. A typical HOV application would convert a three-lane freeway with 12-ft lanes, 10-ft exterior shoulder, and 8-ft interior shoulder to 11-ft general purpose lanes, 14-ft (including buffer striping) HOV lane, 5-ft exterior shoulder, and 2-ft interior shoulder. [21]

In addition to HOV and general purpose capacity, additional existing uses of shoulders include auxiliary lanes, either between interchanges or in merge zones (particularly those that impede upstream traffic on the mainline); lane balancing requirements through bottlenecks; and creation of uniform lane widths. [19]

In most of the above conditions, the shoulders have been converted to general purpose capacity, at least for a short distance. However, in a few applications, the implementing agency has attempted to recover use of the shoulder for refuge purposes during some portions of the day. On Massachusetts State Route 3 and I-93 and I-95 in the Boston area, all vehicles are permitted on shoulders in the peak periods only. Similarly, in Virginia on I-66 (as shown in Figure 11), the shoulder carries general purpose traffic from 5:30 a.m. –11:00 a.m. (eastbound) and 2:00 p.m.–8:00 p.m. (westbound); however, during this time, the interior general purpose lane is open to HOV traffic only. I-66 uses extensive traffic signals and signage in order to communicate the active times of service. In the Seattle area, the right shoulder on the US 2 trestle near Everett is opened to all traffic in the eastbound direction during the afternoon peak period. A similar operation is provided on H1 in Honolulu in the morning peak on the right shoulder. The following sections provide a summary of those States where temporary shoulder use is available for all vehicles during congested periods.

Figure 11. Photo. I-66 HOV/Shoulder Lane Adaptation—Virginia (Photo Courtesy of VDOT).

Florida

As part of an Urban Partnership Agreement project, the Florida Department of Transportation (FDOT), the Miami-Dade MPO, the Broward MPO, Miami-Dade Transit, Broward County Transit, the Miami-Dade Expressway Authority, and the Florida Turnpike Enterprise have incorporated a shoulder into the I-95 Express lanes in Miami. (22) The objective of the project is to provide free-flowing conditions on the managed-lane network and to provide a network of managed lanes throughout the congested region. Between I-395 and I-595, FDOT converted the existing single-lane HOV lane to a two-lane HOT facility by reducing multiple general purpose and HOT lane widths to 11 ft and narrowing the shoulder. The new lanes allow registered vanpools, registered carpools of three people, registered hybrid vehicles, motorcycles, and buses to travel at no charge. All other vehicles with the exception of trucks with three or more axles may pay a toll to use the lanes. With initial sections opening in 2008, the facility uses variable pricing based on demand, and maximum allowed speeds are 55 mph. Operational regulations and toll rates are displayed on overhead electronic signs. The overall cost of the project is 43.4 million dollars. Florida's Turnpike Enterprise enforces toll violations using license plate photographs. The Florida Highway Patrol enforces occupancy requirements using visual inspection. Incident management is handled by the Road Rangers motorist assistance patrol and the Florida Highway Patrol. Outreach efforts for the project include project Web sites, public meetings, media campaigns, and the production of videos.

Hawaii

In Honolulu, Hawaii, the Hawaii Department of Transportation deploys temporary shoulder use on H1 in the morning peak. The intent is to provide congestion relief and added capacity during the morning rush hour in the eastbound direction.

Massachusetts

Various facilities in the Boston area utilize temporary shoulder use during peak travel periods. (23) On I-93, SR 3, and I-95, all vehicles except heavy trucks may use the freeway shoulder during either the morning and/or evening peak depending on the facility. The objective of these treatments is to increase capacity. When the treatment was initiated, congestion on these facilities was to the point where traffic during the peak period was at a standstill and drivers were already using the shoulders. The Massachusetts Department of Transportation (MassDOT), Massachusetts State Police, and Commerce Insurance Courtesy Patrol all assist with the operation of the facility. With each deployment, MassDOT sought approval from FHWA to seek implementation as a temporary measure until funding and approval is obtained for widening. However, each project when constructed was treated as a traditional widening with drainage being moved to the new edge of the pavement and guardrails and fixed object shielding being moved accordingly as well. The typical design is a 10-ft minimum width and a 12-ft desirable width. Rumble strips were removed and scored concrete and block pavers removed as well. Emergency pull-outs are located approximately every ½ mi along the deployment sections.

Minnesota

In Minneapolis along I-94, the freeway shoulder was opened to all traffic in 2007 in response to the bridge collapse on I-35 W. (24) All vehicles were allowed to use the shoulder, which was originally only available to transit vehicles during peak periods. The objective of the treatment was to reduce congestion levels to pre-bridge collapse conditions by providing additional capacity through utilization of existing shoulders. Operational at all times, the shoulder provides an 11-ft travel lane with no additional shoulder on the right side. Traditional lane skip stripe and right shoulder markings are installed, and the existing BOS signs were removed. Incident response along the facility is handled by the Freeway Incident Response Safety Team (FIRST) led by Mn/DOT. Patrols were increased in the area once all vehicles were allowed to use the shoulders.

Virginia

In the suburban Washington, D.C., area, all vehicles are allowed to use the right shoulder on I-66 during peak periods. (25) Originally opened in 1992, the VDOT allows vehicles to use the eastbound shoulder from 5:30 a.m. until 11:00 a.m. and the westbound shoulder from 2:00 p.m. until 8:00 p.m. The treatment was initially installed as a stop-gap measure to add capacity because of the opening of the HOV lane, where the left lane was taken. However, it has become a long-term strategy because of funding shortfalls. Maximum allowed speeds are 55 mph, and the shoulder provides a

12-ft travel lane. An overhead lane control system is operational to indicate to motorists that the shoulder is open. Post-mounted signs also provide notification and termination of restricted use and indicate the presence of emergency pull-off areas. The VDOT hires a contractor for general maintenance of the facility, while VDOT maintains the Intelligent Transportation System (ITS) installation. Incident clearance time is within 90 minutes 90 percent of the time, as typical for the region.

Washington

Along US 2 in Seattle, the Washington State Department of Transportation (WSDOT) opened the freeway shoulder to all traffic in the eastbound direction of the trestle. [26] The objective of the treatment was to improve travel times on the trestle, to reduce impacts of bottlenecks, and to relieve congestion at a critical interchange. The restriping along the 1.55-mi segment allows three different movements to remain in their own lanes when shoulder use is allowed. It also minimizes weaving so that each destination from the trestle (SR 204, 20th St SE, and US2 eastbound) can be reached from a separate lane when shoulder use is allowed. The WSDOT considers the application permanent for the near future as it should be able to accommodate traffic growth over the next few years. Hours of operation are Monday–Friday, 3:00 p.m. to 7:00 p.m. Maximum allowed speeds are 60 mph. The trestle was restriped with a 2-ft left shoulder, two 11-ft lanes, and one 14-ft right shoulder.

Priced Dynamic Shoulder Lanes

A unique combination of strategies is operational on I-35W in Minneapolis where a segment has the left shoulder open during the peak periods. Known as priced dynamic shoulder lanes (PDSL), transit and carpools use the shoulder for free and MnPASS customers can use the shoulder for a fee. As shown in Figure 12, Figure 13, and Figure 14, the left shoulder is open to traffic, with overhead sign gantries indicating its operational status. When the general purpose lanes become congested, the shoulder is opened and the speed limit on the general purpose lanes is reduced.

Figure 12. Graphic. Open Priced Dynamic Shoulder Lane—Minneapolis, Minnesota. [27]

Figure 13. Graphic. Closing Priced Dynamic Shoulder Lane—Minneapolis, Minnesota. [27]

Figure 14. Graphic. Closed Priced Dynamic Shoulder Lane—Minneapolis, Minnesota. [27]

Minnesota

In Minneapolis, Mn/DOT converted a segment of the left shoulder on I-35W from BOS operations to a priced dynamic shoulder lane open to all vehicles. Opened in 2009 as part of Mn/DOT's Urban Partnership Agreement project, the section of I-35 between 42nd Street and downtown Minneapolis is open to buses, carpoolers, and MnPASS users during certain times when traffic is congested. [27] The objective of the project is to improve traffic flow using transit and tolling. The shoulder treatment was also deployed with variable speed limits on the general purpose lanes. Maximum allowed speeds are free-flow freeway speeds on the facility. The shoulder width varies from 17 ft to 19 ft between the barrier and the edgeline striping. Overhead gantries are spaced every ½ mi and include static signs and dynamic message sign (DMS) inserts indicating price and lane control signals. The cost of the deployment was 13 million dollars and included new pavement surface on all lanes in the area. The Minnesota State Patrol enforces the facility through visual inspection. The Mn/DOT is responsible for maintenance, and incident management response is primarily handled by the Minnesota State Patrol. Emergency pull-outs were installed along the right shoulder to facilitate emergency use. In terms of heavy vehicles, only two-axle trucks weighing less than 26,000 lbs can use the MnPASS Express Lanes.

Hurricane Evacuation Routes

Florida and Texas have incorporated the use of certain freeway shoulder lanes into Hurricane Evacuation Routes. These lanes are included in the Evacuation Route planning documents for full scale evacuations.

Complementary ATM Strategies

European applications of the use of shoulder lanes are typically accompanied by one or more ATM operational strategies for a more comprehensive control of the capacity. When these strategies are implemented in concert with temporary shoulder lanes, they fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public. The more frequently used complementary strategies include speed harmonization and junction control. The following sections discuss these strategies to provide a framework for their impact on shoulder use for travel lanes.

Speed Harmonization

Speed harmonization helps manage traffic by posting speed limits on a roadway or over each lane on an advisory or regulatory basis in real time, sometimes referred to as variable speed limits in the U.S. This approach has been in use in Germany since the 1970s and is oriented toward improving traffic flow based on prevailing conditions. Similar installations are in operation in The Netherlands and Great Britain on various roadway sections with high traffic volumes. A typical installation of speed harmonization monitors traffic volumes and weather conditions along the roadway. If sudden disturbances occur in the traffic flow—such as with an incident or building congestion—the system modifies the speed limits upstream accordingly, providing users with the quickest possible warning that roadway conditions are changing. (28)

Figure 15 shows a typical installation of speed harmonization in The Netherlands. The deployment of the speed harmonization is automatic and begins immediately upstream of the congestion point; it does not require remote operator intervention. The system incrementally decreases speeds upstream in a cascading manner often in increments of 10 to 20 km/h to smooth the deceleration of the traffic and help ensure more uniform flow to offset what would otherwise be sudden queues emanating from the incident. When deployed with temporary shoulder use, this strategy works to minimize the speed differential between vehicles in the general purpose lanes and those on the shoulders. Such a combined operation helps to increase the uniformity of traffic flows and reduce the possibility of incidents due to erratic maneuvers and unpredictable driver behavior.

Figure 15. Photo. Speed Harmonization—The Netherlands.

Junction Control

A variation of temporary shoulder use—known as junction control in Germany—involves dynamic lane assignment. Typically, the concept is applied at entrance ramps or merge points where the number of downstream lanes is fewer than upstream lanes. (15) The typical U.S. application to this geometric condition would be a lane drop for one of the outside lanes or a forced merge of two lanes, both of which are static treatments. (29) The German dynamic solution is to install lane control signals over both upstream approaches before the merge (as shown previously in Figure 8), and provide downstream lane priority to the higher volume and dynamically post a lane drop to the lesser volume roadway or approach. This is particularly effective when implemented with temporary shoulder use at on-ramp locations where bottlenecks frequently form.

Chapter Summary

Many urban corridors in most large cities have been expanded to the extent feasible from subsequent widening projects, leaving few options to improving performance and efficiency other than ATM strategies. Limited resources require investments in strategies that generate greater efficiencies without requisite environmental or safety impacts. The current fiscal and physical environment lends itself to greater reliance on these strategies. Identifying potential active management projects and planning for them is a complicated process that involves numerous stakeholder groups. Addressing the interrelationships associated with these projects in the planning and development process is critical to their successful implementation and operation.

The summary of shoulder use applications provides a stark contrast between European and U.S. applications. Part-time shoulder use in Europe is exclusively done as part of a broad application of active traffic management strategies. The domestic applications have tended to be more ad-hoc and have much less consistency from one application to the next. The one exception is the PDSL in Minnesota, which has an active traffic management design.

Chapter 3: Critical Issues

The primary concern related to shoulder use involves its impact on operations and safety. The purpose of this project was to assess the deployments of shoulder use in the United States and determine the impacts on, the experience with, and the addressing of the following safety issues:

- Conflicts at access ramps.
- Sight distance.
- Conflicts with motorists pulling onto the shoulder for emergency purposes.
- Loss of use of the shoulder for emergency refuge.
- Need for bus driver training.
- Speed differential between the general purpose lanes and the shoulder.
- Effect on general purpose lane users.
- Return merge distance adequacy.
- Debris hazards on shoulder.
- Reduced bridge clearance.
- Drainage.
- Operational efficiency.
- Crash experience.

By providing a summary of this information and data related to shoulder use experience, it is expected that the project can assist FHWA with developing guidance on the subject and identifying what, if any, research needs to be conducted to address unknowns related to the operational strategy and its potential long-term and widespread use in the United States.

Through the course of this effort, the project team conducted a thorough informational scan and literature search to identify the existing state of the practice and relevant traffic and safety information associated with safety shoulder usage. Furthermore, they conducted personal telephone interviews to seek additional direct input from various agencies that are known for their use of shoulders for interim or long-term congestion relief. The study regions interviewed were Minneapolis-St. Paul, Virginia, Massachusetts, and Washington. The following sections highlight the critical operations and safety issues related to shoulder use that arose from these activities. Individual case studies on several operational facilities are included in Chapter 4. The interview questions used by the project team are included in appendix A.

Design

It is always desired to have a minimum 12-ft lane width for all freeway travel lanes. A reduction in this lane width reduces the overall capacity and may impact smooth operations. However, with regard to temporary shoulder use, narrower lane widths can be acceptable due to the limited use and operating conditions during their use. For example, the Mn/DOT uses a minimum 10-ft shoulder as an acceptable width on those facilities where BOS is operational. (18) Where the BOS travels across a bridge, 11.5 ft is a required minimum, with 12 ft being the minimum for new construction that may accommodate BOS. The narrow width does not adversely impact operations given the lower speeds of the transit vehicles (35 mph maximum) and controlled speed differential (buses can travel no more than 15 mph faster than the main lane traffic). Additionally, Mn/DOT restriped the shoulder on I-94 to 11 ft when converting the shoulder after the collapse of the I-35W bridge. (24) Additionally, the shoulder on I-35W where Mn/DOT has deployed priced dynamic shoulder lanes on a former BOS left shoulder ranges in width from 17 ft to 19 ft from the barrier to the edgeline stripe.

The temporary shoulder use on I-66 in Virginia does have 12-ft lanes throughout the facility. (25) No special concerns or accommodations have been needed for over-width vehicles in some States. (18), (24), (26) However, in Massachusetts, no heavy trucks are allowed on the shoulder, and only two-axle vehicles weighing less than 26,000 lbs can use the MnPASS PDSL on I-35W. In Virginia, there are some locations along I-66 where a small amount of pavement, ranging from 1 ft to 12 ft, remains outside of the shoulder to help with wider vehicles. While this width is not huge, it can be helpful in some circumstances. In Massachusetts, the minimum shoulder width required is 10 ft with a desired being 12 ft. (23) The WSDOT restriped the US 2 trestle to provide a 2-ft left shoulder, two 11-ft lanes, and a 14-ft right shoulder where the shoulder use is permitted. (26) With the I-94 installation in Minnesota, the shoulders were not widened prior to allowing all vehicles to use the shoulder. The agencies were confident that the shoulders could handle the additional traffic without compromising the pavement integrity. With the Mn/DOT BOS deployments, each installation is unique. Thus, if the agency determines the shoulder can handle the additional bus traffic, no pavement widening is undertaken. For other situations, Mn/DOT has developed cost estimates for BOS deployments if shoulder improvements are needed, recognizing that all facilities may not be able to handle the additional traffic.

One of the potential challenges with using shoulders for travel lanes is the presence of fixed objects within the recovery area of the shoulder. With the Mn/DOT BOS applications, fixed object shielding is not installed since the shoulders are only used when speeds are low and congestion is present. In some cases, though, the agency has had to move guardrails to provide the 11.5-ft minimum pavement width. If an object is such that it cannot be moved, Mn/DOT requests a design exception for the case. Along the I-94 shoulder use installation, some fixed object shielding was installed because of ramp reconfigurations, and some retaining walls were installed to accommodate the widening where the shoulder was not adequate in width. In Virginia on I-66, some barriers were extended to address fixed object issues. Furthermore, some deceleration lanes were shortened and acceleration lanes extended for the same reason. In Massachusetts, each of the shoulder use deployments was treated like a traditional widening project where guardrails and fixed object shielding were moved to appropriate locations.

Treatment at Interchanges

In the domestic applications of temporary shoulder use, the vehicles traveling in the shoulder lane traverse across the entrance and exit ramps as they would if they were in the main lanes. (18), (23), (24), (25) Of interest is the BOS operating rules in Minnesota. On those facilities with BOS, buses must yield to any vehicle entering, merging within, or exiting through the shoulder. (18) Also, if the ramp meter at an entrance ramp is creating significant queues, many transit drivers will merge into the general purpose lane to allow the ramp traffic to merge without conflict with the buses. This maneuver is not mandatory of drivers, but those with significant experience normally execute it to enhance freeway operations. Once they pass the ramp, they move over onto the shoulder and proceed. In Germany and The Netherlands, vehicles on the shoulder continue on the shoulder through an entrance or exit ramp. However, in England, drivers on the shoulder must exit the motorway at the interchange, travel through the intersection at the junction, and reenter the motorway to continue traveling on the shoulder.

Drainage

In general, agencies have made improvements or changes to drainage inlets on those facilities with shoulder operations. In Minnesota, those catch basins on the facilities with BOS are reinforced as a precautionary measure. They are also raised to be flush with the pavement so that operations are not impeded. (18) Along I-94, no additional drainage inlets were installed prior to opening the shoulder to all users, as the conversion was a weekend operation that needed a quick turnaround. With the I-66 installation in Virginia, some design exceptions, which were most likely approved as cross-slopes along the facility, are different than what is typical for other like roadways. (25) Other drainage issues that have arisen as a result of cross-slope issues have been resolved with the installation of additional inlets. In Massachusetts, projects were treated as traditional widening projects, and drainage inlets were moved to the new edge of pavement.

Drainage capacity needs to be reviewed for a design year storm. While some stormwater storage might be acceptable on a safety shoulder, the same is not the case on a travel lane.

Emergency Refuge Areas

Perhaps the most critical concern regarding the use of shoulders as travel lanes is the inability for vehicles to use the shoulder in the event of an emergency. This condition can be minimized by installing emergency refuge areas (ERAs) periodically along the facility. Along the M42 in England, emergency refuge areas are located approximately every 500 m and include emergency roadside telephones. The telephones are accessible to wheelchair users, located behind safety fencing, and feature text messaging and eight different languages. (30) With regard to the design of these ERAs, the entrance taper is 25 m and the exit taper is 45 m. In Virginia on I-66, emergency pull-outs are located wherever space was available. The lowest spacing is less than 0.5 mi, with the greatest spacing being 2.5 mi between pull-out areas. Additionally, there are a number of locations designated as "informal" pull-outs where traffic can pull out of the shoulder lane into a safe area. These areas are located where space permits and are often narrower than a formal shoulder pull-off. However, they do provide some refuge area that is better than none at all. Entrance and exit tapers are typically 300 ft along the corridor. In Massachusetts, emergency pull-out areas are located approximately every ½ mi, and those installed along I-35W in Minneapolis are located off the right shoulder to handle emergency stops while the left shoulder is under use. (24)

Rumble Strips

The Mn/DOT is one agency that has dealt with rumble strips along the facilities with BOS. On those roadways with rumble strips on the shoulder, designers either move the rumble strips so that the buses straddle the strips, or install rumble stripes on the pavement marking. In both cases, the transit vehicles avoid driving on the affected pavement. (18) The MassDOT removed rumble strips where the shoulder operations were deployed and also removed scored concrete and block pavers that would affect driving performance on the shoulders. (23)

Safety Studies

The safety benefits from the U.S. applications have mostly been inconclusive. However, there are specific safety benefits noted in the European case studies. In fact, it is the safety benefits that have been the leading success stories of these applications. It should be noted that these shoulder use applications also have a major investment in active traffic management strategies. In addition, these systems require significant investment in ongoing maintenance, operations, and system control manpower.

Future U.S. studies should also address the freeway sections upstream of the shoulder use section to get the full appreciation of safety benefits. Many congestion related crashes happen well in advance of the actual bottleneck location as traffic queues as a result of the congestion.

ITS Components

The ITS components of the shoulder use deployments varied by location. (18), (23), (24), (25), (26) In Minnesota, components included those typical across the region, including cameras and loop detection. Virginia installed loops in the shoulder pavement and ensured that camera coverage was adequate in the corridor. The WSDOT did not install any additional components along the segment. Massachusetts has some sensors on I-93, along with cameras.

Traffic Control Devices

Most of the traffic control devices deployed with shoulder use are regulatory in nature. The VDOT uses an overhead regulatory sign—displayed in Figure 16—to indicate shoulder operations. The regulatory sign is combined with a lane control signal to indicate when drivers may use the shoulder. Other ground-mounted signs used on the installation include a regulatory sign with hours of operation (Figure 17), a regulatory sign noting the presence of an emergency pull-off (Figure 18), and regulatory signs indicating the beginning and ending of the shoulder operations (Figure 18).

Figure 16. Photo. I-66 Regulatory Sign with Lane Control Signals (Photo Courtesy of VDOT).

Figure 17. Photo. I-66 Hours of Use Regulatory Sign (Photo Courtesy of VDOT).

Figure 18. Photo. VDOT I-66 Regulatory Signs (Photo Courtesy of VDOT).

The Mn/DOT uses ground-mounted signs to indicate BOS operations. The two signs most frequently used are the regulatory sign stating that only buses are authorized to use the shoulder (Figure 19) and a warning sign for transit vehicles indicating they should merge with traffic (Figure 20). Pavement markings for all operations are no different than normal shoulder edgeline markings. It is important to note that it is not advisable for an agency to install the special use lane diamond on the shoulder to indicate temporary shoulder use. (18) This marking is commonly associated with HOV operations, so drivers may assume that HOVs are allowed to use the shoulder at all times. This assumption is of particular concern in Minnesota where only buses are allowed to use the shoulders and only during peak periods of travel.

Figure 19. Photo. Mn/DOT BOS Regulatory Sign (Photo Courtesy of Mn/DOT).

Figure 20. Graphic. Mn/DOT BOS Warning Sign (Image Courtesy of Mn/DOT).

The MassDOT uses a combination of regulatory and warning signs to indicate that the shoulder is open to all users during specified times. As noted in Figure 21, regulatory signs are used to indicate the hours of operation and shoulder use prohibition during non-operating hours. The sign in Figure 22 is displayed to warn drivers to expect vehicles in the right breakdown lane during the shoulder use operating hours. Regulatory signs are also used to indicate the location of emergency pull-off areas.

Figure 21. Photo. Regulatory Shoulder Use Signs (Photo Courtesy of MassDOT). [(23)]

Figure 22. Photo. Warning Shoulder Use Sign (Photo Courtesy of MassDOT). [(23)]

The Mn/DOT uses overhead sign gantries with a combination of static guide and regulatory signs, lane control signals, and DMS panels to indicate the operational status of the PDSLs and the MnPASS fee for using the lanes. These signs are illustrated in Figure 12, Figure 13, and Figure 14.

The WSDOT uses a regulatory sign, as shown in Figure 23, to provide information to the user indicating when the shoulder is open and when it is closed. [(26)] While none of the signs used by the various States are identical in nature, they all fall within the guidance provided by the *Manual on Uniform Traffic Control Devices (MUTCD).* (31) Moreover, the agencies are confident that motorist comprehension of these signs is high when combined with public outreach.

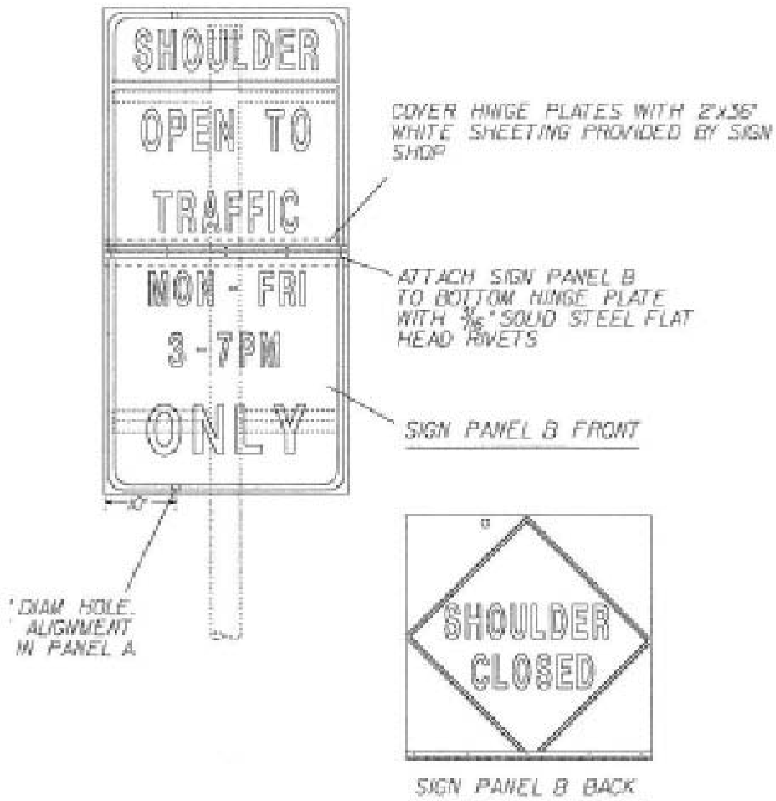

Figure 23. Drawing. Shoulder Use Regulatory Sign (Drawing Courtesy of WSDOT). (26)

Pavement Markings

There has been inconsistency in both the U.S. and Europe on the use of an outside edge line on the shoulders used as travel lanes. This is an area for further research and analysis.

Performance

Performance evaluation of shoulder lanes principally derives from two domestic sources—National Cooperative Highway Research Program (NCHRP) Report 369 (32) and an independent evaluation of I-66 (33) —and one international source—the M42 Program Evaluation. (34) The findings from these sources are summarized here along with other information provided by Mn/DOT, MassDOT, and WSDOT related to their facilities.

Operations

The NCHRP 369 provided a comparative benchmark analysis methodology of eleven corridors in six States, using in-corridor comparisons of "unaltered" segments (full shoulders with 12-ft lanes) and "altered" segments (use of shoulders with or without narrow lanes). (32) The evaluation hypothesis postulated that the lack of shoulders and/or use of narrow lanes would result in different operating conditions.

When isolated by level of service (LOS) categorizations, travel speeds on segments with use of shoulders/narrow lanes were not significantly different from their interstate standards brethren in low-volume and high-volume applications. However, there was a minor difference in speeds in medium-volume applications:

- Level of Service A/B: With volumes less than 1,600 vehicles per hour per lane (vphpl), speeds were identical between altered and unaltered facilities.
- Level of Service C/D: A slight decrease (less than 5 mph) in average travel speeds was found in altered facilities when volumes ranged between 1,600 vphpl and 2,000 vphpl. This was the only statistically significant difference.
- Level of Service E/F: Like LOS A/B, there was no difference in speeds between altered and unaltered facilities at volumes higher than 2,000 vphpl.

At LOS C or worse, there was no significant difference in the choice of lanes (shoulder vs. static lanes) by travelers. However, at LOS A or B, the use of shoulder lanes was significantly less prevalent, especially if the surface of the shoulder was different from the travel lanes. On part-time shoulder facilities (such as SR 3 and I-93 in Massachusetts and I-66 in Virginia), if traffic remains slow and the time is outside the operational shoulder-lane time period, drivers may ignore the shoulder-use restriction and use the lanes anyway. This complicates the ability of the operating agency to recapture the shoulder as a refuge area. In addition to the difference in average speeds, altered facilities exhibit a greater range of speeds in LOS C/D conditions (30–70 mph) than unaltered LOS C/D conditions (50–70 mph).

Lateral clearance effects of altered facilities did have an impact on drivers, causing them to shy away from the barrier. The percent of traffic within a foot of the interior lane line (regardless of lane) was lower at altered sites than unaltered ones. As would be expected, inadvertent lane-line crossings per hour increased significantly with altered sites compared with unaltered ones.

When Mn/DOT converted the BOS on I-94 to all vehicles in response to the collapse of the I-35W bridge, traffic congestion improved along the facility. In both directions, the length of queues and duration of congestion improved to near pre-collapse conditions, and travel times improved as well. [18] One negative impact of the elimination of the BOS was on transit performance on the facility. While previously transit vehicles enjoyed reliable travel times on the shoulders, once other vehicles were allowed to use the shoulders, that advantage disappeared. Metro Transit lost revenues of approximately 1.3 million dollars per year in fixed guideway funds from FTA as a result of the dedicated lane being eliminated. In terms of BOS on other facilities in the Minneapolis region, transit vehicles maintain a reliable travel advantage.

While only recently deployed, the shoulder operations on US 2 in the Seattle area have greatly improved conditions for the regional commute along that corridor. The primary performance measure WSDOT is using is travel time, and delay has fallen from 8-10 minutes to 1-2 minutes on the facility. [26] Travel times are much more reliable on the facility, and throughput has increased on a previously congested ramp.

Safety

As early as the late 1970s, agencies experimented with using freeway shoulders to increase capacity. A 1978 study of restriping the US 59 main lanes in Houston, which encroached on the shoulder and increased capacity, yielded positive results in terms of operations and safety. [21] With the Houston implementation, operations were improved during peak travel periods, travel time and quality of operation improved, and accident frequencies and rates dropped in the year after the deployment. However, a similar study of inside shoulder removals in California did not yield any significant reduction in overall accident rates as a result of the shoulder removal. [20] Instead, the research indicated that the drop in accident rates was a result of a decrease in congestion due to the capacity increase.

Initial safety reviews in the 1980s of shoulder lane usage indicated that projects implemented for short distances to address specific problems often yielded a decline in accident rates. However, the NCHRP Report 369 introduced an alternate methodology to examine accident severity, time of day, type of accident, and characteristics to validate the initial findings. Corridors examined were I-395 (Virginia), I-5 (Washington), I-5 (California), I-85 (Georgia), and I-10 (California). [32] Statistical analysis indicates that in aggregate across the study corridors, there was no significant difference between altered and unaltered segments. However, significant increases in accidents (up to 36 percent more in some segments on I-5) occurred in one specific alteration: a combination of use-of-shoulders and narrow lanes for greater than 1 mi in length. Under these conditions, accident frequency increased significantly, as did sideswipe, nighttime, and truck accidents. [35]

On I-66 in Virginia, investigators found no significant impact of the combined managed-lane (HOV) and shoulder-lane (general purpose) operations on traffic crash frequency. The majority of crashes were rear-end collisions, which are typically a result of congested conditions. Authors hypothesized that advanced incident identification and clearance as well as enhanced dynamic messaging signs contributed to the lack of evidence that the system increased crashes. Since the implementation of BOS in Minnesota in 1993, only 21 collisions have occurred related to the operations, most of which were sideswipes or mirror hits on the bus.

While it is too early to confidently assess safety improvements along US 2 in Washington, anecdotal evidence shows that collisions at the conflict point just upstream of the shoulder usage have been reduced. [26] However, it is difficult to measure the true isolated impact of the shoulder use since its deployment coincided with the deployment of ramp metering on I-5, which feeds into the US 2 trestle.

A critical concern with the deployment of shoulder use is the reduction of the clear zone distance. While an agency may be able to move some fixed objects, guardrails, and other barrier treatments, such accommodation is not always possible. Thus, when traffic is allowed to travel in the shoulder, the effective clear zone is reduced to distances below the minimum allowed. As a result, agencies frequently have to seek design exceptions from FHWA. The potential long-term implications of these exceptions are not known and bear consideration for any possible deployments.

Maintenance

The implementation of shoulder lanes has yielded higher costs and more difficult maintenance activities. Maintenance-related issues as identified by the NCHRP Report 369 include:

- Under altered conditions, highway appurtenances such as signage, barriers, drains, and lights were closer to traffic and were damaged more often and more severely than under unaltered conditions.
- In order to conduct regular maintenance, additional personnel and equipment are needed to close lanes and provide adequate work area protection.
- Most incidents, from minor to major, require some action by personnel that involves shoulders, which in turn requires shoulders to remain closed until the incident is cleared, items are removed, or other action is completed. Estimates by personnel indicate that clearance time for incidents doubles with shoulder lane use.
- As emergency vehicles use shoulders to access scenes of accidents, delays in arriving on the scene have consequent increases in periods of congestion, secondary accidents, and clearance time.

Enforcement

Enforcement is not a problem on those Mn/DOT facilities with BOS. Most of the enforcement issues addressed by Minnesota State Patrol have more to do with ensuring that cars do not block the buses on the shoulder on purpose. [(18)] Visual inspection and using radar to clock the speeds of buses are the methods of enforcement. Those buses that are traveling faster than 35 mph while on the shoulder are reported to the transit agencies, and the drivers receive a reprimand. Never have repeat complaints about speeding been received by Metro Transit or Mn/DOT because the drivers realize that their job depends on following the operational rules and requirements.

Enforcement along I-66 is difficult for both Virginia State Police and county law enforcement personnel. The short distance and tight interchange spacing makes enforcement a challenge for officers wishing to cite a driver using the shoulder during the off-peak period. [(25)] However, the high off-peak violations do not present a safety problem because of the short distances between interchanges.

Enforcement activities in Massachusetts and Washington are typically handled by State police forces. The enforcement approach is visual inspection by the officers. These agencies report little problems with violators along the corridors where shoulder use is provided. [(23), (26)]

Incident Response

Incident response along the facilities with temporary shoulder use is handled in a similar manner for all of the agencies. A typical unified response approach is deployed; this response is led by State police and the DOT first responders and uses typical regional response protocols. [(18), (23), (24), (25), (26)] Average response times are typical for the shoulder use facilities as with other facilities in the regions. In Virginia, the safety service patrol was increased in the corridor, particularly during the operating hours of the shoulder on I-66. (25) Additionally, emergency pull-out areas were installed along I-35W in Minneapolis to help facilitate incident response during the time period when the PDSLs are operational. (27)

Training

Metro Transit, the largest transit operator in the Minneapolis-St. Paul region, uses a training manual along with class time, route, and safety pamphlets for training its bus operators. The manual includes a small section on bus shoulder use, along with a training video and on-board training related to the BOS operations for the drivers. Drivers are trained on the Minnesota statutes (http://www.dot.state.mn.us/metro/teamtransit/docs/mn_statutes_2006.pdf), the Mn/DOT Commissioner Order (http://www.dot.state.mn.us/metro/teamtransit/docs/draft_order_7-29-05.pdf), the Mn/DOT Guidelines on Shoulder Use by Buses (http://www.dot.state.mn.us/metro/teamtransit/docs/bus_only_shoulder_guidelines.pdf), and the Mn/DOT Shoulder Operating Rules (http://www.dot.state.mn.us/metro/teamtransit/docs/operating_rules_on_shoulder.pdf). A copy of the Metro Transit Training Video is available at http://www.dot.state.mn.us/metro/teamtransit/visual/Training%20For%20Bus%20Drivers%202.wmv).

Costs

The installation of a temporary shoulder can be a reasonable expense when compared to the construction of new freeway lanes. While the initial costs to convert the shoulders on I-66 in Virginia are not known because of the lack of current institutional knowledge, a recent assessment to upgrade the lane control system along with the facility was estimated to be 7 million dollars for the entire 6-mi segment. While that installation is somewhat expensive, it is still much less than constructing 6 mi of new pavement in a congested urban area. Project costs are unknown for the Massachusetts projects. In Minnesota, the PDSL project cost 13 million dollars, which included a new pavement surface for the entire facility, including the shoulder lanes and emergency pull-out areas. Contrast those costs to the approximately 70,000 dollars it cost WSDOT to install a 1.5-mi shoulder segment on the US 2 trestle. The cost for Mn/DOT to install BOS along a freeway varies according to the requirements, but most installations are very reasonable, as shown in Table 1.

Liability Issues

In the applications in the United States, no liability issues were of noted concern at the time of installation and deployment. One concern was broached by the American Automobile Association (AAA) with respect to the extension of operating hours along I-66 in Virginia. (25) When VDOT announced plans to extend operating hours to improve operations with longer peak periods, AAA expressed concern because the hours in which the shoulder would be available for emergency refuge in the event of an incident would be reduced even further. However, with concerted effort on the part of VDOT to work with AAA to address their concerns, no issues of significance have emerged since the extension was implemented.

Table 1. Shoulder Use Installation Costs—Mn/DOT. [(18)]

Condition	Costs Plus Signing & Striping
Shoulder width and bituminous depth are adequate. Catch basins do not need adjustment. Signing and striping are only requirements.	$1,500 per mile—Freeway $2,500 per mile—Expressway
Shoulder width and bituminous depth are adequate. Minor shoulder repairs and catch basin adjustments are needed.	$5,000 per mile—Freeway $5,000 per mile—Expressway
Shoulder width is adequate but bituminous depth requires a 2-inch overlay. This assumes shoulder and roadway can be overlaid at the same time.	$12,000 per mile—Freeway $12,000 per mile—Expressway
Same as above but adjacent roadway is not being overlaid. Shoulder must be removed, granular base adjusted, and increased bituminous depth replaced.	$80,000–$100,000 per mile
Shoulder width and depth replacement are required.	$42,000–$66,000 per mile for both freeway and expressway
Installing a 12-ft shoulder rather than a 10-ft shoulder in a new construction project.	$30,000 per mile for both freeway and expressway

Legal Issues

No specific legislation was required to implement the I-66 temporary shoulder use in Virginia. The implementation was under the jurisdiction of the Commonwealth Transportation Board and the Code of Virginia. [(25)] The Mn/DOT deployed the BOS under the order of the Mn/DOT transportation commissioner. Additionally, specific Minnesota statute (169.306) was changed to address the use of shoulders by buses and driving rules for those buses when operating on the shoulder (169.18). [(18)]

Public Outreach and Education

Initially, Mn/DOT did not implement a public outreach and education plan when deploying the BOS. Once the facilities were in operation, they did occasionally host a media event where a local celebrity challenged a transit vehicle to a race on a congested corridor with BOS during the peak period. The intent was to demonstrate the travel time savings and benefit to using transit in the corridor. These events received good media coverage and served as an educational opportunity for the general public. [(18)] Typical outreach efforts were used in the Seattle area prior to the opening of the US 2 shoulder lane. [(26)] The city of Everett, Washington, was a great proponent of the project because of the expected improvements for the commute out of the city.

NCHRP/AASHTO/FHWA Domestic Scan

In November 2009, an NCHRP/American Association of State Highway and Transportation Officials (AASHTO)/FHWA domestic scan was completed to look at the issue of maximizing flow on existing highway facilities. This scan tour visited and documented several temporary shoulder use locations around the United States. There were members of this team from FHWA and the following State DOTs: Washington, Georgia, New Hampshire, Michigan, and New Mexico. The results of the scan team's report are useful for development of guidance in temporary shoulder usage.

Chapter Summary

Agencies need to consider a wide range of issues when determining whether shoulder use is appropriate for a particular corridor or region. Experience both overseas and domestically provide a wealth of experience from which agencies can learn to make informed decisions. From the European perspective, part-time shoulder use is only used during congested periods when queues begin to build at bottlenecks in the system. Moreover, this treatment is almost always deployed in conjunction with speed harmonization. The intent is to reduce the speeds along the corridor and smooth out driver performance and reduce the likelihood of collisions. (1) Furthermore, European agencies have realized both safety and mobility benefits as a result of these projects. While American deployments have been limited, the experience has generally been positive. However, safety benefits have not been conclusive. Those issues that need to be considered include design, traffic control devices, performance measures, potential safety benefits, maintenance concerns, enforcement roles and processes, incident response, training for personnel, costs, liability and legal issues, and public outreach and education. Careful consideration of these issues can help ensure a shoulder use deployment is effective without having negative impacts on safety and operations.

Another area needing further analysis is the topic of left shoulder use versus right shoulder use. Domestically, almost all applications of part-time shoulder use have occurred on the right side, while shoulder conversions to permanent lanes have tended to be more prominent on the left side. Each application has a different subset of design and operational considerations to analyze.

Chapter 4: Case Studies

Case Study: The Netherlands—Temporary Shoulder Use and Speed Harmonization

Overview

Facility

- Various throughout The Netherlands.

Operator

- NTCC and regional control centers.

Years of Operation

- 1981–current.

Operating Strategy Overview

- Advanced queue warning systems that utilize flashing lights and variable speed limit signs alert drivers of recurrent congestion, lane closures, and incidents.
- Requires extensive technological investment and monitoring activities.
- Deployment is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator.
- Only operates during time periods of congestion or when incidents occur along instrumented roadways.

Number of Lanes

- Applied to an entire corridor, encompassing all lanes.

Length

- 1,000 km (620 mi) of roadway.

Project Description

The Area

The Netherlands is home to over 16.2 million residents and 6.9 million cars, with 155 million vehicle miles traveled each day across its network. It covers an area of roughly 16,000 mi^2. Traffic operations are controlled by a series of five regional traffic control centers, which are in turn coordinated by NTCC. [(1)]

Temporary Shoulder Use

The Netherlands implemented temporary right shoulder use—also known as hard shoulder running or the rush hour lane—in 2003 as part of a larger program to improve use of the existing infrastructure. As Figure 24 shows, a gantry with lane control signals indicates when the shoulder is available for use. Where a shoulder lane passes through a junction and at the end of a hard shoulder running section, guidance information will change according to lane use. [(14)]

Figure 24. Photo. Temporary Right Shoulder Use—The Netherlands. (36)

In addition to allowing temporary use of the right shoulder, the Dutch also deploy the use of traveling on a dynamic lane on the median side of the roadway. As Figure 25 shows, the left lane—also known as the plus lane—or a narrowed extra lane provided by reconstructing the existing roadway while keeping the hard shoulder is opened for travel use when traffic volumes reach levels that indicate congestion is growing.

Figure 25. Photo. Plus Lane in The Netherlands. (36)

Temporary shoulder use in The Netherlands is only deployed in conjunction with speed harmonization. This strategy works to reduce speeds in congested conditions in order to improve traffic flows and reduce the likelihood of traffic incidents. Such systems require significant technological development, as traffic speeds must be continually monitored and information must be continually transmitted throughout the entire corridor. The Netherlands' speed harmonization system works through the motor control and signaling system (MCSS), an advance queue warning system that utilizes flashing lights and variable speed signs to alert drivers of congestion and lane closures. (1)

The entire system monitors traffic speeds in the corridors it is implemented in. Should the system detect large drops in overall speed within a certain area, it notifies other travelers of the impending slow down and lowers the speed limit in incremental stages as displayed on variable speed signs for traffic approaching the congested area, as shown in Figure 26. This alleviates the "shock" that can be caused by a sudden reduction in speed, improves traffic flow, and reduces the number of traffic incidents as a result of congested conditions. Speed harmonization is often employed during severe weather conditions and in environmentally sensitive areas to reduce pollutants.

Figure 26. Photo. Speed Harmonization—The Netherlands.

The standard speed limit is 120 km/h (75 mph) on the motorways, but posted speeds can drop to 90 km/h (55 mph), 70 km/h (44 mph), or as low as 50 km/h (31 mph) if a shock wave or speed-drop is detected. These conditions are normally due to high volumes or incidents occurring on the facility. As of 2007, the MCSS system has been implemented on over 1,000 km (620 mi) of roadway in The Netherlands, and 61 km (38 mi) more are planned. The MCSS was first deployed in 1981.

Project Conceptualization

Speed harmonization is only one element of the overall transportation system for The Netherlands. The Ministry of Transport, Public Works and Water Management (Rijkswaterstaat) manages over 2,000 mi of The Netherlands' mainline roadways and operates the country's numerous regional traffic control centers in addition to the NTCC. (36) The primary focus for Rijkswaterstaat is on maintaining high levels of customer service and ensuring trip reliability, which has led the agency to establish the following benchmarks:

- Ninety-five percent of trips are completed on time.
- Trips in urban areas do not take more than twice as long in congested conditions as they do in normal conditions.
- Trips on all other roads do not take more than 1.5 times as long in congested conditions as they do in normal conditions. (37)

Speed harmonization works toward both goals of customer service and trip reliability, as it keeps travelers informed of current conditions and manages roadway conditions so as to maximize throughput and reduce travel time variability. Temporary shoulder use complements speed harmonization to better utilize roadways and improve trip reliability.

Facility Management

In the Dutch national approach to congestion management, information is a primary resource in the overall traffic management architecture, including speed harmonization. Information is the backbone behind all traffic and demand management strategies in the control scheme. The NTCC coordinates the activities of and gathers traffic-related data from the five regional traffic control centers that center on major cities and operate 24 hours a day, 7 days a week. The regional traffic control centers are responsible for the daily operation of the congestion warning and speed harmonization systems. (38) The NTCC, which also operates 24-7, is the focal point for national traffic operations. It establishes national guidelines and procedures on traffic management, coordinates emergencies, communicates with other European national centers, and collects management information from around the country. The NTCC fosters cooperation between the national and regional governments to direct road users for optimal roadway performance. (1)

Technologies Deployed

The Netherlands has used speed harmonization for many years. Some deployments have been implemented to promote safer driving during adverse weather conditions (such as fog), while others have been used to create more uniform speeds. Most recently, The Netherlands' MCSS has been used to reduce speed in a densely populated and environmentally sensitive area to reduce polluting elements. The posted speed limit of 80 km/h (50 mph) is further effectuated by an automated speed enforcement system, which measures average speed over a section of the highway, normally 2 to 3 km long. Temporary shoulder use is a more recent implementation of ATM, having been first implemented in 2003. Additional technologies and facilities are always implemented along with temporary shoulder use to help mitigate any adverse safety consequences the operational strategy may create, including the following:

- Overhead lane signs and full matrix signs.
- Emergency refuge areas with automatic vehicle detection.
- Variable route signs at junctions.
- Advanced incident detection.
- CCTV surveillance.
- Intensified incident management.
- Public lighting. [1]

Performance of System

Highway System Performance

It is estimated that facilities under the MCSS system have seen throughput increase between 4 and 5 percent. Primary accidents decreased by 15 to 25 percent, and secondary incidents decreased by 40 to 50 percent between 1983 and 1996. It is estimated that speed harmonization has reduced collisions by about 16 percent and increased throughput by 3 to 5 percent, and has reduced the cost of work zone traffic control. Regarding temporary shoulder use, assessment of this strategy reveals that its implementation has increased overall capacity 7 to 22 percent (depending on usage levels) by decreasing travel times from 1 to 3 minutes and increasing traffic volumes up to 7 percent during congested periods. [39]

Safety and Incidents

The Dutch have seen a reduction in incidents on facilities with temporary shoulder use, as shown in Figure 27. Additional safety benefits may include fewer queues and shockwaves, lower travel speeds with harmonization, better monitoring, and swifter incident response. Temporary shoulder use is allowed only when speed harmonization is in effect.

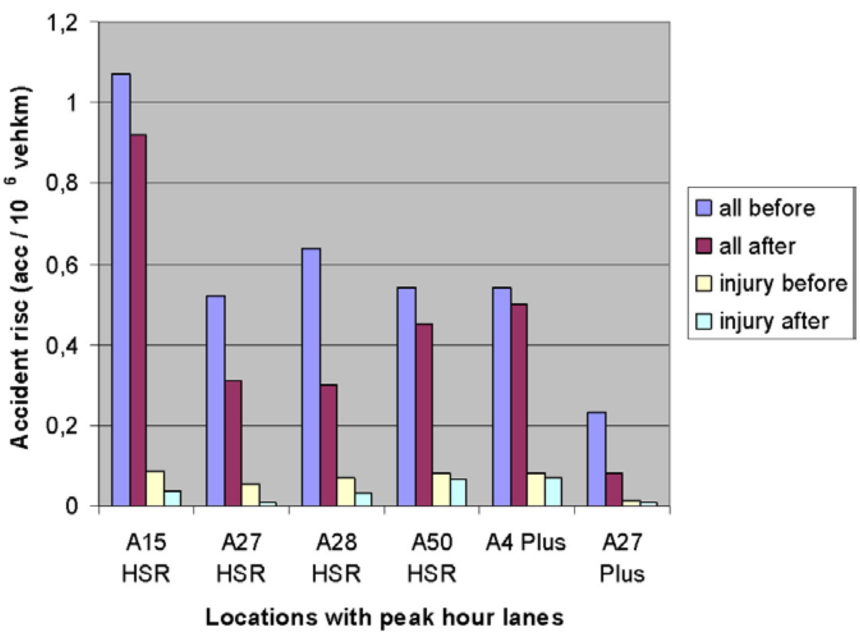

Figure 27. Graph. Incident Reductions with Temporary Shoulder Use—The Netherlands. [14]

Case Study: Germany—Temporary Hard Shoulder Use and Speed Harmonization

Overview

Facility

- Various.

Operator

- Federal Ministry of Transport and regional traffic management centers.

Years of Operation

- 1996–current.

Operating Strategy Overview

- Variable speed limit signs alert drivers to reduce speeds as a result of recurrent congestion, lane closures, and incidents to address bottlenecks on the freeway network caused by these conditions.
- Temporary shoulder use designated by sign gantries with variable message signs and shoulder-mounted diagrammatic signs to indicate availability for use; operational when traffic volumes are high and the hard shoulder is strong and wide enough for use.
- Temporary hard shoulder use only deployed with speed harmonization (line control) when the maximum allowable speed limit is 100 km/h (62 mph) and if dynamic message signs are used for lane control.
- Deployment of variable speed limits is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator.
- Operates both between junctions and through junctions.

Number of Lanes

- Applied to an entire corridor, encompassing all lanes.

Length

- Over 200 km of roadway currently in congested corridors across the country.

Project Description

The Area

Germany is home to an estimated 82 million inhabitants and covers an area of about 138,000 mi^2. Its federal motorway network is about 7,500 mi spread across 10 states. Most of these major highways are four- to six-lane facilities that carry average daily traffic volumes of about 49,000 vehicles. Overall demand on the German transportation network is expected to increase by 16 percent for passenger transport and 58 percent for freight transport by 2015. Officials hope to accommodate this growth with the construction of over 1,000 mi of new roadways, widening 1,300 mi of existing roadway and constructing 717 bypasses. (16)

Temporary Shoulder Use

Temporary shoulder use in Germany, also known as hard shoulder use, is only deployed in conjunction with speed harmonization to address capacity bottlenecks on the freeway network. In Germany, it provides additional capacity during times of congestion and reduced travel speeds. The use of the right shoulder during peak travel periods has been used in Germany since the 1990s, with the first deployment on the A4 near Cologne in December 1996. [12] Today, nearly 125 mi of temporary hard shoulders are in operation around the country. This temporary shoulder use is one of several traffic control systems developed by the Federal Ministry of Transport and is used in various locations in the country. [29] When travel speeds are reduced, signs indicate that travel on the shoulder is permitted, as Figure 28 shows. This installation is located on the Autobahndirektion Südbayern (South Bavaria) and has had the official signs added digitally for illustrative purposes. Figure 29 shows the complete series of signs indicating operations related to temporary shoulder use, including one with a supplemental speed limit indication (used when overhead gantries are not present). These signs and the overhead lane messages are blank when travel on the shoulder is not permitted. Temporary shoulder use is permitted only when speed harmonization is active and speed limits are reduced.

Figure 28. Photo. Right Shoulder Use with Speed Harmonization—Germany. [13]

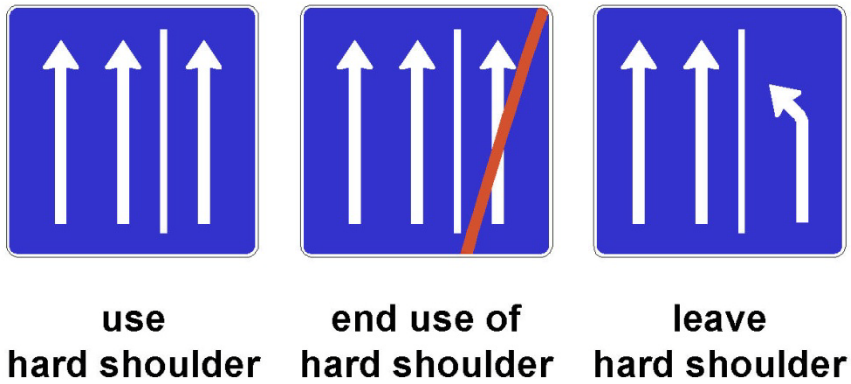

Figure 29. Illustration. Temporary Hard Shoulder Use Signs—Germany. [13]

Temporary shoulder use in Germany can either end or continue through interchanges depending on the bottleneck locations and overall characteristics of the corridor. Figure 30 and Figure 31 illustrate the signing and marking used when temporary hard shoulder use continues through an interchange. Figure 32 and Figure 33 illustrate those signs and markings used when temporary hard shoulder use terminates at an interchange.

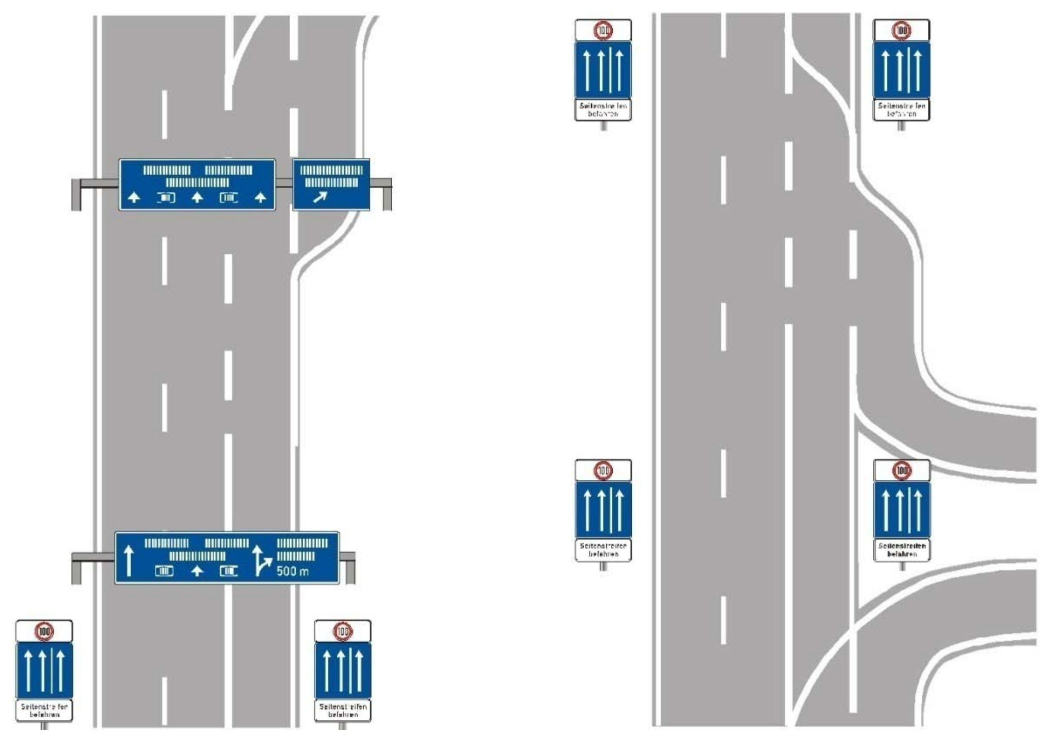

Figure 30. Illustration. Signs and Markings for Temporary Hard Shoulder Use Continuation through Interchange—Germany. [13]

Figure 31. Photo. Continuation of Temporary Hard Shoulder Use through an Interchange—Germany. [13]

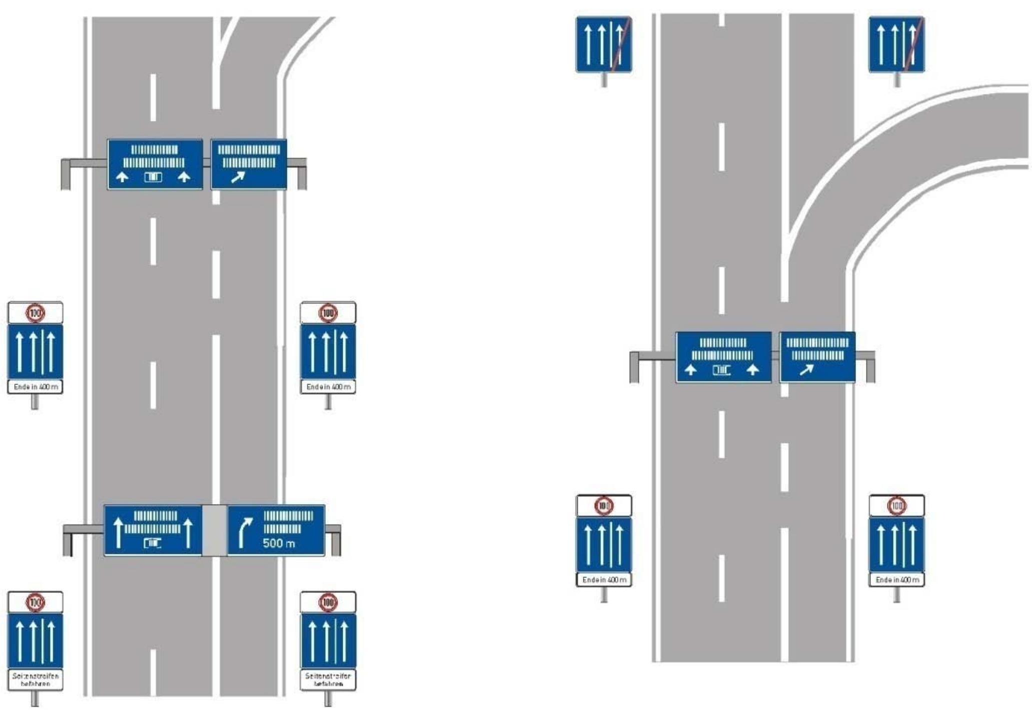

Figure 32. Illustration. Signs and Markings for Temporary Hard Shoulder Use Termination at Interchange—Germany. [13]

Figure 33. Photo. Termination of Temporary Hard Shoulder Use at Interchange—Germany. [13]

Project Conceptualization

In response to the growing demand on its roadways, the Federal Ministry of Transport, Building, and Urban Affairs established a Federal Transport Infrastructure Plan to upgrade the road network by 2015 through major construction projects. This plan includes constructing 1,074 mi of new motorways, widening 1,340 mi of existing motorways, and constructing 717 bypasses across the country.[16] In addition, the ministry has a comprehensive 5-year Programme for Traffic Control on Federal Motorways, which is oriented toward overall management of the federal motorway network. This program's objectives are to (1) increase by 745 mi the length of motorways equipped with traffic control systems, (2) increase by 1,500 mi the length of motorways with dynamic diversion possibilities, and (3) increase by 15 the number of traffic control centers across the country. Both federal initiatives illustrate a national movement to upgrade and actively manage the motorway network for efficient operations and to enhance the mobility of the country's citizens. Temporary hard shoulder use and speed harmonization are critical components of this management program.

The German federal government also has a policy on telematics and transport, with a primary emphasis on public-private cooperation. The intent is to define specific responsibilities that are best handled by the public sector, those that are best handled by the private sector, and those that can best be accomplished by public-private partnerships. This policy recognizes the strengths of the private sector in some arenas and acknowledges that some activities can be undertaken only by governmental agencies and should remain under public control. The federal government owns the federal motorways and highways and finances their construction, maintenance, and telematic infrastructure deployment, while the individual states are responsible for maintenance, operations, traffic safety, traffic regulations, and financing of the planning and operational activities for the network.

Facility Management

At the regional level, German states establish freeway operation programs for their motorway networks with two primary objectives. The first objective is to maintain or increase safety by harmonizing traffic flow, providing hazard warnings to motorists, and providing dynamic in-vehicle information on traffic conditions to users. The second objective is to maintain and improve mobility, which is achieved through the optimal use of the existing network capacity and the use of various operational strategies to temporarily increase road capacity. [40]

Regional traffic management centers, like the Traffic Center Hessen, have established a proactive traffic management approach. This approach is a comprehensive framework that encompasses benchmarking of network performance; deploys and maintains various traffic management strategies to meet the aforementioned objectives; incorporates data management, traffic analysis, and forecasting to evaluate and assess the impacts of those strategies; and facilitates the implementation of innovations to enhance mobility. Temporary use of hard shoulders and line control are two tools in this proactive congestion management toolbox.

Technologies Deployed

Components typically installed with the required regulatory signs include:

- Overhead gantries.
- Dynamic speed limit displays.
- Dynamic message signs.
- Roadway sensors.
- CCTV cameras.

Performance of System

Highway System Performance

Overall, Germany has seen considerable benefits from the deployment of temporary hard shoulder running and speed harmonization. These benefits include a travel time reduction of up to 20 percent, a temporary increase of up to 25 percent in freeway capacity, and a high motorist acceptance of variable traffic signs given reasonable speed limits are displayed for speed harmonization. Temporary shoulder use affords congested motorways with higher throughput, as shown in Figure 34. The addition of the third lane in the form of temporary shoulder use, while slightly decreasing speed and initially reducing volumes on the motorway, actually delays the onset of congestion and breakdown and increases the overall throughput on the facility. Similar operational improvements are realized as a result of speed harmonization, with breakdown flow under breakdown conditions being reduced, as shown in Figure 35.

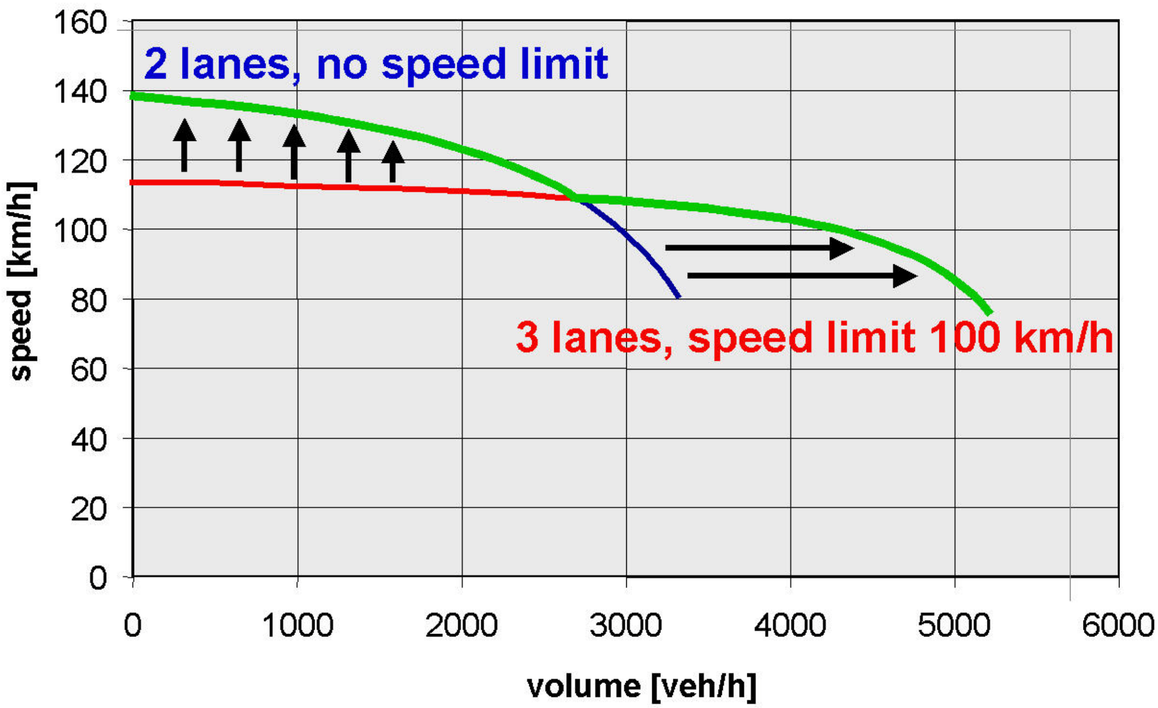

Figure 34. Graph. Speed-Volume Relationship of Temporary Shoulder Use—Germany. (13)

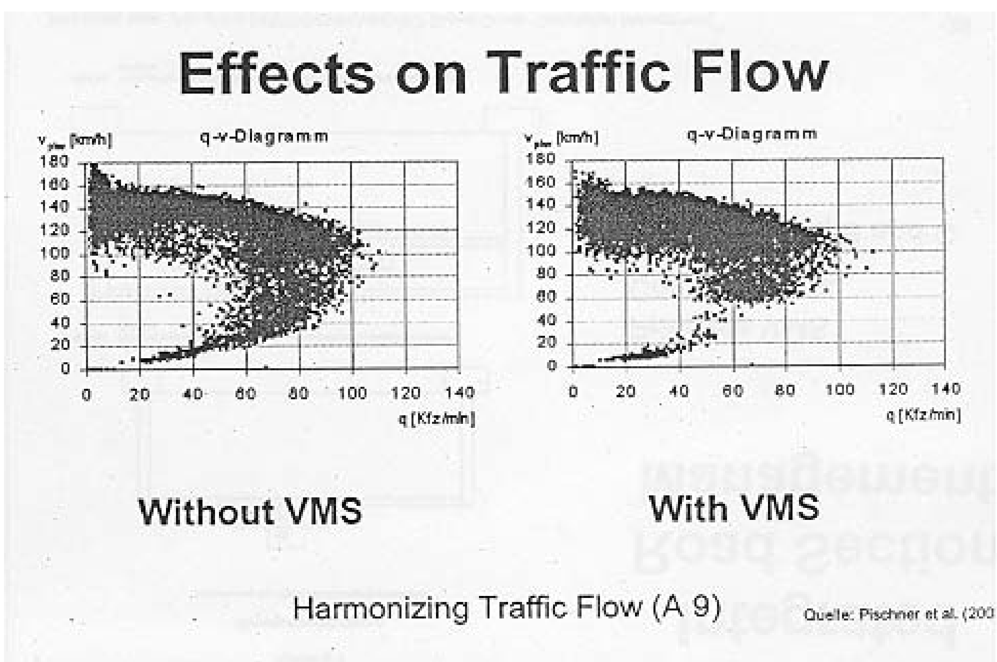

Figure 35. Graph. Flow Impacts of Speed Harmonization—Germany. (41)

Safety and Incidents

The safety benefits realized through the use of speed harmonization are significant. Facilities with speed harmonization have seen a reduction of up to 29 percent in accidents with personal damage, a reduction of up to 27 percent in accidents with heavy material damage, and a reduction of up to 3 percent in accidents with light material damage, as shown in Figure 36.

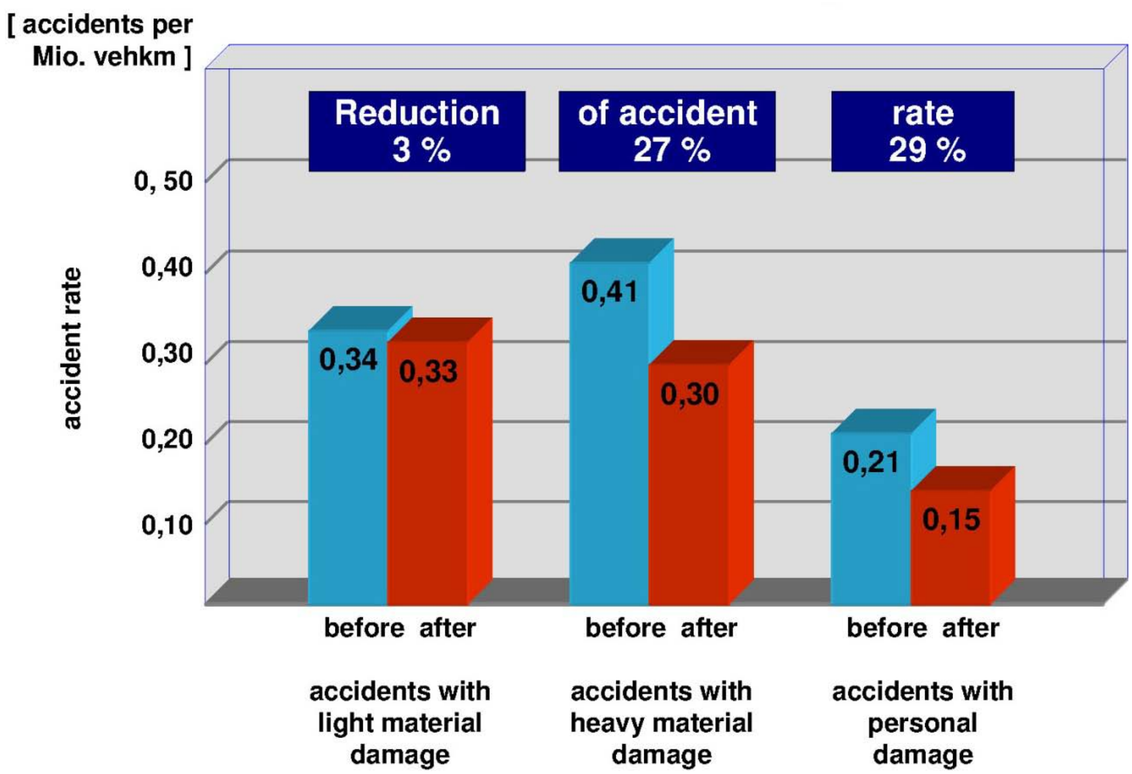

Figure 36. Graph. Safety Benefits of Speed Harmonization—Germany. [40]

Case Study: Great Britain—Temporary Shoulder Use System

Overview

Facility

- M42 Motorway (J3A to J7).

Operator

- Highways Agency.

Years of Operation

- 2006–current.

Operating Strategy Overview

- Variable speed limit signs alert drivers to reduce speeds as a result of recurrent congestion, lane closures, and incidents.

- Temporary shoulder use designated by sign gantries with dynamic message signs to indicate availability for use.
- Temporary shoulder use deployed only when speed limits are reduced (initially to 50 mph).
- Deployment of variable speed limits is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator.
- Only operates (1) during time periods of congestion or when incidents occur along instrumented roadways, and (2) between junctions, requiring users to exit at each junction and reenter the roadway beyond.
- Emergency refuge areas provided for use when vehicles break down.

Number of Lanes

- Applied to an entire corridor, encompassing all lanes.

Length

- 11 mi of roadway currently with plans to expand to other congested corridors.

Project Description

The Area

As with other countries across Europe, the United Kingdom (UK) now faces a number of new challenges regarding transportation and mobility. Trends in traffic growth predict that volumes will increase by 29 percent by the year 2010, and with increased volumes comes increased congestion on the transportation network. Estimates are that non-recurrent congestion in the form of incidents (25 percent) and construction (10 percent) account for 35 percent of congestion. [42]

Active Traffic Management (ATM)

Introduced in 2001 by the Minister of Transport, the M42 ATM pilot is an operational strategy intended to provide reliable journeys, reduced recurring and non-recurring congestion, and enhanced information to drivers. [43] It is a direct response to the road users' demands for better service within the realistic limitations of widening and expanding the roadway network. Building on advancements in technology and experience from across the globe, this pilot project works to make the best use of the existing capacity on the segment of M42 between junctions 3A and 7. The ATM pilot also provides additional capacity during periods of congestion or incidents. The pilot project combines the strategies of speed harmonization and temporary shoulder use. To ensure safe operations of the temporary shoulder use, emergency refuge areas are spaced at 1,640-ft intervals along the shoulder (as shown in Figure 37), and emergency call boxes are provided at each refuge area (as shown in Figure 38).

Figure 37. Photo. Emergency Refuge Area on Facility with Active Traffic Management—England.

Figure 38. Photo. Emergency Call Box on Facility with Active Traffic Management—England.

The roadway provides traditional information to travelers as seen on other motorways across the region. Under such conditions, all normal rules apply. However, information provided to travelers changes during periods of recurring congestion or incidents depending on whether or not the hard shoulder is open for travel. In both cases, gantries with lane control signals and dynamic message signs indicate reduced speed limits and the availability of the hard shoulder for travel use rather than for emergency refuge only. Overall benefits include increased capacity; enhanced journey reliability; reduced driver stress, number and severity of crashes, traffic noise, emissions, and fuel consumption; and improved driver behavior. [44]

Project Conceptualization

In 2004, the Department for Transport established a long-term strategy for a modern, efficient, and sustainable transport system that is supported by a high level of investment. Acknowledging that transportation is vital to the economy and quality of life, the strategy focuses on providing a 2030 transportation network that can meet the challenges of a growing economy and an increasing demand for travel while achieving environmental objectives. Three themes support this strategy: (1) a sustained investment in the transportation network over the long term; (2) continued improvements in transportation management to maximize the benefits of public spending; and (3) planning for the future and considering new and innovative approaches to improving transportation. Underlining these themes is the objective to balance the need to travel with the need to improve quality of life. The ATM is a key component of the agency's approach to meeting its long-term strategy for its transportation network. [45]

A primary goal for improving transportation across the UK is related to safety—which is an acknowledged contributor to roadway congestion. The national goal, which has been in place since 2000, is to maintain the network in a safe and serviceable condition. A continuous review of measures to improve roadway and work zone personnel safety through engineering and design improvements are key activities related to this goal. Specific numbers that the Highways Agency is working to meet include a 33 percent reduction in the number of deaths or severe injuries in motor-vehicle related accidents, a 10 percent reduction in the number of minor injuries – both of which will contribute to a 50 percent reduction in child casualties. [46]

Facility Management

The national focal point for congestion management in the UK is the NTCC. At this information hub, NTCC staff monitor a network of over 1,730 CCTV cameras and 4,450 traffic sensors 24 hours a day, 365 days a year. Staff members review the network and deliver vital information to the news media and other operational partners including the police and the Highways Agency traffic officer service. They also display real-time messages on the 350 DMS placed at strategic points on the motorway network.

The NTCC coordinates and is interconnected with seven regional control centers across the country. These centers monitor and maintain the roadway network within their jurisdiction and are the first line of control regarding congestion management. If minor incidents occur, the regional centers initiate appropriate responses related to incident and congestion management and report information to the NTCC regarding the incident. For major incidents, actions are coordinated with the NTCC as needed to optimize the remaining capacity and to minimize the duration and impact of the incident on the entire motorway network and the adjacent local road system. The West Midlands Traffic Control Center in Birmingham is responsible for operating the ATM system on the M42 as part of its overall duties.

Technologies Deployed

The ATM project on the M42 has numerous technological components that ensure its successful operation. In addition to the traffic sensors, CCTV cameras, and DMS deployed on the roadway network as part of the regional traffic control center, the completed system includes the installation of the following:

- Lightweight gantries.
- Lane control signals.
- Dynamic speed limit signals.
- Dynamic message signs.
- Digital enforcement technology.
- Closed-circuit television cameras.
- Enhanced lighting.
- Roadway sensors.
- Emergency roadside telephones.
- Emergency refuge areas. (43)

Performance of System

Highway System Performance

Overall, traffic conditions on the M42 have become smoother and more consistent since the implementation of ATM. Weekday travel times have reduced in variability by 27 percent, and capacity has increased by an average of 7 to 9 percent when hard shoulder running is in effect. Travel times have improved by 24 percent in the northbound direction and 9 percent in the southbound direction during peak periods as a result of the speed harmonization deployment. (47) Moreover, the travel time variability has been reduced by 22 percent to 32 percent since deployment, allowing drivers to more accurately predict their journey times. These trends are shown for both winter and summer seasons despite the increase in demand experienced during the summer season. Additionally, the ATM on the M42 improved the distribution of traffic across the travel lanes and has not had an adverse effect on traffic in the surrounding areas.

Safety and Incidents

Overall, traffic operations on the M42 have improved, with traffic congestion and the speed differential between lanes being reduced. Furthermore, there is a higher occurrence of free-flow conditions with headways greater than 5 seconds. During the first year of operation, a limited crash analysis indicated that accidents along the corridor in the ATM section decreased from 5.08 per month to 1.83 per month. (48)

Other Impacts

Initial vehicle emission and air quality measurements indicate that vehicle emissions for carbon-monoxide, particulate matter, carbon-dioxide, and oxides of nitrogen have dropped between 4 and 10 percent and fuel consumption has dropped by 4 percent since deployment. Noise reduction along the corridor has also been measured between 1.8 dB(A) and 2.4 dB(A). [48]

Case Study: Virginia—I-66 Temporary Shoulder and HOV Lanes

Overview

Facility

- I-66 (U.S. 50 to I-495).

Operator

- Virginia Department of Transportation.

Years of Operation

- 1992–current .

Operating Strategy Overview

- Use of rightmost shoulders by general purpose traffic only during peak periods Monday–Friday (eastbound, 5:30 a.m.–11:00 a.m.; westbound, 2:00 p.m.–8:00 p.m.).
- Installation was as a result of the adaptation of leftmost general purpose lane to HOV-2 lane concurrent with opening of shoulder lane (eastbound, 5:30 a.m.–9:00 a.m.; westbound, 3:00 p.m.–7:00 p.m.).
- Advance signage and traffic control signaling provide travelers information of operations, including large signs alerting drivers to nine emergency refuge areas.
- Opening of the shoulder lane during traffic incidents/construction.

Number of Lanes

- One HOV-2 lane, captured from interior-most general purpose lane, operational concurrent with opening of exterior shoulder for use by general purpose traffic.

Length

- 6.5 mi of dual HOV/Shoulder Lane operations.

Project Narrative

The Area

As the primary highway connecting Washington, D.C. (population 600,000), and Northern Virginia (population 2,400,000), I-66 suffers heavy traffic throughout the Fairfax County section. Although the corridor features concurrent metro-rail service (Washington Metro Orange Line, operating between Vienna and western Arlington County), the freeway’s three lanes in each direction are often overtaxed.

Temporary Shoulder Use

Built in 1964, the segment of I-66 between U.S. 50 and I-495, where the case study HOV/shoulder lane combination is operational, includes three main lanes in each direction. Starting in 1992, the shoulder was opened to peak-period, peak-direction general purpose traffic, allowing the leftmost lane to operate as an HOV lane (illustrated in Figure 39). This lane provides continuity to HOV lanes that continue on I-66 west of U.S. 50 for an additional 15 mi to VA-234 [(49)]. The cross-section west of U.S. 50 includes a static HOV lane (interior) and three general purpose lanes (exterior), as shown in Figure 40.

In the combined HOV/shoulder lane segment (hereafter referred to as HOV/SL), three travel lanes and one shoulder are present for the entire segment with a posted speed limit of 55 mph. When shoulder lanes are active, four emergency refuge areas (eastbound) and five refuge areas (westbound) provide accommodation for breakdowns and enforcement activities. Additionally, collector/distributor roads (barrier separated from main lanes) provide access to and from the corridor's three ingress/egress ramps (eastbound) and four ingress/egress ramps (westbound). The shoulder lanes and C/D roads can be seen in Figure 41. As shown in the cross-section in Figure 42 and Figure 43, the general purpose lanes are 12-ft wide, the interior shoulders are 8- to 12-ft wide, and the exterior shoulders are 11-ft wide.

Figure 39. Photo. I-66 Peak Period Shoulder Use—Virginia [(50)].

Figure 40. Photo. I-66 HOV Lanes, West of HOV/SL Portion—Virginia [50].

Figure 41. Photo. I-66 HOV/SL Portion—Virginia [50].

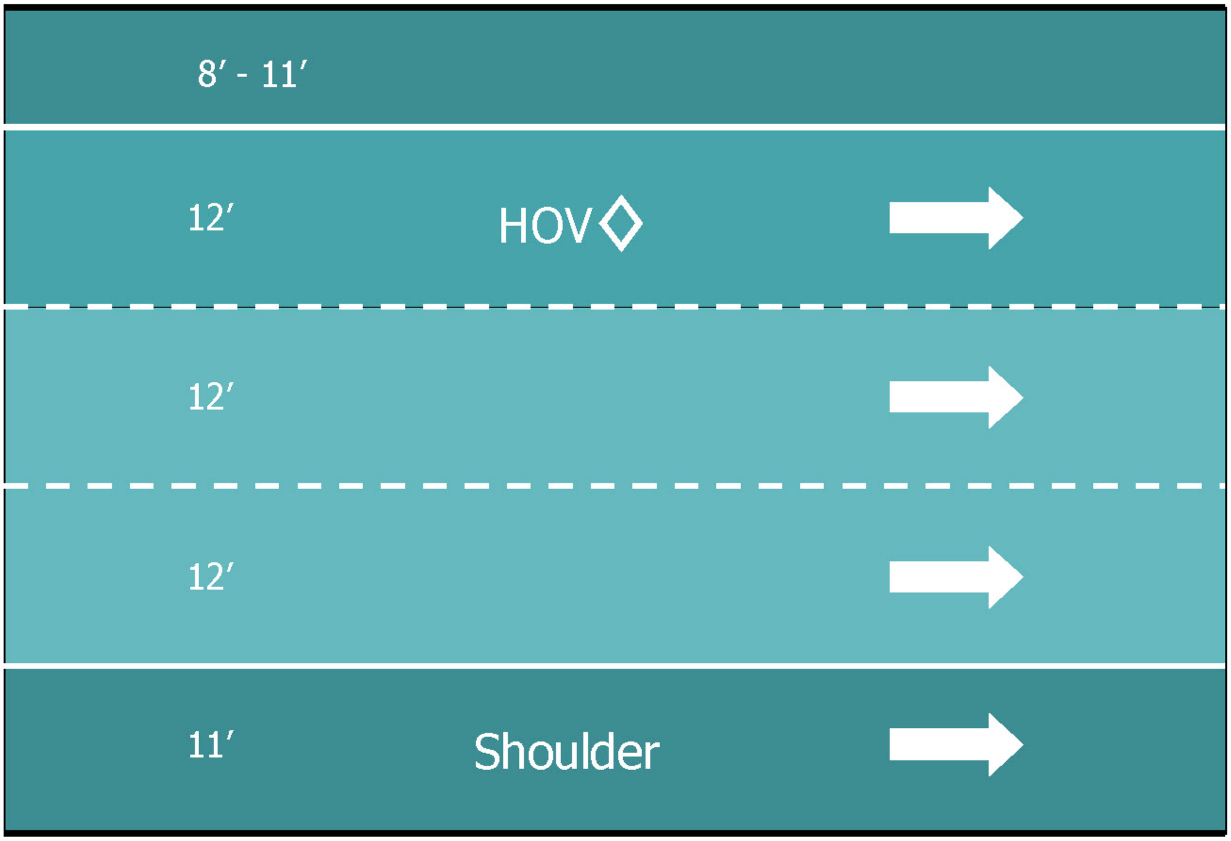

Figure 42. Illustration. I-66 HOV/SL Lane Plan View—Virginia (50).

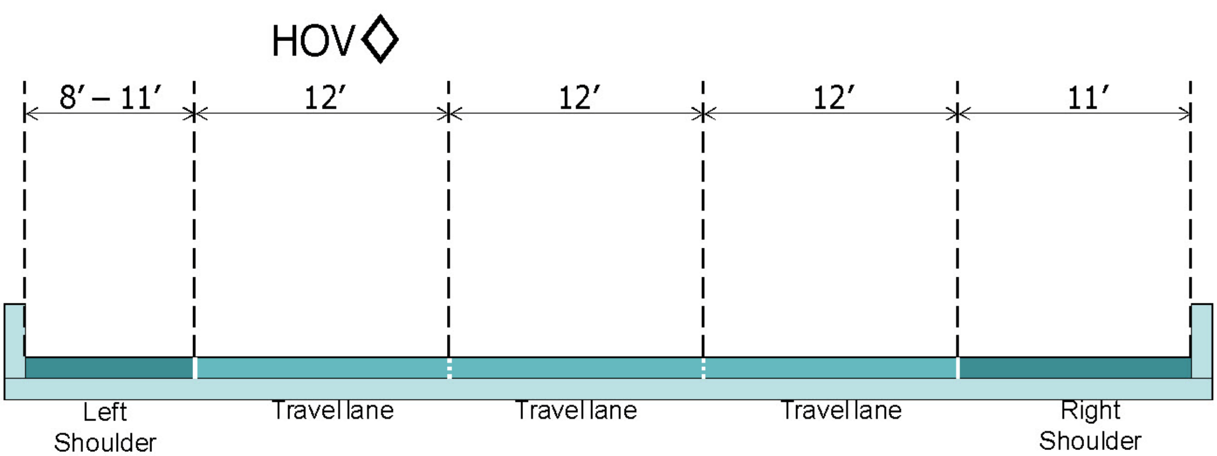

Figure 43. Illustration. I-66 HOV/SL Typical Cross-Section—Virginia (50).

Project Conceptualization

I-66 has a storied history. Originally conceived in 1956 and designed in the 1960s, I-66 was one of the initial highway construction projects to be successfully sued on the grounds of lacking an environmental impact statement (despite the approval and design occurring prior to the enactment of the National Environmental Policy Act). The HOV/SL was constructed prior to this lawsuit, but in 1972, the U.S. Court of Appeals required the U.S. Department of Transportation to halt construction and conduct an environmental impact statement specifically for the portion east of I-495. The end result was a four-lane freeway (two in each direction) between Washington, D.C., and I-495, with HOV-2+ required for the peak period/peak-direction portion of the freeway between I-495 and Rosslyn (although single occupant vehicle (SOV) travel to/from Dulles airport is permitted) (51). This cross-section allows the HOV/SL portion to have an interesting design—two separate ramps to I-495 from I-66 directly accessible from both the HOV lane and the shoulder lane, as shown in Figure 44. Lane balancing is not an issue, given the constrained design within the beltway.

Figure 44. Photo. I-495, Viewing Dual Entrance Ramps from I-66—Virginia.

Facility Management

Whereas the shoulder lanes are open to general purpose traffic, the HOV lane is open to all vehicles meeting either two-person restrictions or permitted hybrid vehicles. An overhead sign enables a downward pointing green arrow when the SL is active, and a red X appears when the shoulder has been recovered, as seen in Figure 16. To respond to the need for incidents and breakdowns, emergency refuge areas have been constructed since the implementation of the facility. [52] Furthermore, the operational hours of the shoulder lanes have changed since 1995 to respond to changing traffic conditions. Peak period conditions often extended beyond the original 10:00 a.m. eastbound threshold, and prior to the 3:00 p.m. westbound initialization. As a result, VDOT extended the operational times to 11:00 a.m. and 2:00 p.m., respectively. [53], [54]

Performance of System

Highway System Performance

In 2007, typical traffic volumes during the eastbound HOV/SL hours ranged from 19,500 to 27,000 vehicles, with 21,000 to 25,000 vehicles westbound. These volumes compare with 190,000 average annual daily traffic (AADT) for the corridor in this segment. Truck volumes are low (approximately 2-3 percent), as are bus volumes (1 percent) within the HOV/SL portion of I-66. Within the HOV/SL segment, morning volume-to-capacity (V/C) ratios fell between 0.90 and 1.00 (eastbound), indicating at capacity, heavy volume usage. In the westbound direction, LOS F conditions typically resulted, with V/C ratios between 0.83 and 1.01 (suggesting the backward-bending portion of the V/C curve, whereby saturated conditions depress both volumes and speeds). [33]

Safety and Incidents

Based on a safety analysis using negative binomial regression models and crash data from 2002 to 2004, researchers concluded that there was no evidence that the HOV/SL managed-lane strategy had a statistically significant effect on crash frequency during peak hours. As the authors of the study commented, "A typical factor, high AADT volume, and a natural causal factor, light conditions, especially combined with motorists' aggressive lane change behaviors in merging and diverging areas, are presumably major factors influencing crashes in the study area," and not the effect of the SL operations directly. [33]

Case Study: Minnesota—Priced Dynamic Shoulder Lanes

Overview

Facility

- I-35W, north of 42nd Street to Downtown Minneapolis.

Operator

- Minnesota Department of Transportation.

Years of Operation

- 2009–current.

Operating Strategy Overview

- Use of leftmost shoulder provides MnPASS Express Lane service during certain times when traffic along the general purpose lanes is congested.
- Transit vehicles, carpools, and MnPASS customers (SOV) are able to use the converted shoulder lane when operational.
- Transit vehicles and high-occupancy vehicles operate at no charge in the PDSLs. MnPASS customers (SOV) pay the displayed fee for shoulder access to the PDSL.
- Prices for MnPASS customers are set to ensure free-flow travel.

- Installation was a conversion of a right shoulder bus-only-shoulder operation to a left PDSL and was included as part of a larger Urban Partnership Agreement project for Mn/DOT.

Number of Lanes

- One left shoulder lane.

Length

- Approximately 2.5 mi of PDSL.

Project Description

The Area

IH-35W is a major north-south corridor that connects the southern suburbs and downtown Minneapolis, Minnesota. Congestion is extensive along the corridor and increases with proximity to downtown. Until the deployment of PDSLs and high-occupancy toll lanes on the facility, the right shoulder was used for BOS operations to provide reliable transit trips into the city.

Priced Dynamic Shoulder Lanes

The Mn/DOT incorporated priced dynamic shoulder lanes along I-35W to improve traffic flow along the corridor using transit and tolling. The PDSLs connect with approximately 10 mi of additional new MnPASS lanes along the corridor. This project, along with the addition of two new transit stations, is part of a partnership between the local, State, and Federal Government funded through the U.S. Department of Transportation's Urban Partnership Agreement. The MnPASS lanes provide a new option on I-35W during peak periods.

The PDSLs are deployed along with variable speed limits across the general purpose lanes on I-35W. As shown in Figure 45, sign gantries are located approximately every ½ mi along the section of freeway. These gantries incorporate traditional guide signs along with dynamic speed limit panels over the general purpose lanes. Over the PDSL, regulatory signs provide information on the hours of operation and the MnPASS restrictions and toll rates for access. The width of the PDSL varies from 17 ft to 19 ft between the left median barrier and the edgeline striping for the leftmost general purpose lane.

Figure 45. Illustration. PDSL on I-35W—Minneapolis, Minnesota. [27]

Project Conceptualization

The PDSLs are part of a larger congestion relief program along I-35W. In addition to the PDSLs, additional MnPASS lanes were installed along with two new park-and-ride lots in the corridor. New electronic signs were installed every ½ mi between 42nd Street and downtown Minneapolis to provide real-time information to help motorists make informed decisions about their commute and the availability of the PDSLs. Lane control signals located over the PDSLs indicate whether or not the lane is open to users, and DMS panels on the regulatory signs display the MnPASS toll for SOV access to the lanes. As part of this project, emergency refuge areas were also installed off the right shoulder to facilitate breakdowns and incident management. The entire facility, including the general purposes lanes, was resurfaced as part of this project. The PDSL portion of the project cost 13 million dollars, including the resurfacing. Unlike BOS elsewhere in the region, speeds on the PDSL can remain at free-flow freeway speeds to optimize travel time savings.

Facility Management

When operational, the left shoulder is available to all transit vehicles, carpools, and MnPASS customers. Transit and carpools are able to use the PDSL for free, while MnPASS vehicles with only one occupant are required to pay a fee to access the PDSL. All tolls are collected electronically, and there are no tollbooths on the facility. Incident response along the facility is primarily handled by Minnesota State Police and FIRST.

Technologies Deployed

In addition to the traditional ITS components of cameras and loop detection, Mn/DOT added sign gantries spanning the entire facility, with variable speed limit panels, lane control signals, and DMS panels for toll display.

Performance of System

Highway System Performance

Since the deployment of the PDSLs is very recent, extensive performance statistics are not available. Mn/DOT personnel state that the lane is working very well and is operating as planned. The full impact of the shoulder lane will occur during 2010 when the Crosstown Project is completed.

Safety and Incidents

As with system performance, safety statistics are not available at this time. However, Mn/DOT personnel believe that the facility is operating safely and as planned.

Case Study: Massachusetts—Shoulder Lane Use

Overview

Facility

- I-93: Exit 41 to Exit 47 from Wilmington to Methuen.
- SR 3: Exit 15 to Exit 12.
- I-95: Exit 12 to Exit 20.
- I-93: Exit 1 to Exit 4 (12 mi).

Operator

- Massachusetts Department of Transportation (MassDOT), Massachusetts State Police, and Commerce Insurance Courtesy Patrol.

Years of Operation

- 2002–current.

Operating Strategy Overview

- Use of rightmost breakdown lane (shoulder) by general purpose traffic only during peak periods Monday–Friday. Hours of operation vary from 5:00 a.m.–10:00 a.m. in the morning and 3:00 p.m.–7:00 p.m. in the evening depending on the facility.
- Post-mounted signs in yellow and white provide information to drivers on breakdown lane availability. The DMS are being installed along I-93 in the northern section that will also be used to provide breakdown lane availability.
- Rumble strips, scored concrete, and block pavers were removed during installation.
- Emergency pull-out areas are located approximately every ½ mi along deployment locations.
- Heavy trucks are prohibited from using the breakdown lane as a travel lane during operational periods.

Number of Lanes

- One right shoulder.

Length

- 45 mi of breakdown lane use on four facilities.

Project Description

The Area

The facilities where breakdown lane use is operational during the peak travel periods are roadways in the Boston area that provide critical access to the region. Congestion on these facilities was to the point where traffic was at a standstill and drivers were taking the initiative to use the shoulder as a travel lane despite restrictions.

Breakdown Lane Use

The objective of opening the breakdown lanes to general purpose traffic during peak periods was to increase capacity. The maximum allowed speed on the shoulder is 65 mph (60 mph on SR 3), which is the posted speed for the general purpose lanes. A minimum of 10-ft shoulder width is required for the breakdown use operations, with 12 ft being the desired shoulder width. For each of the projects listed, MassDOT treated the deployment as a traditional widening project. To that end, drainage features were moved to the new edge of pavement, and guardrails and fixed object shielding were moved accordingly. Emergency pull-off areas were installed approximately every ½ mi along the facilities where breakdown lane use was deployed to facilitate incident management and response. The shoulders were resurfaced as part of these projects as well. Figure 46 shows the start of the breakdown lane use along I-93. A regulatory sign indicates the hours of operation and user restrictions.

Figure 46. Photo. Breakdown Shoulder Use on I-93—Massachusetts. (23)

Project Conceptualization

With each deployment, MassDOT has to seek approval from FHWA to implement the strategy as a temporary measure until funding and approval are obtained for widening. The intent is for these facilities to be temporary in nature and not a permanent fixture for long-term capacity provision. The portion of I-95 with the breakdown lane use is currently in the construction phase of a project that will add a general purpose lane, at which time the shoulder use will be terminated. Bridges along that roadway that are being widened will have enough width to add another lane at a later date and still provide a shoulder for breakdown use. SR 3 is at the preliminary and environmental state of project approval for widening, which when completed will add a general purpose lane and terminate the temporary use of the breakdown lane as a travel lane.

Facility Management

The MassDOT oversees the general operation of the breakdown lane use in the Boston area. The Massachusetts State Police enforces the operational strategy, and the Commerce Insurance Courtesy Patrol provides roadside assistance in the corridors. Incident response along the facilities is typical of that across the region, with a unified response manual guiding procedures. Agencies involved include MassDOT, local fire departments, local police departments, environmental services, and other agencies with varying responsibilities for incident management.

Technologies Deployed

Some sensors are located within the I-93 corridor, along with cameras and overhead DMS. Most of these technologies existed prior to the deployment of the breakdown lane use. The DMS are currently being installed on the northern section of I-93 to facilitate user information.

Performance of System

Highway System Performance

The MassDOT does not maintain any specific measures of effectiveness for the breakdown shoulder use. In general, there has been a definite improvement in travel speeds along these corridors, though specific improvements are difficult to track because of the lack of complete deployment of devices in the field for data collection purposes.

Safety and Incidents

In general, MassDOT has seen no significant change in crash rates along these facilities with breakdown lane use operational. However, crash statistics are difficult to assess since crash data and crash locations do not really indicate whether a crash is in the breakdown lane or not.

Case Study: Washington—State Route 2, Temporary Shoulder Use

Overview

Facility

- US 2, eastbound direction of trestle.

Operator

- Washington State Department of Transportation.

Years of Operation

- 2009–current.

Operating Strategy Overview

- Use of rightmost shoulder deployed during evening peak period to alleviate congestion on the trestle.
- All vehicles allowed to use the facility during operational hours.

Number of Lanes

- One right shoulder.

Length

- Approximately 1.55 mi.

Project Description

The Area

This particular facility is a congested location, as the trestle serves as a merge point for eastbound traffic coming from the Everett city center and high volumes from northbound I-5. While the capacity of I-5 was recently improved and HOV lanes were added to the facility, the previous I-5 bottleneck shifted from 526 to the Snohomish River Bridge—the US 2 trestle. Even the addition of an auxiliary lane on I-5 did not reduce congestion in the area.

Temporary Shoulder Use

The WSDOT saw the potential to alleviate congestion on the trestle by opening up the right shoulder during the evening peak. The objective of the project was to improve travel times, reduce the impacts of the bottleneck at the trestle, and relieve the congestion at a critical interchange in the region. All vehicles are allowed to use the right shoulder of the US 2 trestle in the eastbound direction during the evening peak. As shown in Figure 47, the skip striping indicates to the user that the shoulder is open for travel. Hours of operation are Monday–Friday, 3:00 p.m.–7:00 p.m., with a maximum allowable speed of 60 mph on the trestle.

Figure 47. Photo. US 2 Shoulder Use—Everett, Washington. (55)

Project Conceptualization

The US 2 trestle is a highly congested corridor in the Seattle region. The WSDOT provides temporary use of the right shoulder in the evening peak to alleviate some of the congestion. The restriping deployed allows for three different movements on the trestle to remain in their own lanes when shoulder use is allowed. Each destination off the bridge (SR 204, 20th Street SE, and US 2 EB) can be reached from a separate lane when the shoulder use is allowed, eliminating the need for weaving and shared lane use. The intent of WSDOT is for this treatment to be a permanent one for the near future.

Facility Management

The WSDOT restriped the trestle to provide adequate space for the shoulder use. Figure 48 and Figure 49 show the cross-sections before and after the restriping, respectively. During the restriping project, one barrier had to be minimized to allow for a wider shoulder on the trestle. Regarding traffic control devices, a typical skip strip and solid edgeline strip were used, and one overhead sign was added to mark the Homeacre Road exit. No lane control signals are used on the trestle. Shoulder-mounted or barrier-mounted regulatory signs, which are manual flip signs, are posted every 1,200 ft. One display reads "SHOULDER OPEN TO TRAFFIC," while the closed version reads "SHOULDER CLOSED." The WSDOT personnel can flip these signs in the event of an incident on the trestle or when it is closed for log removal in the river. The DMS signs on I-5 can be used to provide traveler information to those drivers destined for the US 2 trestle.

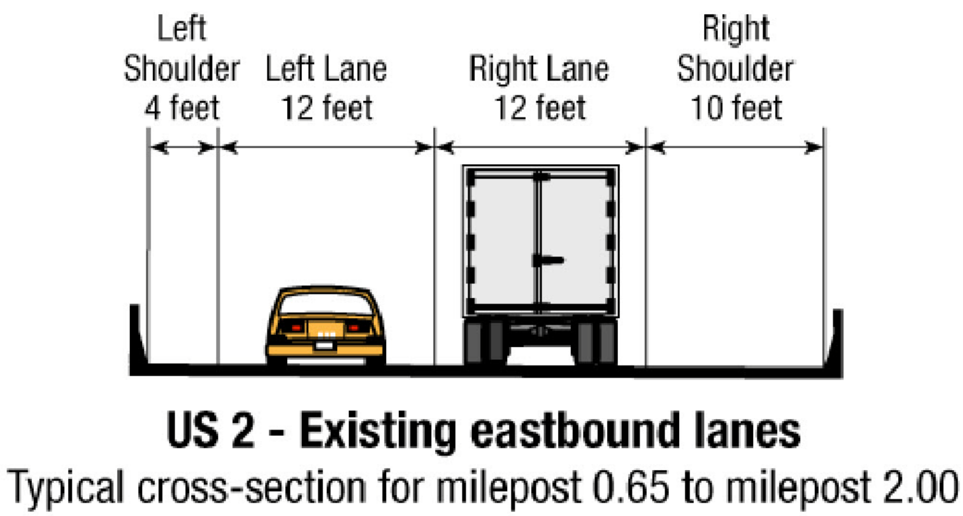

Figure 48. Illustration. US 2 Trestle Original Cross-Section—Everett, Washington. [55]

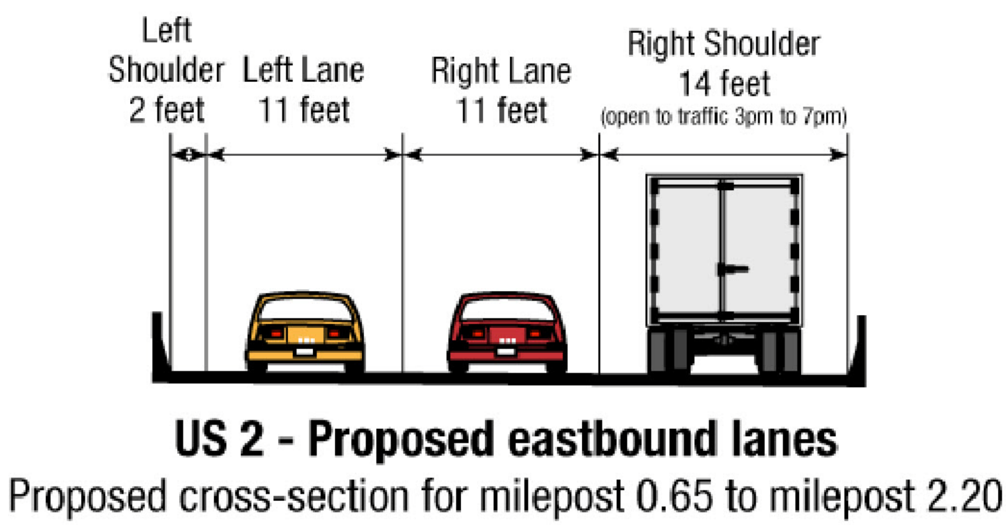

Figure 49. Illustration. US 2 Cross-Section for Shoulder Use—Everett, Washington. [55]

Technologies Deployed

No unique ITS technologies were deployed as part of this shoulder use project.

Performance of System

Highway System Performance

The primary performance measure for the trestle is travel time. After deployment, delay in this area was reduced from 8-10 minutes to 1-2 minutes on the facility. Travel times are much more reliable for this commute, and throughput on the access ramps has increased. The average speed on US 2 after implementation of the shoulder use and ramp metering on I-5 has increased from 10 mph to 37 mph, which is close to the maximum feasible of 42 mph because of ramp curvature.

Safety and Incidents

It is too early to confidently assess the safety improvements along the trestle. Anecdotal evidence provided by WSDOT personnel indicate that collisions at the conflict point where the roads merge on the trestle have been reduced. It is difficult to measure the true impact of the shoulder use since its deployment coincided with ramp metering on I-5, which feeds the US 2 trestle.

Chapter 5: Final Remarks

This report was developed to summarize the implementation of safety shoulders as travel lanes as a method to increase the efficient use of highway capacity. Its purpose is to provide a succinct overview of efforts to use left or right shoulder lanes as temporary or interim travel lanes. As part of this summary, information related to the impact of shoulder usage on highway safety and/or accidents during operations was reviewed as well. The report provides critical information that the FHWA can use to formulate guidance for agencies on providing temporary shoulder use as a means of increasing roadway capacity. The study that generated this product was conducted at the request of Congress through the 2008 Technical Corrections Act.

Agencies need to consider a wide range of issues when determining whether shoulder use is appropriate for a particular corridor or region. Experience both overseas and domestically provides a wealth of experience from which agencies can learn to make informed decisions. From the European perspective, temporary shoulder use is only used during congested periods when queues begin to build at bottlenecks in the system. Moreover, this treatment is almost always deployed in conjunction with dynamic lane control signing and speed harmonization. Furthermore, European agencies have realized both safety and mobility benefits as a result of these projects. While American deployments have been limited, experience has been positive, though safety benefits have not been conclusive. The issues that need to be considered include design—such as the treatment at interchanges and auxiliary lanes, drainage, emergency refuge areas, rumble strips, and ITS components; traffic control devices; and operational and safety performance measures. In addition, maintenance concerns, enforcement roles and responsibilities, incident response procedures, personnel training, costs, liability and legal issues, and public outreach and education are issues that should be examined. Careful consideration of these issues can help ensure that a shoulder use deployment is effective without having negative impacts on safety and operations.

The following results can be taken away from this summary:

- The use of buses on shoulders has generally significantly benefited transit trip time reliability in those corridors where it has been implemented.
- There have been shoulder use projects that have shown bottleneck relief at spot locations.
- Incident data provided from the U.S. seems to be inconclusive at this point. There are safety benefits provided from the European applications. However, the shoulder use is only a part of a much larger investment in ATM technology and resources to manage them.
- There have been longer incident clearance times in areas that don't have shoulders available to move incidents off the highway. Also, responders don't have the benefit of traveling the shoulder to reach the incident scene.
- European usage of hard shoulder running has always been accompanied by additional ATM strategies such as dynamic lane control signals and variable speed limits. These additional support strategies have generally been lacking in U.S. applications.

As a result of the information gained from this study, consideration should be given to the following:

- FHWA should consider developing clearer agency guidance on the use of shoulders. This would need to be a joint effort from the Offices of Infrastructure (Design), Safety, and Operations (including how the MUTCD relates to shoulder use lanes). The lack of existing U.S. performance data would also point to the need for more research in this area.
- Hard shoulder running was one of the ATM strategies recommended for implementation in the U.S. from a recent international scan. As FHWA and AASHTO develop guidance on ATM, they should clarify guidance on temporary shoulder usage. This would include comparing the differences in current U.S. usage to that of the European countries.
- Research and modeling for temporary shoulder use is lacking at this time. This could be covered in research being developed for the ATM program.
- The results of the NCHRP/AASHTO/FHWA Domestic Scan on Maximizing Flow on Existing Highway Facilities should be considered in the development of shoulder use guidance.

Acknowledgements

This study was conducted in cooperation with the staff from the Federal Highway Administration (FHWA), Battelle Memorial Institute, and other agencies across the United States. Greg Jones—Regional Transportation Operations Specialist with the FHWA Resource Center—served as the project director and provided guidance throughout the study. Special thanks are also extended to the following organizations for their participation in case study interviews: Massachusetts Department of Transportation, Minnesota Department of Transportation, Virginia Department of Transportation, and Washington State Department of Transportation.

Bibliography

1. **Mirshahi, M., et al.** *Active Traffic Management: The Next Step in Congestion Management.* Alexandria, VA : American Trade Initiatives, 2007. FHWA-PL-07-012.

2. **Research and Innovative Technology Administration.** *Intermodal Surface Transportation Efficiency Act of 1991.* [Online] Federal Highway Administration, 1991. http://ntl.bts.gov/DOCS/istea.html.

3. **Federal Highway Administration/Federal Transit Administration.** *A Guide to Metropolitan Transportation Planning Under ISTEA: How the Pieces Fit Together.* Washington, D.C. : U.S. Department of Transportation, 1995. FHWA-PD-95-031.

4. **Transportation Planning Capacity Building Program.** *The Metropolitan Transportation Planning Process: Key Issues.* Washington, D.C. : Federal Highway Administration/Federal Transit Administration, 2004. FHWA-EP-03-041.

5. **Task Force for Public Transportation Facilities Design of the AASHTO Subcommittee on Design.** *Guide for High Occupancy Vehicle (HOV) Facilities.* Washington, D.C. : American Association of State Highway and Transportation Officials, 2004. ISBN # 1-56051-295-4.

6. **Schrank, D. and Lomax, T.** *The 2005 Urban Mobility Report.* College Station, TX : Texas Transportation Institute, Texas A&M University System, 2005.

7. **Federal Highway Administration.** *Fiscal Year 2003 Performance Plan.* [Online] September 2002. http://www.fhwa.dot.gov/reports/2003plan/index.htm#natneed6.

8. —. *Congestion Mitigation.* [Online] U.S. Department of Transportation. http://ops.fhwa.dot.gov/congestionmitigation/congestionmitigation.htm.

9. **Collier, T. and Goodin, G.** *Managed Lanes: A Cross-Cutting Study.* College Station, TX : Texas Transportation Institute, Texas A&M University System, 2004. FHWA-OP-05-037.

10. **FHWA Freeway Management Program, Office of Operations.** *Managed Lanes Initiative.* [Online] U.S. Department of Transportation. http://ops.fhwa.dot.gov/freewaymgmt/managed_lanes.htm.

11. **Transportation Research Board Joint Subcommittee on Active Traffic Management - AHB20(5).** *Definition of ATM.* s.l. : Unpublished Committee Document, 2009.

12. **BBC News World Edition.** Creative ways to beat congestion. [Online] November 2004. http://news.bbc.co.uk/2/hi/uk_news/magazine/4044803.stm.

13. **Lemke, K. and Irzik, M.** *Temporary Use of Hard Shoulders-Experiences and Economic Assessment.* Bergisch Gladbach, Germany : Federal Highway Research Institute, Traffic Planning, Highway Design, and Safety Analyses Section, June 2006. Original photos courtesy of

Autobahndirektion Sudbayern (South Bavaria). Presentation to Planning for Congestion Management Scan Team.

14. **Helleman, B.** *Hard Shoulder Running (HSR) in The Netherlands.* AVV Transport Research Centre, Rotterdam, The Netherlands : Ministry of Transport, Public Works, and Water Management, Directorate-General of Public Workds and Water Management, June 2006. Presentation to Planning for Congestion Management Scan Team.

15. **Differt, D., et al.** *Managing Travel Demand: Applying European Perspectives to U.S. Practice.* Alexandria, VA : American Trade Initiatives, 2006. FHWA-PL-06-015.

16. **Bolte, F.** *Transport Policy Objectives: Traffic Management as Suitable Tool.* Bergisch Gladback, Germany : Federal Highway Research Institute (BASt), June 2006. Presentation to Planning for Congestion Management Scan Team.

17. **Martin, P.** *Bus Use of Shoulders.* Washington, D.C. : Transportation Research Board, 2006. TCRP Synthesis 64.

18. **Kuhn, B.** *Personal Interview with Mn/DOT Staff, Mn/DOT Metro District.* 2009.

19. **American Association of State Highway and Transportation Officials.** *A Policy on Geometric Design of Highways and Streets.* 4th Edition. Washington, D.C. : AASHTO, 2004.

20. **Urbanik, T. and Bonilla, C. R.** California Experience with Inside Shoulder Removals. *Transportation Research Record 1122.* 1987.

21. **McCasland, W. R.** Use of Freeway Shoulders to Increase Capacity. *Transportation Research Record 666.* 1978.

22. *I-95 Express Website.* [Online] Florida Department of Transportation. http://www.95express.com.

23. **Kuhn, B.** *Personal Interview with MassDOT Staff.* 2009.

24. —. *Personal Interview with Mn/DOT Staff, Regional Transportation Management Center.* 2009.

25. —. *Personal Interview with VDOT Staff.* 2009.

26. —. Personal Interview with WSDOT Staff. [Online] October 2009.

27. *Mn/DOT Urban Partnership Agreement Website.* [Online] Minnesota Department of Transportation. http://www.dot.state.mn.us/upa/managed.html.

28. **Hessen Road and Traffic Authority.** *Traffic Control Hessen, Hessen Road and Traffic Authority.* Weisbaden, Germany : s.n., 2006.

29. **Tignor, S., et al.** *Innovative Traffic Control Technology and Practice in Europe.* Alexandria, VA : American Trade Initiatives, 1999. FHWA-PL-00-021.

30. *Active Traffic Management.* [Online] Highways Agency. http://www.highways.gov.uk/knowledge/1361.aspx.

31. **Federal Highway Administration.** *Manual on Uniform Traffic Control Devices.* Washington, D.C. : U.S. Department of Transportation, 2010.

32. **Curren, J. E.** *Use of Shoulders and Narrow Lanes to Increase Freeway Capacity.* Washington, D.C. : Transportation Research Board, 1995. National Cooperative Highway Research Program Report 369.

33. **Lee, J. T., Dittberner, R. and Sripathi, H.** Safety Impacts of Freeway Managed-Lane Strategy: Inside Lane for High-Occupancy Vehicle Use and Right Shoulder Lane as Travel Lane During Peak Periods. *Transportation Research Record 2012.* 2007.

34. **Sultan, B., Meekums, R. and Brown, M.** *The Impact of Active Traffic Management on Motorway Operation.* Manchester, UK : Institution of Engineering and Technology, 2008.

35. **Bauer, K. M., et al.** Safety Effects of Narrow Lanes and Shoulder-Use Lanes to Increase Capacity of Urban Freeways. *Transportation Research Record 1897.* 2004.

36. **Middelham, F.** *Dynamic Traffic Management.* AVV Transport Research Centre, Rotterdam, The Netherlands : Ministry of Transport, Public Works, and Water Management, Directorate-General of Public Works and Water Management, June 2006. Presentation to Planning for Congestion Management Scan Team.

37. **Wormgoor, F.** *The Netherlands Director-General for Public Works and Water Management.* AVV Transport Research Centre, Rotterdam, The Netherlands : Rikswaterstaat, June 2006. Presentation to Planning for Congestion Managment Scan Team.

38. **Koot, A.** *Operational Aspects of Traffic Information.* AVV Transport Research Centre, Rotterdam, The Netherlands : Ministry of Transport, Public Works, and Water Management, Directorate-General of Public Works and Water Management, June 2006. Presentation to Planning for Congestion Management Scan Team.

39. **Taale, H.** *Regional Traffic Management Method and Tool.* AVV Transport Research Centre, Rotterdam, The Netherlands : Ministry of Transport, Public Works, and Water Management, Directorate-General of Public Works and Water Management, June 2006. Presentation to Planning for Congestion Management Scan Team.

40. **Sparmann, J.** *Freeway Operation in Germany: Experiences in Hessen.* Athens, Greece : Hessian Ministry of Economy and Transport, June 2006. Presentation to 1st International Symposium on Freeway and Tollway Operations.

41. **Pilz, A.** *Presentation of the Traffic Centre Hessen.* Frankfurt, Germany : Jessian Ministry of Economy and Transport, June 2006. Presentation to Planning for Congestion Management Scan Team.

42. **Grant, D.** *M42 Active Traffic Management Pilot Project.* London, England : Highwas Agency, Department for Transport, June 2006. Presentation to Planning for Congestion Management Team.

43. **Highways Agency, Department for Transport.** *Active Traffic Management (ATM) Project M42 Junctions 3A-7.* [Online] http://www.highways.gov.uk/knowledge/tcc/atm/index.htm.

44. —. *M25 Controlled Motorways Summary Report, Issue 1.* London, England : Highways Agency, Department for Transport, 2004.

45. **Department for Transport.** *About DfT.* [Online] http://www.dft.gov.uk/stellent/groups/dft_about/documents/divisionhomepage/031259.hscp.

46. **Tailor, P.** *Journey Time Reliability and Network Monitoring.* London, England : Highways Agency, Department for Transport, June 2006. Presentation to Planning to Congestion Management Scan Team.

47. **Highways Agency, Department for Transport.** *M42 Active Traffic Management Results - First Six Months.* London, England : Highways Agency, Department for Transport, 2007.

48. —. *4-Lane Variable Mandatory Speed Limits - 12 Month Report.* London England : Highways Agency, Department for Transport, 2008.

49. *12th International HOV Systems Conference: Improving Mobility and Accessibility with Managed Lanes, Pricing, and BRT.* **Federal Highway Administration.** Houston, TX : U.S. Department of Transportation, 1995. http://ops.fhwa.dot.gov/publications/12hovsysconf/.

50. **Ungemah, D., Kuhn, B.** *Special Use of Shoulders for Managed Lanes: Review of Practice and Research.* Texas Transportation Institute. College Station, TX : s.n., 2009. Technical Report for Mn/DOT.

51. **Virginia Department of Transportation.** *I-66 Multimodal Transportation and Environmental Study.* Fairfax, VA : Virginia Department of Transportation, 2003. http://www.infoi66.com/PurposeandNeedDocument.pdf.

52. **Schintler, L.** *ITS Center Project: I-66 Integration Model.* Arlington, VA : Virginia Department of Transportation, Federal Highway Administration, Partners in Motion Evaluation Subcommittee, 2001. http://www.gmupolicy.net/its/papers3/66/paper-Schintler-I-66.htm.

53. **Virginia Department of Transportation.** *I-66 Spot Improvements Citizen Information Meeting.* Fairfax, VA : Virginia Department of Transportation, 2007. http://www.virginiadot.org/info/resources/I-66_Spot_Improvements-CIM-9-26_2007.pdf.

54. —. *High Occupancy Vehicle (HOV) Systems: Wehn and Where.* Fairfax, VA : Virginia Department of Transportation, 2009. http://www.virginiadot.org/travel/hov-novasched.asp.

55. **Swires, M., et al.** *US 2 - Hard Shoulder Running Case STudy.* Washington State Department of Transportation. Vancouver, WA : s.n., 1009. Presentation.

56. **Virigina Department of Transportation.** *2007 Traffic Data.* Fairfax, VA : Virginia Department of Transportation, 2007. http://www.virginiadot.org/info/ct-TrafficCounts-2007.asp.

Appendix A: Interview Questions for Agency Representatives

1. What facilities have had shoulder use either in the past or currently?
2. What was the intent of the implementation (goals & objectives)?
3. Were other operational strategies evaluated prior to identifying shoulder use as the alternative to deploy?
4. What are the specifics of that operation?
    a. Facility name/number, city
    b. Date implemented
    c. Date terminated (if applicable)
    d. Length of implementation
    e. Allowed vehicles
    f. Operating partners
    g. Conditions associated with implementation: Is this an interim treatment until future widening occurs? Are speeds restricted or other conditions changed from the prior condition?
5. Operational hours (part-time vs. permanent)
6. What is the maximum speed allowed for the shoulder lane?
7. What are the geometric features of the implementation?
    a. Cross-sectional details, including shoulder width
    b. Treatment at interchanges
    c. Handling of inlets (if applicable)
    d. Handling of existing rumble strips (if applicable)
    e. Guardrail and fixed object shielding / adjustments (if applicable)
8. What traffic control devices are part of the implementation?
    a. Pavement markings
    b. Overhead signs and signals
    c. Ground-mounted signs
9. What are the ITS-related elements of the implementation?
10. What performance measures are associated with the facility and how are they used?
    a. Specific measures of effectiveness
    b. Who is responsible for monitoring?
11. What were the costs associated with implementation?

12. How is the facility enforced?
    a. Who is responsible?
    b. What are the related fines?
    c. What is the enforcement approach?
13. How is the facility maintained?
    a. Who is responsible?
    b. Other specific
14. How are incidents within the facility handled?
    a. Who is responsible?
    b. What is the average response time?
    c. Are there unique strategies deployed here that are not deployed elsewhere in the region?
15. What is the overall evaluation of the implementation?
    a. Overall safety experience (crashes / severity)
    b. Operational experience (travel speeds / delay)
    c. In-service compliance rates
16. What, if any, liability issues or concerns posed a problem with the implementation of shoulder operations?
17. Were their impacts with oversize and/or overwidth vehicles? How were they addressed?
18. Was there a public outreach or education component to the deployment?
19. Was any legislation required to enable the strategy?
20. Are there any issues with compliance or return to traditional operation on adjacent sections or on other local facilities that do not permit emergency shoulder/breakdown lane use as peak period travel lanes?

Contact Information

For additional information on this report, contact:

Federal Highway Administration
Resource Center
Mr. Gregory M. Jones
404- 562-3906
gregm.jones@dot.gov

Beverly T. Kuhn, Ph.D., P.E.
Texas Transportation Institute
3135 TAMU
College Station, TX 77843-3135
979-862-3558
b-kuhn@tamu.edu

Federal Highway Administration
1200 New Jersey Avenue SE
Washington, DC 20590

May 2010

Publication # FHWA-HOP-10-023