Use of Freeway Shoulders for Travel

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CONVERSION FACTORS

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)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°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)		
°C	Celsius	1.8C+32	Fahrenheit	°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)

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INTRODUCTION

Part-time shoulder use is a transportation system management and operation (TSM&O) strategy that allows use of the left or right shoulders as travel lanes during some, but not all, hours of the day. Use of the shoulder is typically restricted to certain classes of vehicles. It is one possible strategy for addressing congestion and reliability issues within the transportation system, and can be particularly cost-effective where alternatives to add lanes are infeasible, undesirable, or cost-prohibitive. In such situations, TSM&O alternatives, including part-time shoulder use, may be most appropriate for cost-effectively reducing delays and improving travel-time reliability. Part-time shoulder use is most cost-effective in constrained right-of-way conditions; however, there are certain minimum geometric clearances, visibility, and pavement requirements that must be considered before part-time shoulder use can be implemented.

PURPOSE, SCOPE, AND TARGET AUDIENCE

The purpose of this guide is to provide guidance for planning, designing, implementing, and operating part-time shoulder use. This guide provides guidance on factors that need to be considered in:

- Deciding through a comprehensive Performance-Based Practical Design(PBPD) process if the part-time use of the shoulder is a viable alternative for meeting the current and projected goals of the region;
- Determining the impacts and feasibility of implementing part-time shoulder use; and
- Designing and operating part-time shoulder use to optimize safety and lane utilization.

This guidance does not address the “part-time” use of a shoulder in work zones during construction (e.g., as part of a lane shift or lane closure), nor does it include the permanent, full-time “conversion” of a shoulder into a travel lane. Full-time conversion of the shoulder constitutes the “permanent elimination” of the shoulder and needs to be addressed in that context. This guide does not address pedestrian and bicycle considerations because it is focused on freeway applications. Part-time shoulder use on other types of roadways in the U.S. has been limited to bus-only shoulder use on a handful of arterials, and this guide presents only limited arterial-specific considerations.

The target audience for this guide consists of State Department of Transportation (DOT), toll agency, and Metropolitan Planning Organization (MPO) planners and designers.

ORGANIZATION OF GUIDE

The guide is organized in the typical sequence of steps required to plan, design, implement, and operate part-time shoulder use.

Part I of this guide addresses the planning steps for considering part-time shoulder use.

- Chapter 1 introduces part-time shoulder use and shows images of various facilities with part-time shoulder use.
- Chapter 2 provides planning considerations and screening criteria to help users assess if part-time shoulder use is feasible on a specific facility using a Performance Based Practical Design (PBPD) approach.

Part II of this guide provides guidance on how to analyze part-time shoulder use.

- Chapter 3 offers guidance on conducting operations analysis, including reliability analysis, of part-time shoulder use.
- Chapter 4 provides guidance on assessing the safety impacts of part-time shoulder use.
- Chapter 5 presents guidance on assessing the environmental impacts of part-time shoulder use, including air quality and noise.
- Chapter 6 provides guidance on conducting benefit-cost analysis and computing the life-cycle costs of part-time shoulder use.

Part III of this guide provides information on how to design, implement, and operate part-time shoulder use once a decision to use it has been made.

- Chapter 7 identifies and describes the various design considerations for part-time shoulder use, including geometry, pavement, drainage, signing and marking, and ITS design.
- Chapter 8 describes how the environmental approval process and the design exception process are handled for part-time shoulder use, how to coordinate with stakeholders such as emergency responders and maintenance personnel, and how to successfully conduct outreach to the general public prior to beginning part-time shoulder use.
- Chapter 9 presents best practices for maintenance, incident management, and other day-to-day operational issues of part-time shoulder use.

The appendices provide example applications of the guidance, along with case studies of successful applications of part-time shoulder use in the United States.

CHAPTER 1. WHAT IS PART-TIME SHOULDER USE?

Part-time shoulder use is a transportation system management and operation (TSM&O) strategy for addressing congestion and reliability issues within the transportation system. It is a strategy that may be used as part of a congestion management process (CMP). There are many forms of part-time shoulder use or “shoulder running”; however, they all involve use of the left or right shoulders of an existing roadway for temporary travel during certain hours of the day. Part-time shoulder use has primarily been used in locations where there is recurring congestion due to lack of peak period capacity through the corridor, particularly where other alternatives to improve peak period operations are infeasible or cost-prohibitive (at least in the near term). In such situations, TSM&O alternatives, including part-time shoulder use, may be most appropriate for cost-effectively reducing delays and improving travel-time reliability. Part-time shoulder use is a form of Active Traffic Management (ATM) and modifies roadway conditions and controls—in this case the number of lanes—in response to forecast or observed traffic conditions. It may be used in combination with other ATM strategies, such as overhead lane control signs, dynamic speed limits, and queue warning. Converting a shoulder to a full time travel lane—known as shoulder elimination—is fundamentally different than using a shoulder on a part-time basis as an ATM strategy. This strategy should be used with much greater caution, and involves additional considerations not presented in this guide.

Although part-time shoulder use can be a very cost-effective solution, it may not be an appropriate strategy where minimum geometric clearances, visibility, and pavement requirements cannot be met, or it may have an adverse impact on safety. Part-time shoulder use is primarily used on freeways. There are multiple examples of how highway agencies have used the shoulders of roadways to address congestion and reliability needs and to improve overall system performance. These options vary in terms of the location of the shoulder (left/right shoulder options) used, vehicle-use options [e.g., bus only, high-occupancy vehicle (HOV) only, all vehicles except trucks], operating schedule, and special speed controls. In all of these options, the use is “temporary” for part of the day, and the lane continues to operate as a refuge/shoulder when not being used for these travel purposes. This condition is referred to as “**part-time shoulder use**” throughout this guide.

The decision to pursue the option of part-time shoulder use should be made as part of a comprehensive Performance-Based Practical Design (PBPD) assessment of design and TSM&O options for achieving the agency’s performance objectives for the facility design and operations. First the physical feasibility of part-time shoulder use should be evaluated to determine if it is a feasible option, and a region should decide if part-time shoulder use is consistent with its long-term transportation goals and objectives. Then, a preliminary assessment should be made to identify one or more design and operations concepts for evaluation. This assessment, conducted under the overall umbrella of a PBPD process, should assess the operational and safety effects of part-time shoulder use to ensure it is indeed a cost-effective means for achieving the agency’s performance objectives for the facility. Throughout this evaluation, key planning and environmental, maintenance, operations, design, and emergency responder stakeholders should be involved to ensure a successful outcome.

SHOULDERS AND SHOULDER USAGE

> It remains the policy of the Federal Highway Administration (FHWA) that constructing and maintaining roadway shoulders along all major and minor arterials and freeways provides inherent value. Shoulder width is one of the controlling criteria that FHWA requires a formal written design exception if minimum design criteria are not met on the National Highway System.[1]
>
> Aside from their structural benefits for pavement and drainage, shoulders provide refuge for vehicles in emergency situations, access for first responders, and an additional recovery area for drivers trying to avoid conflicts in the adjoining travel lanes. The safety benefits of shoulders are documented in the AASHTO Highway Safety Manual and other studies. Because of these factors, the decision to use shoulders for travel should be carefully considered and limited in both its application and time of usage.

Part-time shoulder use may be an effective TSM&O strategy for operations and reliability of a facility in particular situations. In this context, part-time shoulder use is defined as follows:

- The shoulder is used for travel only during those times of day when the adjoining lanes are likely to be heavily congested (e.g., during peak hours, when congestion is detected, or when general purpose lanes are closed for construction or incidents).
- When not needed as an additional travel lane, the shoulder will be restored to its original purpose as a "shoulder," and the basic physical characteristics of the shoulder are retained and recognizable.

The term "part-time" does not require that the use of shoulders as a TSM&O strategy is "short-term" and will be discontinued by some fixed date. Although part-time shoulder use may be used as an interim treatment while a conventional project (e.g., construction of additional lanes) awaits funding or completion, it may also be used indefinitely.

This guidance does not address the "part-time" use of a shoulder in **work zones** during construction (e.g., as part of a lane shift or closure). The Manual on Uniform Traffic Control Devices (MUTCD) and agency-specific guidance on maintenance of traffic plans address such usages. Additionally, this guidance does not address the **permanent, full-time** usage of a shoulder as a travel lane. Such usage constitutes the "permanent elimination" of the shoulder and the creation of a new travel lane. This is a major design change and not a TSM&O strategy.

Additionally, this guidance does not address the use of shoulders to remove slow-moving trucks from general purpose lanes on steep upgrades. This effectively converts the shoulder into a permanent truck-climbing lane. A handful of shoulders are open to slow moving trucks on rural and suburban freeways in the U.S.

DIFFERENT PART-TIME SHOULDER USE CONCEPTS

The term “part-time shoulder use” covers a broad range of different design and operational options. In some cases, the particular physical limitations and conditions of the site ultimately drive these options, which in turn influence the design of the facility. Likewise, the travel demands and traffic characteristics of the corridor will very much influence the operational choices needed. Specifically, part-time shoulder use may be used to fulfill any number of “functions,” such as the following:

- Reduce peak-period recurring congestion.
  - In lieu of a conventional add-a-lane capacity improvement.
  - As an interim treatment while a conventional widening or expansion project works through the planning/design/construction process.
- Increase bus ridership by improving bus travel time and reliability.
- Provide short-term benefits for a minimal cost compared to ultimate solution.
- Mitigate the loss of general purpose lane capacity if a general purpose lane is converted to a managed lane such as an HOV lane.

Given these various uses, a variety of part-time shoulder use options exist. Generally speaking, all of these options take advantage of the existing shoulder infrastructure and include a combination of treatments such as left/right shoulder option, vehicle-use option, operating schedule, and special speed controls, as listed below:

- Left/Right Shoulder Option
  - Right shoulder
  - Left shoulder
- Vehicle-Use Options
  - Open shoulder to transit vehicles only
  - Open shoulder as an HOV lane that permits carpools and transit vehicles to use it
  - Open shoulder as a HOT lane that allows vehicles to pay a toll to use it if they don’t meet HOV occupancy requirements
  - Open shoulder to all vehicles except trucks
  - Open shoulder to all vehicles
  - Open shoulder to slow moving trucks in rural mountainous areas
- Operating Options
  - Dynamically open shoulder when certain congestion thresholds are reached (an ATM strategy referred to as “Dynamic Shoulder Use”)
  - Statically open shoulder during specified historical peak periods (time of day)
- Speed Control Options
  - Same speed limit as other lanes (at posted speed limits).
  - Same speed as other lanes (at a reduced speed relative to normal posted speed limits)

- Lower speed limit than other lanes.

FHWA generally consolidates these numerous types of part-time shoulder use into three types:[(2)]

- Bus-only use of shoulders (Bus on Shoulder, or BOS) to improve bus travel time and reliability,
- Static shoulder use for most vehicles during predetermined hours of operation, and
- Dynamic shoulder use for most vehicles based on need and real-time traffic conditions.

Vehicle-use restrictions vary by facility, but static and dynamic shoulder use is typically open to all vehicles except trucks.

PART-TIME SHOULDER USE GUIDANCE

This section summarizes key guidance presented throughout this document. It is intended to provide readers with a concise summary of key information presented in the remaining chapters of this document.

Planning, Screening, Decision Making, and Preliminary Engineering

The evaluation of part-time shoulder use as a strategy for relieving congestion in a corridor should begin at the regional level as part of a planning process. Practitioners should consider part-time shoulder use if it is consistent with a region's long-range plan, and congestion management process (CMP). More complex part-time shoulder-use projects, such as dynamic shoulder lanes, should also be consistent with the regional intelligent transportation system (ITS) architecture. More viable candidates for part-time shoulder use over "unmanaged" corridors include corridors monitored by a traffic management center (TMC), supported by a Traffic Incident Management (TIM) program, and generally highly managed. The National Environmental Policy Act (NEPA) should determine if part-time shoulder use is the preferred solution for a corridor, and preliminary engineering activities determine specific operating conditions. If congestion reduction (or transit service improvements in the case of BOS) is desired and traditional improvements are not feasible, part-time shoulder use may be the right solution for a corridor, and a NEPA process should be initiated.

Implementation of part-time shoulder use typically occurs within the existing paved roadway area and primarily has the potential to impact environmental categories related to traffic volume and speed such as air quality, greenhouse gas emissions, and noise. However, some part-time shoulder use projects involve widening the shoulder, which creates the potential for impacts to many other environmental categories such as water quality, plants, animals, and socio-economic elements. Part-time shoulder use projects often receive a categorical exclusion (CE).

Preliminary engineering activities should inventory the physical roadway conditions and consider the following:

- Is shoulder width adequate, or can it be widened?
- Are vertical clearances adequate?
- Is the shoulder pavement structural capacity adequate in terms of drainage and rideability?
- Is it feasible to provide supplemental emergency pull-off or refuge areas beyond the shoulder at reasonable intervals?
- Is a sufficiently long segment available, or is an acute bottleneck being relieved?

If the answers to these questions determine part-time shoulder use is feasible, a specific operating scheme can be selected.

- Should the right or left shoulder be used? The right shoulder is used most often because it is usually wider than the left shoulder and thus easier to implement. Both shoulders should not be used.
- What vehicles will the shoulder be open to?
- If the shoulder is open to more than buses, should it be a static shoulder lane (fixed hours of operation) or dynamic shoulder lane (variable hours in response to traffic conditions)?
- Will there be speed restrictions?

Mobility Analysis

The capacity of a shoulder used for travel depends on design features such as shoulder width, length of the segment used for travel, and speed limits. For example, I-66 in Virginia features a 12-foot wide shoulder lane with a two- to four-foot wide paved "shoulder" beyond it, overhead dynamic lane control signs, and the same observed capacity as adjacent general purpose lanes. I-93 in Massachusetts has shoulder lanes less than 12 feet wide, a one- to two-foot paved "shoulder" beyond the shoulder lane, limited dynamic signs, and generally older-style interchanges with more-constrained geometry than I-66. The shoulder on I-93 was observed to have only one-half to two-thirds the capacity of adjacent general purpose lanes.

A simulation study found a "low quality" 10-foot-wide shoulder that is closed to trucks and only willing to be used by slightly more than half of drivers has a capacity of approximately 1,300 vehicles per hour, and a 12-foot-wide shoulder with "normal freeway lane design standards" that all drivers are willing to use has a capacity of approximately 1,650 vehicles per hour.

When analyzing a potential part-time shoulder use project, capacities should be set by first determining the approximate geometric dimensions of shoulder elements and then choosing a capacity value observed or simulated on a similar facility noted above.

Operations analysis of freeways is typically conducted with the procedures of the Highway Capacity Manual (HCM) or microsimulation. Both sets of tools can be adapted for analysis of part-time shoulder uses.

The HCM does not provide for lane-by-lane analyses, so shoulders designated for part-time use must be combined with the general purpose lanes for the purpose of capacity analysis and the estimation of speed and delay. A proportional capacity reduction should be applied to all freeway lanes to account for the reduced capacity of the shoulder lane. Use of the FREEVAL software tool should be considered for part-time shoulder-uses projects encompassing multiple interchanges. Many microsimulation programs enable parameters to be adjusted on a per-lane basis, so capacity of the shoulder can be adjusted directly.

Safety Analysis

Experience in the U.S. to date has not identified major safety issues with part-time bus, static, or dynamic shoulder use that led implementing agencies to discontinue part-time shoulder use due to poor safety performance. Before/after crash studies of part-time shoulder use in the U.S. and internationally have not consistently indicated whether part-time shoulder uses has a positive or negative effect on crash frequency.

An analysis of existing crash data, including crash type, the time of crashes, and the location of crashes should be the basis of a safety analysis of potential part-time shoulder use. Part-time shoulder use would likely reduce congestion-related crashes occurring during the hours part-time shoulder use would operate. Crashes related to erratic driver behavior, driver confusion, or suboptimal geometry may increase with part-time shoulder use. Assessment of the safety impacts of part-time shoulder use on a given facility should begin with a review of three or more years of historical crash data. The review should consider the crash type, temporal factors (e.g., time of day, day of week), and location. Congestion-related crashes, such as rear-ends occurring during times a shoulder would be open to travel, may potentially decrease with part-time shoulder use if congestion is reduced. Crashes related to erratic driver behavior or suboptimal geometry, such as run-off-road, fixed-object, or sideswipe crashes, may increase with part-time shoulder use. Crashes related to right-side ramp-freeway junctions may increase with part-time use of the right shoulder. The mere presence of crash types that may increase with part-time shoulder use should not prevent the application of part-time shoulder use, but a preponderance of those crash types indicates a given freeway may be a poor candidate for part-time shoulder use.

The 2014 Supplement to the Highway Safety Manual (HSM), 1st Edition, provides crash-prediction models for freeways and ramp terminals, but does not explicitly model part-time shoulder use. The HSM models would have limited utility in evaluating projects that involve only adding part-time shoulder use. For this guide, HSM models were used to conduct a comparative analysis of freeways with typical lane widths and shoulder widths and freeways with an additional lane in each direction, but narrower shoulder widths (and in some cases narrower lane widths). The HSM freeway crash-prediction models indicate that implementing freeway part-time shoulder use could have the following influence on crash frequency and severity:

- Reduce property damage only (PDO) crashes
- Slightly increase fatal and injury (FI) crashes when converting existing 4- or 6-lane freeways
- Have little to no effect on FI crashes when converting existing 8-lane freeways

Environmental Analysis

As with all federal-funded or permitted actions, the National Environmental Policy Act (NEPA) applies. The environmental categories most likely to be affected by part-time shoulder use include air quality, greenhouse gas emissions, and noise.

Air Quality

Given the variety of characteristics of shoulder use projects, generalizing the effect of shoulder use on air quality remains difficult. Shoulder use may reduce congestion, which is generally beneficial to air quality. Shoulder use also has the potential to increase traffic volume, which generally worsens air quality. There may also be no net effect on traffic characteristics that would affect air-quality pollution concentrations.

Areas that do not meet, or previously did not meet, federal air quality standards are identified as "non-attainment" and "maintenance" areas, respectively. The Environmental Protection Agency (EPA) requires air quality analysis of federal transportation projects in these designated areas for the transportation-related pollutants—ozone, nitrogen dioxide, carbon monoxide, and particulate matter per the transportation conformity rule [(3)]. Shoulder-use projects are typically federal projects because they require design exceptions. Projects in metropolitan non-attainment and maintenance areas must be incorporated into regional emissions analysis associated with the region's Transportation Improvement Plan (TIP) and long-range plan (MTP). Transportation conformity rules also require the analysis of potential localized emissions impacts where applicable. Non-attainment and maintenance areas have standing transportation conformity procedures in place that address how projects are handled to assess for conformity status (exempt/non-exempt) and whether a project-level analysis is required. These procedures may assist in assessing individual part-time shoulder-lane projects.

Outside of non-attainment and maintenance areas, air quality analysis may be conducted as part of a NEPA analysis. For example, agencies may consider the following questions when deciding whether or not to conduct air quality analysis in these areas:

- Is there concern about the project within the community?
- Is the shoulder only open to buses, or will other vehicles have access?
- If the shoulder is only open to buses, is service being added or will bus headways remain the same?
- For PM impacts, are diesel vehicles being moved closer to sensitive roadside receptors?

- Is the project in a dusty area where dust will be stirred up when the shoulder opens each day?

The degree of analysis conducted should be proportional to the project scope. Qualitative analysis without the use of modeling software is likely acceptable for low impact projects and more-complex analysis may provide useful information for projects with a higher potential for impact.

Greenhouse Gas Emissions

In some states—currently California, Massachusetts, New York, and Washington—analysis of greenhouse gas (GhG) emissions is required for some transportation projects. Part-time shoulder-use projects in these states may require GhG analysis depending on the circumstances.

Noise

Noise analysis measures the noise impact when the predicted noise level approaches or exceeds the Noise Abatement Criteria (NAC) in 23 CFR 772 or represents a substantial increase over existing noise levels. Per 23 CFR 772, noise analysis is required for all Federal or Federal-aid Highway Projects authorized under Title 23, United States Code that are categorized as Type I or Type II. Type I projects include adding a travel lane such as during part-time shoulder use, and similar to air quality analysis, design exceptions required for part-time shoulder use will make these projects federal thus subject to 23 CFR 772.

The level of noise analysis necessary will depend upon the type of part-time shoulder use. For BOS, noise analysis may be qualitative because the number of additional vehicles and changes in speed are small or nonexistent. For static and dynamic part-time shoulder use, noise analysis will typically be conducted in a manner similar to a conventional widening project. For the noise analysis, the location of the part-time shoulder use would affect the proximity to sensitive receptors. Left side part-time shoulder use is less likely to have noise impacts compared with right side part-time shoulder uses, which places the traffic closer to sensitive receptors. Noise analysis and determination of noise mitigation needs are focused on peak noise conditions. This may or may not correspond to peak volume conditions (when shoulders are typically open for travel), and analysis will determine if part-time shoulder use affects peak noise or not. Noise levels are determined by using the FHWA Traffic Noise Model (FHWA TNM).(4)

If part-time shoulder use does increase peak noise, and there are impacts associated with it, noise abatement must be considered and implemented if found to be feasible and reasonable. The likelihood of noise issues is greater with use of the right shoulder than with use of the left shoulder, since the right shoulder places traffic closer to noise receptors.

Costs and Benefits

Compared to traditional capacity-adding projects, part-time shoulder use projects typically have lower initial construction costs and higher operations and maintenance costs due to the ongoing management of the shoulder and any associated ITS equipment. For this reason, a life-cycle cost should be computed for any part-time shoulder use project under consideration. A 10-, 15-, or

20-year time horizon should be considered. Shorter horizons may be appropriate if part-time shoulder use is being implemented as a temporary measure until larger capacity-adding project such as widening is completed.

The following are costs that are often incurred with part-time shoulder use projects and should be incorporated into a life-cycle cost analysis:

- Capital Costs
  - Activities associated with systems engineering
  - Shoulder reconstruction and widening
  - Bridge raising or widening, if required
  - Ramp treatments
  - Training
  - Emergency patrols
  - Public outreach and communications
  - ITS
- Operations and Maintenance Costs
  - Compliance (additional police presence)
  - Driver training (for bus on shoulder)
  - Sweeps, including manual or video
  - ITS, including TMC operation and hardware maintenance
  - Roadway maintenance

Benefit cost ratios are useful for comparing part-time shoulder-use projects to other alternatives on a corridor and other projects in a region. FHWA's TOPS-BC tool was developed specifically for TSM&O projects such as part-time shoulder use and is one means of conducting a benefit-cost ratio.

Design

Beginning and End Segments

Logical termini should be established during project scoping and preliminary engineering consistent with NEPA guidance. Part-time shoulder use can begin and end along basic segments or at ramps. If the beginning or end of a static or dynamic shoulder use segment falls along a basic freeway segment, then it would desirably be located such that it is highly visible and easily comprehended to approaching drivers. Horizontal curves, crest vertical curves, and overpasses may limit a driver's visibility of a downstream roadway, and dropping any type of lane, including a shoulder open to part-time travel, within or immediately beyond these features should be avoided if possible. Likewise, dropping any type of lane in or immediately beyond an area with extensive, complex signing or other features contributing to high driver workload should be avoided, if possible. The desirable locations for lane drops are also desirable locations to begin shoulder use.

Part-time shoulder use along basic freeway segments should include pavement markings at the beginning of the area designated for shoulder use that guide drivers from the adjacent general purpose lane onto the shoulder but also maintain continuity of the general purpose lane. Shoulder use ends along basic freeway segments are designed similar to shoulder use adds. A solid edge line is typically used to transition traffic from the shoulder back to the adjacent general purpose lane.

Carrying part-time shoulder use through system interchanges is more complex due to conflicts with exiting and entering traffic. At major forks, the shoulder lane can be carried onto one of the forks. This is desirable if the ramps downstream of the fork have more lanes than the freeway approaching the fork.

Georgia and Hawaii maintain static part-time shoulder use between (but not through) adjacent interchanges to create auxiliary lanes and mitigate the effects of closely-spaced entrance and exit ramps. In this case, lanes designated for shoulder use do not function as basic freeway lanes, and a drop onto a service interchange is necessary and inherent in the design.

Lane Width

For shoulders designated for part-time travel, a width of 12 or more feet is generally preferred. Narrower shoulders may be adequate depending upon the type of vehicles using the part-time shoulder lane, the available lateral offset to obstructions beyond the pavement edge, and if speed restrictions will be used when the shoulder is open. If trucks are prohibited from using the shoulder, then widths as narrow as 10 feet may be adequate. Shoulders less than 10 feet wide are not recommended for part-time shoulder use.

A 10-foot shoulder may be inadequate for part-time shoulder use if the lateral offset to obstructions is less than 1.5 feet or a high volume of larger vehicles such as buses is anticipated. Opening the shoulder only when congestion is present and reducing the speed limit when the shoulder is open will likely to improve the safety of a narrow shoulder designated for part-time use.

Shoulders less than 12 feet wide will typically require a design exception if they are designated for part-time shoulder use. If an entire roadway is repurposed, and general purpose lanes are reduced to less than 12 feet wide to accommodate part-time shoulder use (for any shoulder width), a design exception is also required.

Shoulder Width

It is desirable to leave several feet of pavement beyond the portion of the shoulder designated for part-time shoulder use to decrease the likelihood of vehicles departing the roadway and decrease pavement maintenance needs. Part-time shoulder use will require a design exception, since the remaining paved shoulder (beyond the portion of the shoulder designated for part-time shoulder use) will not meet the minimum width requirements.

Lateral Offset to Obstruction

Lateral offset to obstruction is the distance from the edge of the traveled way to the nearest physical obstruction such as a median barrier, guard rail, bridge support, or bridge rail. The lateral offset between the edge of a lane designated for part-time shoulder use and an obstruction should be at least 1.5 feet.

In practice, states have relocated guardrails and other obstructions (sign and lighting structures), and obtained design exceptions for segments adjacent to bridge rails/barriers and abutments or other concrete barrier where lateral offset to obstruction is less than 1.5 feet.

Bridge Width

Many bridges have narrower shoulders than the approach roadways. The minimum width of a bridge shoulder that could be designated for part-time shoulder use is 11.5 feet. This dimension provides 10 feet of the shoulder as an effective part-time lane and 1.5 feet of the shoulder as an effective lateral offset to obstructions. It is not necessary for a shoulder designated for part-time use on a bridge to be the same width as a shoulder designated for part-time use on the approaching roadway; however, it does need to be 11.5 or more feet wide. In these circumstances, design exceptions may be needed for shoulder widths less than 12 feet and/or if the lateral offset to obstruction dimension is not met.

Stopping Sight Distance

On the inside of horizontal curves, a shoulder designated for part-time use will be closer to guardrails or median barriers if they are present. This may reduce sight distance, and it may reduce it below AASHTO minimum design values. If this occurs, it may be appropriate to relocate the barrier causing the sight-distance obstruction, impose speed restrictions, or obtain a design exception.

Cross Slope

Cross slopes on shoulders are sometimes greater than adjacent general purpose lanes to facilitate drainage, creating potential issues for part-time shoulder use. An agency may need to round a grade break between the travel lane and the shoulder or reduce shoulder cross slope by adding pavement on top of existing pavement to modify the cross slope.

Vertical Clearance

Prior to implementing part-time shoulder use, agencies typically field measure the height of bridges along a route, and any substandard vertical clearances dictate vehicle restrictions.

Ramp-Freeway Junctions

Chapter 8 describes how to maintain part-time shoulder use through on- and off-ramps. Part-time shoulder use may be implemented on freeways with taper-style or parallel-style ramps. Maintaining part-time shoulder use through a two-lane entrance or exit ramp is more challenging, and is not possible in some cases depending on the design details of the ramp-freeway junction. Ramp meters are effective at mitigating potential conflicts in merge areas because they break up platoons of ramp traffic and make it easier for traffic using the shoulder to cross the ramp taper or enter the speed change lane. This benefit occurs even with BOS operation if on-ramps have meters, the meters should be active when the shoulder is in use.

Turnout Placement and Design

Providing periodic emergency refuge spaces for disabled vehicles beyond the shoulder is highly desirable with part-time shoulder use. Sometimes, gore areas or ramp shoulders at entrances and exits provide a refuge space large enough to store a vehicle. When this is not the case, or when ramp spacing exceeds a half-mile, emergency turnouts should be constructed desirably at half-mile intervals. Turnouts should be long enough and 16-or-more feet wide so a vehicle with poor control and in the process of breaking down can enter it and be out of the shoulder. They should also be long enough to enable a tow truck to park and load a broken-down vehicle.

If turnouts cannot be constructed, such as on bridges or other constrained areas, part-time shoulder use can still be implemented, but there is a greater probability the shoulder will be blocked by disabled vehicles. Dynamic lane control signs should be given greater consideration on these facilities to enable closure of the shoulder in response to a disabled vehicle.

Turnouts have fewer benefits and are generally not constructed on BOS facilities because buses can reenter a general purpose lane to pass a disabled vehicle without greatly affecting traffic flow on the freeway or bus travel time.

Arterial Part-time Shoulder Use

Similar to freeways, arterial shoulder widths of 10 or 11 feet are adequate for part-time use on an open section for a low volume of buses at lower, congested speeds, and a 12-foot shoulder is desirable for part-time shoulder use. A 10-foot lane should not be used for part-time travel if the lateral offset to obstructions is less than the 1.5-foot AASHTO standard or if curbs are present. If curbs are present, then vehicles should be able to remain entirely in the shoulder and maintain a 1.5-foot separation between right side tires and the face of curb.

Signs

The 2009 MUTCD[5] does not contain signs specifically intended for part-time shoulder use, although signs developed by agencies should be compliant with the MUTCD. The next edition of the MUTCD is expected to include signs for shoulder use.

Primary static signs regulating part-time shoulder use, or the static portions of the dynamic signs, should be black on white. They may be supplemented with black-on-yellow warning signs.

Signs—static or dynamic—should be provided at the following locations, except for BOS operation:

- At the beginning of the segment designated for part-time shoulder use

- At exit ramps, to manage the conflict of exiting traffic from general purpose lanes and through traffic in lanes designated for part-time shoulder use
- At and on entrance ramps
    - To notify entering drivers that the shoulder may be used as travel lane
    - To manage the conflict between entering traffic and traffic on the shoulder
- At recurring intervals between interchanges
- At the end of the segment designated for part-time shoulder use

Similar to exit ramps on a freeway, a series of signs provided in advance of a pull-off and at the pull-off itself is recommended to increase driver awareness of its existence.

Signing on roadways with BOS operation is generally limited to static, ground mounted signs. Such signs should be installed along a roadway with BOS operation at regular intervals and near on- and off-ramps. There is typically no need for signs specifying hours of operation. Along a route, buses sometimes must merge back into a travel lane to avoid a narrow section of shoulder, often on or beneath a bridge. Black on yellow warning signs should be used if this is necessary.

If dynamic signs are used, then they should, at a minimum, include dynamic lane controls indicating that the shoulder lane is currently closed, open, or will soon be transitioning to be closed.

Pavement Markings

On basic segments away from ramps, this is straightforward, and there is consistency across states:

- The solid edge line typically used between the shoulder and adjacent travel lane remains in place.
- A second solid line is used on the outside of the shoulder beside the edge of pavement. This line functions as an edge line for traffic using the shoulder. The second solid line should be continuous even when the shoulder narrows or has a physical barrier beside it, such as a bridge rail.
- The two solid lines should be the same color—white for part-time use of the right shoulder and yellow for part-time use of the left shoulder.
- Striping can create parallel or taper-style merges and diverges.

The 2009 MUTCD limits use of diamond pavement marking symbols to HOV lanes, and they should not be used on shoulders open only to buses.

Colored pavement

The Section 3G of the 2009 MUTCD and an interpretation letter specify the use of colored pavements for the following situations:

- Yellow pavement for median islands separating traffic flows in opposite directions or left shoulders of divided highways or one-way streets or ramps(5)
- White pavement for channelizing islands or right-hand shoulders(5)
- Green pavement for bicycle lanes(6)
- Red pavement for streetcar and/or bus-only lanes on an experimental basis(6)

No color is designed for part-time shoulder use, and none should be used at this time unless a request to experiment is submitted to and approved by the MUTCD team.

Implementation

NEPA

If part-time shoulder use projects make use of federal funding or require federal action, then they require NEPA evaluations. Most to date have received a categorical exclusion (CE) because they are typically implemented within the existing ROW and largely within the existing paved surface.

Design Exceptions

Implementing static or dynamic part-time shoulder use will typically require a design exception. By definition, part-time shoulder use decreases shoulder width (when the shoulder is open to traffic), and shoulder width is one of the controlling criteria with specified minimum values on the National Highway System. Part-time shoulder use often impacts other controlling criteria as well. A number of factors mitigate the substandard geometry created with a part-time shoulder use and may justify the design exception:

- Reduced speeds, achieved through lower speed limits during periods of part-time shoulder use coinciding with congestion.
- Annual average daily traffic (AADT) in ranges where Highway Safety Manual (HSM) analysis (summarized in CHAPTER 4) predicts a reduction in crashes with narrowing of the shoulder and addition of a lane.
- Use on commuter facilities during commuting periods with a high percentage of familiar drivers.
- Prohibition of trucks in shoulder lanes.
- Enhanced monitoring of the facility with intelligent transportation systems (ITS) and/or patrol vehicles.
- Variable lane controls allowing closure of the shoulder if it is blocked by a disabled vehicle.
- Emergency turnouts.

The specific requirements of design exception requests vary by state. Design exceptions are typically submitted to and approved by FHWA Division Offices. Part-time shoulder use may have a relatively short implementation timeframe compared to conventional projects, so a design exception request should be prepared and submitted to FHWA as early as possible in the project development process. Most part-time shoulder use projects that have recently been implemented or are currently in the planning process are long-term implementations. Temporary approval is not recommended, since it may create the need for re-approval.

Requests for Experiment

Most part-time shoulder use projects have not required experimental traffic control devices. However, some more-complex part-time shoulder use projects, such as those with other ATM elements or extensive use of dynamic lane control signs, may require a request for experimentation. Chapter 8 describes the items that should be included in a request.

Stakeholder Engagement

As soon as a state DOT determines part-time shoulder use is desirable and feasible, they should reach out to stakeholders including planning, operations, design, maintenance, and executive leadership staff within a DOT; law enforcement; emergency responders; bus operators (particularly if the shoulder lane is only open to buses); MPO staff; and FHWA Division Office staff. Most agencies that have successfully implemented part-time shoulder use have formed working groups to ensure the needs of all stakeholders are incorporated into the concept of operations. Stakeholder involvement and education—assuming that some stakeholders may not be aware of the benefits and potential issues associated with part-time shoulder use—is an ongoing process, and working groups should continue to meet during the early years of part-time shoulder use. Engaging executive leadership early is critical because policies may need to change and laws potentially prohibiting driving on the shoulder may need to be interpreted or changed.

Public Engagement

Successful implementation of the first part-time shoulder use project in a metropolitan area includes explicit and proactive outreach and education to the general public and should be undertaken consistent with state public information guidance.

Best Practices

The following case studies from around the nation have evidenced several practices that aid in the successful implementation of part-time shoulder use:

- Maintenance of the shoulder is more similar to maintenance of general purpose lanes.
- Part-time shoulder use is typically implemented on some of the highest volume and most congested freeways in a region. These roadways typically have incident management plans and infrastructure in place, and it can be adapted for part-time shoulder use. Emergency turnouts, service patrols, and CCTV are typically implemented during part-time shoulder use.

- On BOS facilities, shoulders can still be used by police to pull vehicles over.
- A lane designated for static or dynamic part-time shoulder use should be inspected in entirety before each opening by "sweeping" (driving) the length of the facility or viewing CCTV if there is full camera coverage of the facility.
- Although expert systems can electronically, rather than manually, sweep a facility, it is still necessary to have incident response vehicles on standby in the event that debris or disabled vehicles are identified and need to be cleared.
- Currently, no facilities in the U.S. use a fully-automated process to open and close the shoulder without a human making the final decision.

EXAMPLES OF PART-TIME SHOULDER USES

In recent years, part-time shoulder use has emerged as a cost-effective way to help alleviate both recurring and non-recurring congestion, exploiting limited improvements to the existing infrastructure. The earliest application of part-time shoulder use launched in the mid-1970s on Seattle's SR 520 as a means to help remediate peak-hour congestion by letting HOVs jump a queue approaching a bridge leading to the city center. Since then, the range of applications for part-time shoulder use has grown to cover a wide variety of strategies and has seen implementation in more than 16 states.

These applications, which are highlighted in the Appendix, often form in an ad-hoc manner, and there has been little consistency among applications to date. For example, some applications use the left shoulder and others use the right, some employ changeable message signs and some employ static displays. Strategies have been adapted to best fit the specific conditions of the corridor. One common theme throughout, however, has been the complexity of the project development processes necessary to implement part-time shoulder use. Coordination across multiple stakeholder groups, including state DOTs, state and local government officials, transit agencies (if applicable), MPOs, enforcement entities, and various safety and emergency response stakeholder groups is essential for successful implementation. Figure 1 illustrates states that have employed part-time shoulder uses.

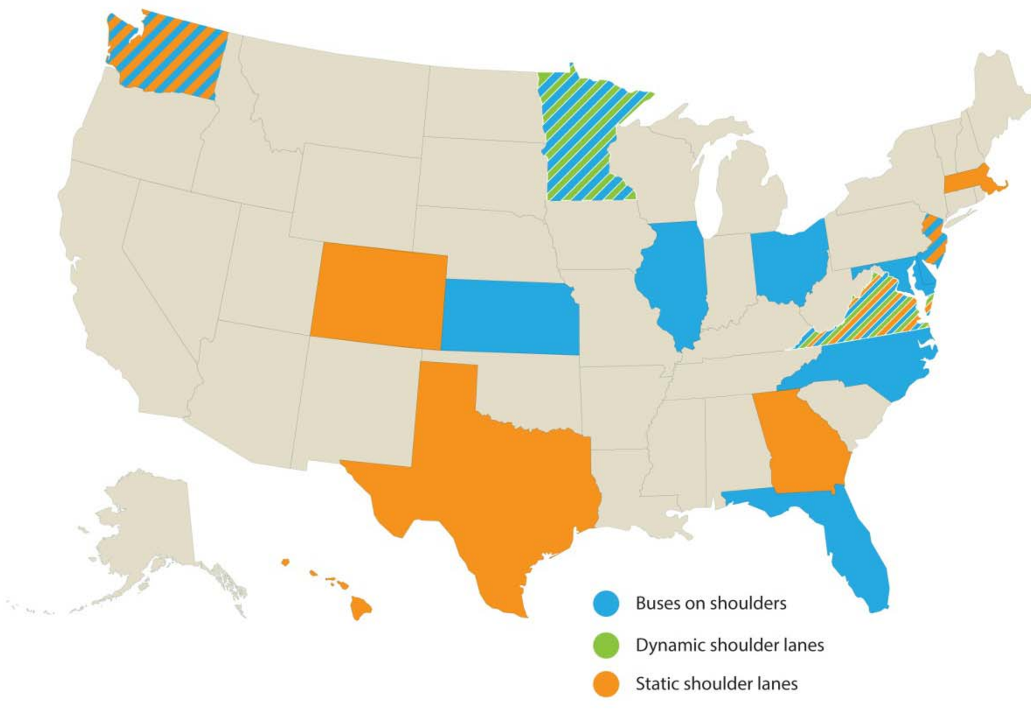


Figure 1. Map. Part-time shoulder use locations in US, 2015.

(Source: Kittelson & Associates, Inc.)

The remainder of this section highlights trends and applications of part-time shoulder use, both domestic and international. Descriptions of the several part-time shoulder use locations and a complete list of known locations in the United States are located in the Appendix.

Bus on Shoulder (BOS) Use

Designed to improve transit reliability, bus-on-shoulder (BOS) operation allows authorized transit vehicles to use the shoulder to avoid congestion in the general purpose lanes. This application improves person-throughput along a corridor and incentivizes the use of mass transit. BOS is unique from other part-time shoulder use strategies, as low volumes on the shoulder (compared to opening the shoulder to general traffic) minimize the need for signing, pavement markings, and ITS equipment. BOS also minimizes the impacts for emergency response to incidents and storage of broken down vehicles. While most BOS applications utilize the right shoulder, systems in Chicago, Cincinnati, and Columbus utilize the left shoulder. Overall, twelve states currently use BOS strategies on their urban corridors:

- California
- Colorado
- Delaware
- Florida
- Illinois

- Kansas
- Maryland
- Minnesota
- New Jersey
- North Carolina
- Ohio
- Texas
- Virginia
- Washington

Additional information on BOS shoulder use in these states is included in the Appendix.

BOS operation is primarily used on freeways, but is also used on arterials in several states. Figures 2 through 4 show BOS facilities.

Figure 2. Photo. Bus-on-shoulder operations in Minneapolis-St. Paul.
(Source: Metro Transit)

Figure 3. Photo. Bus-on-shoulder operations on the left-shoulder in Chicago.

(Source: Pace Bus)

Figure 4. Photo. Static Bus-on-shoulder message sign on US 9 arterial in Old Bridge, New Jersey.

(Source: TCRP Report 151)

Static (Time of Day) Part-time shoulder use

This strategy aims to reduce recurring congestion during peak periods by allowing all vehicle types to use the shoulder during fixed periods of the day. Though the predetermined hours of operation lend themselves to static message signs, dynamic signing may be used to reinforce restrictions or occasionally change them due to blockage of the shoulder, closure of general purpose lanes for construction, or major special events generating off-peak traffic. Overall, eight states currently use static part-time shoulder use:

- Colorado
- Georgia
- Hawaii
- Massachusetts
- New Jersey
- Virginia
- Texas
- Washington

All of these applications are on freeways. Additional information on static part-time shoulder use in these states is included in the Appendix. Figures 5 through 7 show static part-time shoulder use, some of which implement dynamic lane control signs. The specific facility shown in Figure 5—I-66—has since been converted to dynamic part-time shoulder use, although other static part-time shoulder use facilities remain in Virginia.

Figure 5. Photo. Previous Static Part-time shoulder use on I-66 in Northern Virginia

(Source: Virginia Department of Transportation)

Figure 6. Photo. Static part-time shoulder use on New Jersey Turnpike Newark Bay Extension with variable speed limit and changeable message sign.

(Source: Kittelson & Associates, Inc.)

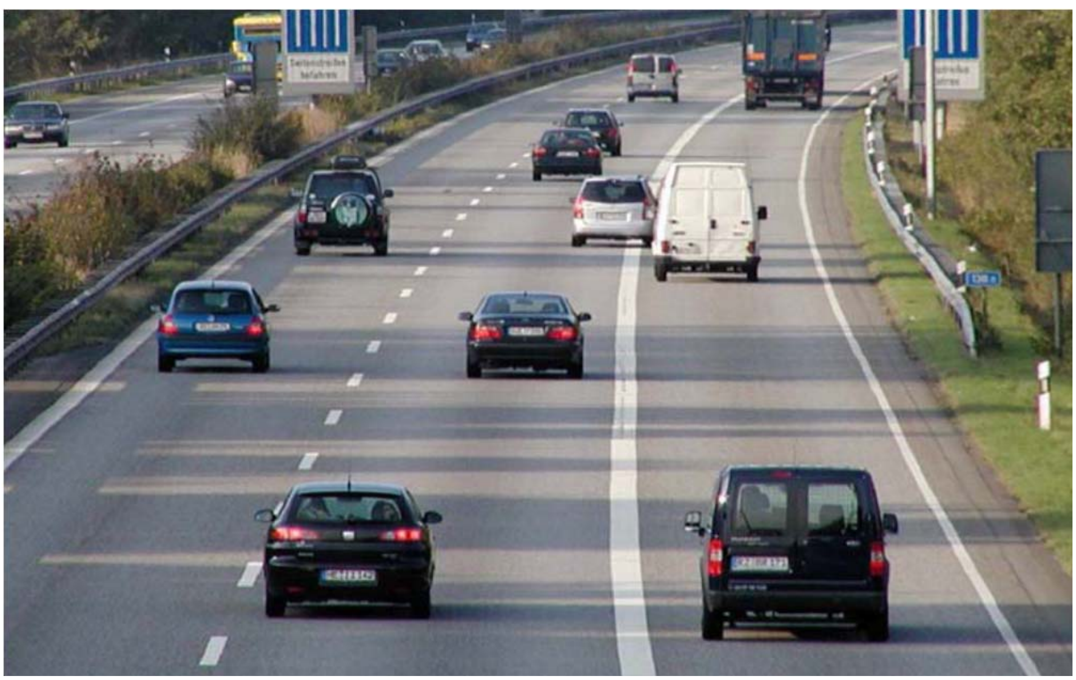


Figure 7. Photo. Part-time shoulder use in Germany.

(Source: Efficient Use of Highway Capacity Summary: Report to Congress, FHWA-HOP-10-023)

Dynamic (Traffic Responsive) Part-time shoulder use

Rather than limit shoulder running to periods of estimated recurring congestion, dynamic part-time shoulder use allows for general purpose traffic to temporarily use the shoulder as a travel lane *as needed* based on real-time traffic conditions. Through ITS equipment, a Traffic Management Center (TMC) can monitor conditions on the corridor and open the shoulder for use as congestion arises or in anticipation of increased traffic (e.g., special event or emergency scenario). Dynamic signs actively inform motorists when the shoulder is open for use. Variants of this strategy have employed dynamic part-time shoulder use exclusively for (HOV) during peak periods to incentivize carpooling; these applications can also operate as HOT lanes, allowing single-occupant vehicles to utilize the shoulder for a fee based on traffic conditions. Currently there are two known dynamic part-time shoulder use installations in the US: one on I-35W in Minneapolis, and one on I-66 in Virginia that was converted from static part-time shoulder use in 2015. However, several states—including California, New Jersey, and Michigan—are in the process of planning dynamic part-time shoulder use. Figure 8 shows dynamic part-time shoulder use in Minneapolis.

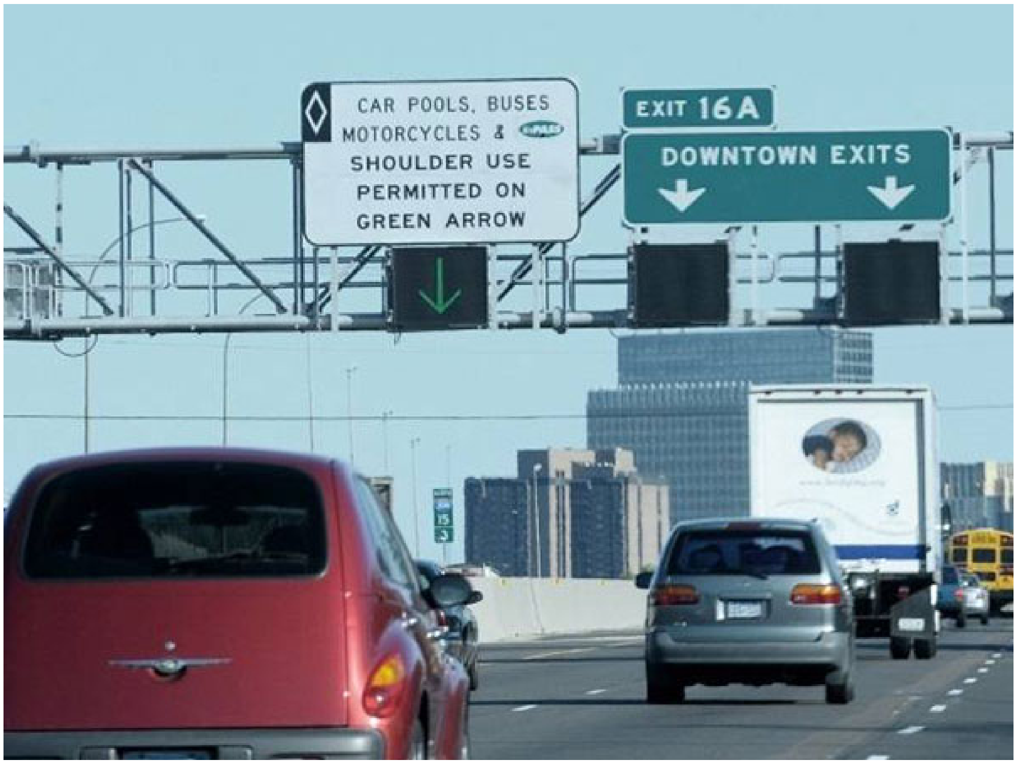


Figure 8. Photo. High-occupancy-toll part-time shoulder use in Minneapolis-St. Paul.

(Source: Minnesota Department of Transportation)

Unique Applications

Part-time shoulder use is typically used on long segments of freeway encompassing multiple interchanges, and it has typically been installed as a long-term TSM&O strategy. However, it has also been used in other manners:

- Massachusetts implemented part-time shoulder use on a portion of I-95/SR 128 in 1985. A portion of this facility has since been widened—effectively replacing the shoulder with a full-time general purpose lane—and part-time shoulder use was discontinued on this segment. Widening of the remaining section of I-95 is under design, and upon completion, part-time shoulder use will be eliminated from I-95.
- Maryland allows buses to use the shoulder on a portion of US 29 to bypass queues at signalized intersections. The majority of intersections have been replaced with at-grade interchanges, and part-time shoulder use has been discontinued on the portions of US 29 that no longer have signals.
- Georgia and Hawaii do not carry part-time shoulder use through interchanges. When open, lanes designated for static part-time shoulder use function as auxiliary lanes between entrance and exit ramps.
- New Jersey is currently utilizing static part-time shoulder use on the New Jersey Turnpike Newark Bay Extension portion of I-78 to mitigate the closure of an adjacent freeway—the Pulaski Skyway—for reconstruction. The part-time shoulder use will be discontinued when the Pulaski Skyway reopens.

CHAPTER 2. PLANNING, SCREENING, DECISION MAKING, AND PRELIMINARY ENGINEERING

Part-time shoulder use is a TSM&O strategy for relieving congestion and improving peak period operation of a corridor. It should be considered if consistent with a region's long-range plan and congestion management process (CMP). More-complex part-time shoulder use projects, such as dynamic part-time shoulder use, should also be consistent with the regional intelligent transportation system (ITS) architecture and viable to support with a traffic management center (TMC). The National Environmental Policy Act (NEPA) process is used to determine if part-time shoulder use is the preferred solution for a corridor, and preliminary engineering activities determine specific operating characteristics. Throughout these processes, a number of questions should be addressed, such as the following:

- Is part-time shoulder use consistent with the goals and priorities identified in the Regional Plan and Congestion Management Process?
- What is the transportation need in the corridor?
- Should part-time shoulder use be considered as a reasonable alternative to meet a transportation need or as a component of an alternative?
- Does the region have experience with transportation system management and operation (TSM&O) implementation?
- Is part-time shoulder use feasible from a constructability standpoint?
- Is real-time monitoring and incident response in place?
- What are the impacts?
- Does part-time shoulder use reduce cost compared to traditional projects?
- How can lanes designated for part-time shoulder use be designed and operated to optimize benefits and mitigate any adverse impacts?

PART-TIME SHOULDER USE CONSIDERATION IN THE PLANNING PROCESS

Part-time shoulder use can be a cost-effective strategy for relieving congestion and improving operations. As such, it can be an important element in the overall planning of the region's transportation system. Although it can be less expensive than other alternatives, part-time shoulder use can represent a sizable investment, which should be considered in a planning process within the context of regional goals and objectives. Likewise, the value also needs to be weighed against the other needs and goals a region may have.

During the planning process, a number of issues should be examined to determine the viability of this strategy as an alternative for addressing the needs in the region. The extent to which these issues need to be addressed as part of the regional planning process varies depending on the scope and purpose of the project being considered. In some cases, the implementation of various

TSM&O options can change the dynamics of the transportation network in a region, but in others, the impacts may be more marginal and localized. As such, the amount of focus that needs to be given to each of these points should be commensurate with the scope and significance of the strategy.

1. **Regional Needs to Address Congestion, Reliability, and Safety Performance Issues.** The regional planning process provides an opportunity to look at the transportation network as a whole and the performance of that network under different scenarios. It also points to the importance of having data to understand the current conditions and the future possibilities. This data provides the strongest justification for action, but also allows options to be evaluated in terms of their impact on performance.

   To the extent to which an objectives-driven, performance-based approach to planning for operations has been adopted, the consideration of part-time shoulder uses should also be part of the evaluation of other operational strategies that may also result in improving overall performance under multiple objectives. As an example, if data shows congestion is primarily a result of non-recurring problems, a look at other alternatives such as improved incident response in the area may be worthwhile. Likewise, the regional data can also provide a baseline for the region’s current congestion, reliability, and safety performance. In modeling future scenarios, this will also allow a basis for comparison, particularly when looking at a network level.

2. **Relationship to Other Planned Projects in the Region**. A focus on a single problem (e.g., reoccurring congestion along a particular highway) may not provide a complete view of either the consequences of a particular action or the opportunities to leverage other planned projects. Such challenges and opportunities may include improvements such as interchange reconstruction, repaving projects, or new transit facilities in the area. In Transportation Management Areas, MPOs are required to maintain a Congestion Management Process (CMP), and this will coordinate potential projects, such as part-time shoulder use, with other planned projects. Likewise, if the region has developed a coordinated plan of TSM&O strategies, there may be an opportunity to connect those systems or at least coordinate their operation as part of a broader Active Traffic Management (ATM) or Integrated Corridor Management (ICM) system approach.

   Another scenario relates to the staging of projects and the use of TSM&O strategies, such as part-time shoulder use, in the CMP as an interim solution while a longer-term solution is being developed. Because the long-term solution may include large capital improvements, the interrelationship between the TSM&O improvement and the ultimate project should be considered beforehand to avoid future conflicts. As an example, will implementation of the TSM&O strategy actually reduce the support needed for the long-term project?

3. **Support of Other Regional Goals.** Although congestion, reliability and safety are the primary performance areas that are most often considered in the transportation planning process, many jurisdictions are promoting the use of an expanded range of indices that better reflect their overall goals for their community. As an example, Caltrans has

developed a Smart Mobility Framework for transportation planning in California.[7] The Framework is built around the following six "Mobility Principles:"

- Location Efficiency
- Reliable Mobility
- Health and Safety
- Environmental Stewardship
- Social Equity
- Robust Economy

Other communities have incorporated similar elements into their planning processes, looking beyond what has traditionally been limited to transportation performance considerations. Some communities also incorporate conditions associated with natural or manmade disasters, such as evacuation, into their transportation planning.

4. **Maturity of TSM&O in the Region**. Early in the planning process, it is important to consider what the region's current TSM&O capabilities are and if they could be applied to the implementation of a part-time shoulder uses project. The Federal Highway Administration (FHWA) and the SHRP2 program have looked closely at the issue of "maturity" as it relates to the skills and experience that are needed to implement major TSM&O strategies, and they have developed "Capability Maturity Models" to describe the critical knowledge, skills, and abilities needed to make those deployments successful.

Reaching the full potential of TSM&O is not primarily an issue of "technology" or best operations practices. Rather, the key is to put in place and manage specific supportive business and technical processes and supporting institutional arrangements—in essence, to "mainstream operations" into the institutional framework of the transportation agency.

The SHRP2 L06 product, *Institutional Architectures to Advance Operational Strategies*, identifies the following six dimensions of organizational capability[8]

- **Business processes—**Formal scoping, planning and programming, and budgeting (resources).
- **Systems and technology—**Using systems engineering, systems architectures, standards (and standardization), and interoperability.
- **Performance—**Defining measures, data acquisition and analytics, and utilization.
- **Culture—**Technical understanding, leadership, outreach, and program legal authority.
- **Organization and staffing—**Programmatic status, organizational structure, staff development, recruitment and retention.
- **Collaboration—**Relationships and partnering among levels of government and with public safety agencies, local governments, MPOs, and the private sector.

The implementation of part-time shoulder use can be challenging given the need for specialized skills and coordination across multiple disciplines and organizations. As such, an organization that is contemplating part-time shoulder use needs to first confirm it has developed TSM&O skills and has the experience to apply them to this kind of undertaking.

In addition to the organization's own maturity, basic elements of an operational infrastructure should also be in place before part-time shoulder use, particularly more-complex part-time shoulder use such as dynamic part-time shoulder use, is implemented. The infrastructure to conduct traffic surveillance and monitoring, as well as rapid incidence response are logical precursors to any temporary lane use strategy. These early TSM&O strategies will also provide decision makers with much better information regarding the performance issues on the system.

The planning process provides the first opportunity to consider the viability of part-time shoulder uses as a means to respond to the region's goals. As part of a performance-based planning process, relevant performance objectives are identified to define the basic "yardstick" the region wants to use in evaluating their capital programs and TSM&O strategies. If this process confirms that part-time shoulder use is a viable option, then the next question needs to focus on the feasibility of designing a facility to achieve or contribute to those performance objectives.

PLANNING FOR OPERATIONS

Planning for operations is "a joint effort between planners and operators to integrate management and operations strategies into the transportation planning process for the purpose of improving regional transportation system efficiency, reliability, and options".(9) In the context of part-time shoulder use, a planning for operations process incorporates part-time shoulder use into the planning process as a tool for improving operations, similar to widening a road or constructing a new road. Static and dynamic part-time shoulder use should be broadly considered as congestion management strategies for freeways, and bus-on-shoulder (BOS) should be broadly considered as a bus reliability strategy. Incorporating part-time shoulder use into the planning process increases the likelihood of reasonable consideration under NEPA to meet a defined transportation need and ultimately implementing it.

ENVIRONMENTAL DECISIONMAKING PROCESS

NEPA requires and FHWA is committed to the identification and avoidance, minimization, or mitigation of potentially adverse impacts to the social, cultural and natural environment when considering approval of proposed transportation projects. In addition to evaluating the potential environmental effects, NEPA also takes into account the transportation needs of the public in reaching a decision that is in the best overall public interest. The FHWA NEPA project development process is an approach to balanced transportation decision-making that takes into account the potential impacts on the human and natural environment and the public's need for safe and efficient transportation.(10)

It is FHWA's policy that(11)

- To the fullest extent possible, all environmental investigations, reviews, and consultations be coordinated as a single process, and compliance with all applicable environmental requirements be reflected in the environmental document required by this regulation.

- Alternative courses of action be evaluated and decisions be made in the best overall public interest based upon a balanced consideration of the need for safe and efficient transportation; of the social, economic, and environmental impacts of the proposed transportation improvement; and of national, state, and local environmental protection goals.
- Public involvement and a systematic interdisciplinary approach are essential parts of the development process for proposed actions.
- Measures necessary to mitigate adverse impacts are incorporated into the action.

The types of NEPA processing options are shown in Figure 9.

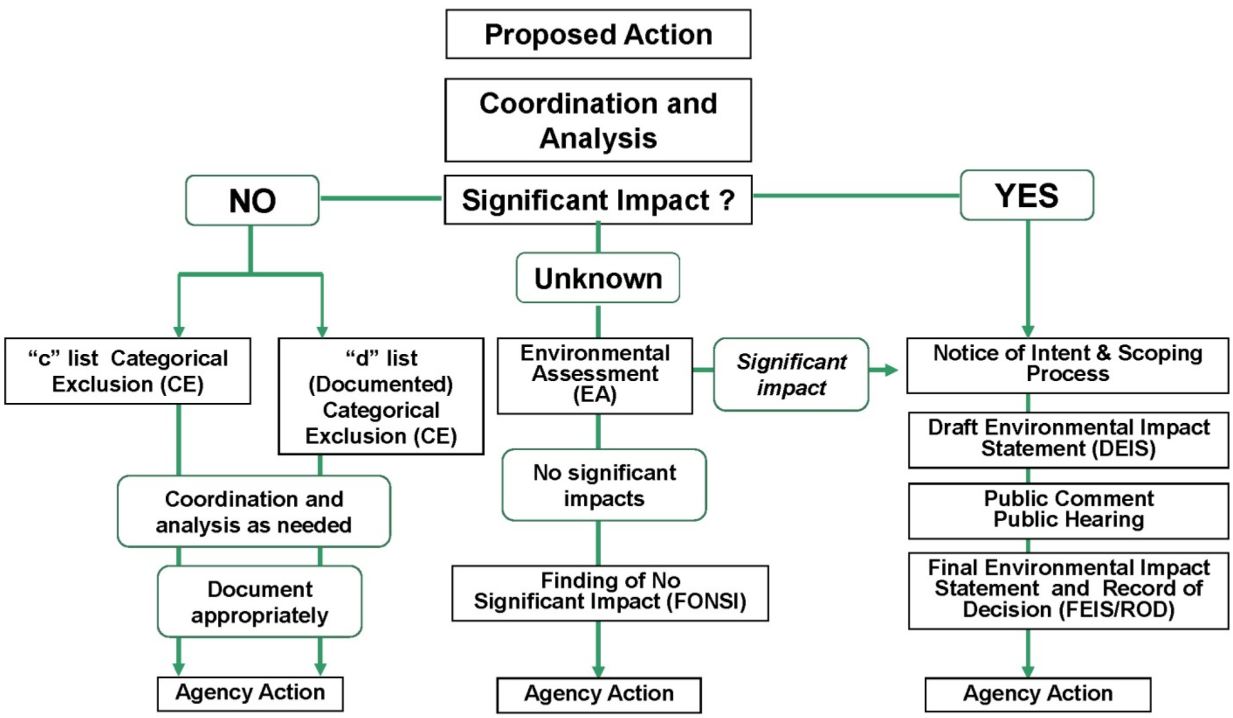


Figure 9. Illustration. National Environmental Policy Act Processing Options (Classes of Actions).

(Source: NEPA and the Transportation Decisionmaking Process course, FHWA-NHI-142005)

Part-time shoulder use often meets the criteria for a categorical exclusion (CE) because it is typically implemented within the existing ROW and largely within the existing paved surface. BOS projects and shorter static and dynamic part-time shoulder use projects that relieve acute bottlenecks are most likely to be a CE because of the relatively small effect they have on environmental resources, including social resources such as local or regional travel patterns. Larger projects that add part-time shoulder use over many miles and through multiple interchanges may have greater environmental impacts, possibly including social, traffic-related impacts, and may not be Ces. A review of the state's Stewardship and Oversight agreement should be evaluated to determine the most appropriate NEPA approval action.

Likely Environmental Impacts

Most part-time shoulder use projects have been implemented within the existing paved area of a road. Some, however, have involved widening the paved area of the roadway because the shoulder was not wide enough for a part-time lane.

If the pavement is not widened, then some environmental effects related to traffic volume may be similar to that of a traditional widening improvement along an existing roadway alignment, and others will be lesser or non-existent. Effects on the environment associated with traffic volume—specifically the effects on air quality, greenhouse gas emissions, and noise—may need to be analyzed, and Chapter 5 describes how this should be done. In general, the analyses of impacts related to traffic volumes, such as air quality and noise analyses, would be similar to analyses conducted for a project that adds a travel lane. Part-time shoulder use would potentially increase peak-hour volumes and thus vehicle-miles traveled (VMT) and would affect average speeds and delays along the corridor. The environmental analysis will also need to reflect the specific type of part-time shoulder use being considered within its context of the larger roadway system and adjacent land uses. Depending upon the type of part-time shoulder use, as well as other treatments or strategies, such as the use of variable speed limits, the effects can vary.

Many other environmental categories, such as water quality, plants, animals, and cultural resources, are unlikely to be affected if the pavement is not widened and are unlikely to require analysis. However, if the pavement is widened, a part-time shoulder-use project becomes more similar to a conventional widening project, and a much broader set of environmental categories should be assessed. A recent part-time shoulder use project on I-495 in Virginia involved widening the roadway by 4 feet. A summary of the analysis conducted for this project—which ultimately resulted in a CE—is presented below. It should be noted that no two projects or project settings are the same, and impacts from part-time shoulder use will vary accordingly.

I-495 Virginia Example

In 2015, Virginia implemented part-time use of the left shoulder for approximately 2 miles in the northbound direction on the Capital Beltway (I-495). The shoulder was added downstream of a managed-lane section to mitigate a bottleneck at the end of the managed lanes. The right shoulder was widened by four feet, and northbound lanes were shifted and narrowed from 12 to 11 feet. Static and overhead dynamic lane control signs are being installed, and two emergency turnouts are being constructed. The project was given a CE based upon the minimal impacts to the following:[12]

- Socio-economic – No impacts. The project is in the existing ROW of the Interstate Highway System and potentially sensitive socio-economic groups and features (low income/minority populations, public recreational facilities, community services, bicycle and pedestrian facilities, etc. are not present)

- Section 4(f) and 6(f) – 4(f) properties are adjacent to the project but there will be no transportation "use" of them.
- Cultural resources – A Section 106 effect determination of No Effect found the project as defined will not impact historical properties.
- Natural resources – No impacts to Waters of the US are anticipated.
- Agricultural/open space - No impacts because the project is in the existing ROW of the Interstate Highway System and no easements are present. Adjacent land is developed and residential.
- Farmland – No impacts because the project is in the existing ROW of the Interstate Highway System and adjacent land is primarily residential.
- Invasive species – Invasive species are likely present and soil disruption should be minimized to limit their spread.
- Air quality
    - The project is incorporated in the MPO's air quality conforming TIP and MTP.
    - A traffic study determined the project will have no impact on traffic volumes or vehicle mix.
    - The project is in a PM 2.5 non-attainment area, but is exempt because it is not expected to have a significant increase in the number of diesel vehicles because it is primarily providing capacity downstream of express toll lanes limited to 2-axle vehicles.
    - Mobile source air toxins – None due to the forecast of no impact on traffic volumes or vehicle mix.
- Noise – A noise study was required and completed. Noise barriers were found to be feasible not reasonable.
- ROW and relocations – No temporary or permanent property acquired. The physical widening of the shoulder was done within existing right-of-way.
- Cumulative and indirect impacts – None.
- Public involvement – One public information meeting was held, and the CE was made available for public review and comment.

PRELIMINARY ENGINEERING

Preliminary engineering activities typically occur concurrently with NEPA and inform the NEPA decision-making process. Once planning activities determine part-time shoulder use is a desired mobility improvement for a given facility, a quick "checklist" review can be conducted to see if any design and operation concepts are feasible. As shown in Figure 10, the following criteria are assessed:

- Does the paved shoulder width meet agency minimum widths for carrying traffic?
  - Would a lower speed limit or prohibiting trucks solve the problem?
- Do bridges over the shoulder meet agency minimum clearance height requirements?
  - Is a special height restriction on shoulder lane users acceptable?
- Does the shoulder pavement cross-section meet agency minimum depths for carrying traffic?
  - Is prohibiting heavy vehicles from using the part-time shoulder use an option?
  - Can the equivalent annual axle load be limited (for example, allowing only relatively infrequent heavy vehicle use of the shoulder, such as scheduled local buses)?
- Is the drainage compatible with driving on the shoulder?
  - Are additional inlets or other drainage modifications needed to manage hydraulic spread and remove standing water from the shoulder?
  - Does the current drainage use a superelevation rate on the shoulder that will not support vehicle travel?
- Is the segment long enough?
  - Is there a long enough segment to provide meaningful congestion relief?
  - If short, is the segment addressing an acute bottleneck?
- Can safety concerns be resolved?
  - Can ramp merge visibility and merging distance issues be resolved?
  - Can substandard geometry be mitigated through lower speeds, vehicle restrictions, or ATM?
  - Can the concerns of emergency responders and maintenance personnel be resolved?

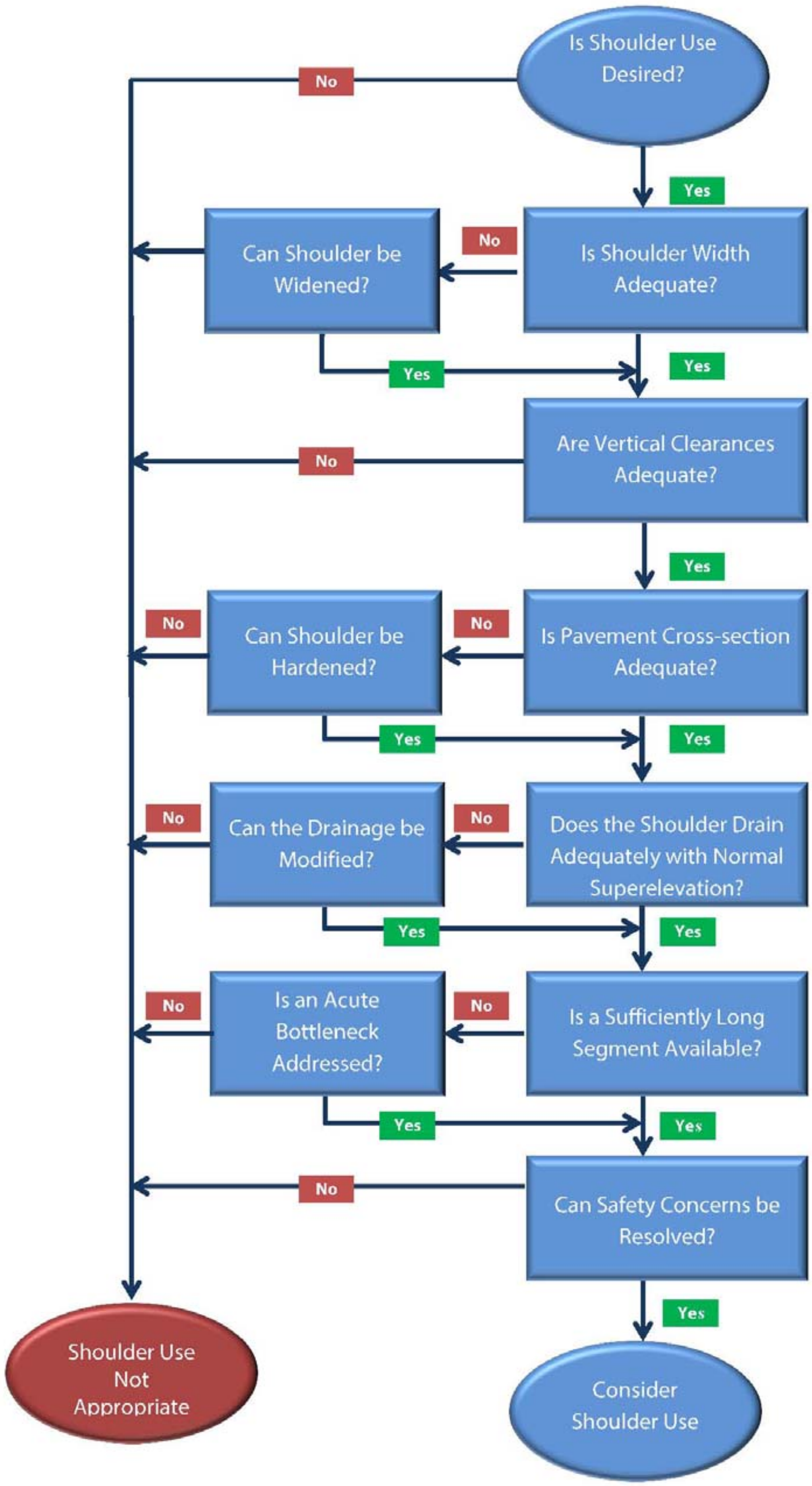


Figure 10. Illustration. Part-time shoulder use screening decision tree.

(Source: Kittelson & Associates, Inc.[13])

If assessment of a given facility with the decision tree in Figure 10 determines part-time shoulder use is generally feasible, then the checklist shown in Table 1 can be completed to determine specific type(s) of feasible part-time shoulder use. Information gathered during the assessment of the decision tree can be used to complete the feasibility checklist. For example, a region's transportation goals may dictate whether the shoulder is open to buses, HOVs, or all vehicles except trucks, and pavement conditions and vertical clearances may dictate whether trucks are permitted to use the shoulder.

Table 1. Feasibility checklist of design and operation concepts for part-time shoulder use.

Feasibility Checklist for Use Options, Time of Day Options, Design Options					
Shoulder Design Type:	Left side		Right side		Comments
At Posted Speed Limit:	Current	Lower	Current	Lower	
Shoulder User Type					
▪ Bus Only					
▪ HOV's Only					
▪ HOT Only					
▪ All But Trucks					
▪ All Vehicles					
Hours of Operation					
▪ Set Time of Day					
▪ Dynamic Hours					

HOT = High occupancy and toll paying vehicles.

Note to User: please check off all usage options that are feasible (under the operating agency's design and operations policies) and note whether a lower posted speed limit for part-time shoulder uses might affect that assessment. Provide comments to document rationale for assessment.

A key element of Table 1 is the option of using the left shoulder or right shoulder. Unless there is an opportunity to remark all lanes on the freeway—such as after a resurfacing project—the choice of which shoulder to use may be determined based on a review of the existing shoulder width. Table 2 presents advantages and disadvantages of left and right shoulder lanes. Currently, the majority of U.S. part-time shoulder use facilities utilize the right side.

Table 2. Advantages and disadvantages of left and right part-time shoulder use.
(Source: Kittelson & Associates, Inc.[2])

Design Alternatives	Advantages	Disadvantages
Use of left shoulder	▪ Left shoulder not used as much for emergency stops or law enforcement stops. ▪ Least expensive if width is available. ▪ Further from most large vehicles – trucks often restricted from left lane. ▪ No conflicts with ramps (unless left exits/entrances present).	▪ Usually requires restriping. ▪ Potential sight distance problems with some median treatments. ▪ Less likely to provide a 12 foot shoulder.
Use of right shoulder	▪ Often the easiest to implement because right shoulders are generally wider than left shoulders. ▪ More likely to have large adjacent areas for turnouts .	▪ Right shoulder is preferred area for emergency stops and enforcement. ▪ Conflicts and sight distance challenges at merge and diverge areas of ramps.

PERFORMANCE BASED PRACTICAL DESIGN (PBPD)

PBPD is a broad concept applying to the entire project development process. It encompasses performance evaluations in the preliminary engineering phase of projects to guide NEPA alternative selections and, ultimately, geometric design decisions. PBPD encourages the evaluation of the performance impacts of highway design decisions in relation to the cost of providing various design features. While PBPD may lead to reductions in individual project costs, savings from projects can be redirected to other transportation projects and improvements such that overall system performance exceeds what would have been achieved otherwise; i.e., the goal is to have a well-performing highway system, rather than a scattering of high-performing highway segments.[14]

PBPD can be articulated as modifying a traditional design approach to a "design up" approach in which transportation decision makers exercise engineering judgment to build up the improvements from existing conditions to meet both project and system objectives. PBPD uses appropriate performance-analysis tools, and considers both short- and long-term project and system goals, while addressing project purpose and need.[15]

PBPD is consistent with FHWA's objectives-driven, performance-based approach to planning for operations FHWA has provided substantial guidance including, *Advancing Metropolitan Planning for Operations: The Building Blocks of a Model Transportation Plan Incorporating Operations – A Desk Reference*".[15] This Desk Reference offers a process for, as well as examples of, objectives-driven, performance-based approaches, and includes information related to part-time shoulder use. The Desk Reference details the ways in which TSM&O strategies, including part-time shoulder use, can be integrated into the planning process.

Notable attributes of PBPD are the following:

- PBPD focuses on performance improvements that benefit both project and system needs.
- Agencies make sound decisions based upon performance analysis.
- By scrutinizing each element of a project's scope relative to value, need, and urgency, a PBPD approach seeks a greater return on infrastructure investments.
- PBPD strengthens the emphasis on planning-level corridor or system performance needs and objectives when planning, scoping, and developing individual projects.
- PBPD can be implemented within the Federal-aid Highway Program regulatory environment utilizing existing flexibility. PBPD does not eliminate, modify, or compromise existing design standards or regulatory requirements.

The keys to successful implementation of PBPD are the following[(15)]

- State department of transportation (DOT) executives embrace PBPD and communicate this support to all state employees and consultants.
- State DOT PBPD champion leads implementation throughout all levels of the agency.
- Agencies revise policies and guidance as appropriate to include the values of PBPD, thus securing a multi-disciplinary and comprehensive approach to delivering projects under PBPD.
- Agencies encourage and empower engineers to exercise judgments on projects based on PBPD principles.
- FHWA Division Offices support state DOTs in their implementation with early and close coordination.

PBPD should consider multiple design and operating solutions, including part-time shoulder use, to find the combination that best addresses the project objectives. It is also useful for arriving at the best design and operation concept for part-time shoulder use.

Part-time shoulder use is just one of many possible TSM&O treatments for cost-effectively improving the operation and reliability of a facility. Although it may be tempting to immediately assume that part-time shoulder use is "the solution," looking deeper may reveal issues that were not originally anticipated or other alternatives that may better fit the circumstances. There are several design/operating concepts for part-time shoulder use. The decision to pursue the design of part-time shoulder use and the selection of the appropriate design/operating concept should be made as part of a comprehensive Performance-Based Practical Design (PBPD) assessment of design and TSM&O options. The assessment may be informed by systems engineering processes, with the ultimate goal of achieving the agency's performance objectives for the facility design and operations.

PBPD AND OBJECTIVES-DRIVEN DECISION-MAKING

Transportation decision-making typically occurs through a NEPA process and identifies a solution to an identified problem. Although part-time shoulder use can make sense in some situations, it can also have unintended consequences. Solving a problem at one location may create other problems in the future, or it may simply result in maintaining the status quo. A piecemeal approach may result in a suboptimal allocation of resources, as well as lost opportunities to do more.

A performance-based approach to decision-making focuses not on the problem, but rather on the desired outcome. “Performance” is the ultimate objective measure of the system’s ability to satisfy or exceed user needs and expectations, particularly relating to congestion, reliability and safety. Understanding the factors affecting performance, and measuring those, allows decision makers to look beyond short-term solutions and take a longer-range view of system performance. By establishing performance objectives, a clear message is not only established in the planning and prioritization of projects, but those same performance objectives can guide the design and operations decisions further into the process.

DETERMINING PERFORMANCE OBJECTIVES AND CONSTRAINTS

An agency should work with its internal and external stakeholders to identify the performance objectives and constraints for the facility they are evaluating for possible part-time shoulder use. Table 3 presents potential performance objectives for a PBPD analysis.

Table 3. Example performance objectives for Performance Based Practical Design analysis.

Dimension	Performance Measures	Example Objectives, to be achieved in opening year of project
Mobility	1. Throughput (VMT) 2. Average Speed 3. Delay per vehicle	▪ Increase corridor throughput by 5% ▪ Increase average peak period speed by 5% between point X and Y ▪ Reduce average peak period delay by 5% between point X and Y
Reliability	4. Planning Time Index (PTI) 5. Percent Trips below 45 mph	▪ Reduce peak period PTI for trips from X to Y to below 3.0 ▪ Reduce percent of peak period corridor trips below 45 mph to < 30%.
Safety	6. Crash rate 7. Number of Fatalities	▪ Reduce corridor crash rate by 5% ▪ Reduce number of fatalities in corridor to zero
Incident Management	8. Incident Response Time 9. Incident Clearance Time	▪ Reduce response time by 5% ▪ Reduce clearance time by 5%
Maintenance	10. Lane-hours closed for maintenance. 11. Work zone crash rate	▪ Reduce lane closures by 5% ▪ Reduce work zone crash rates by 5%
Environmental	12. Emissions	▪ Reduce specific pollutants emitted from vehicles by 5% in the peak period throughout corridor
Resiliency	13. Evacuation Time	▪ Reduce the per capita time to evacuate individuals from an at-risk area by 25%

Many of the objectives in Table 1 could be achieved with conventional widening or part-time shoulder use on a given facility. However, on many freeways, conventional widening may not be viable due to expected impacts identified in the NEPA process or fiscal considerations. Part-time shoulder use is most viable in comparison to conventional widening in constrained situations.

TSM&O STRATEGIES THAT CAN SUPPORT PART-TIME SHOULDER USE

Part-time shoulder use is not the only means for addressing recurring congestion, and part-time shoulder use often works more effectively when it is combined with other TSM&O strategies. The Congestion Management Process (CMP) and subsequent preliminary engineering activities can identify and refine which TSM&O strategies are appropriate and practical to implement in combination with part-time shoulder use on a given facility. Table 4 lists TSM&O strategies that can support part-time shoulder use.

Table 4. Transportation System Management & Operations strategies that can support part-time shoulder use.

TSM&O Strategy	Description (adapted from Transportation Research Circular E-C133)	Support of Part-time shoulder uses
Ramp Management	The application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, or to smooth out the rate at which vehicles enter and exit the freeway.	Potential mitigation for heavy merge volumes from a ramp into the shoulder.
Incident Management	The systematic, planned, and coordinated use of human, institutional, electrical, mechanical, and technical resources to reduce the duration and impact of incidents, and improve the safety of motorists, crash victims, and incident responders.	Strategies to notify drivers of incidents and clear them quicker can mitigate the loss of a shoulder refuge for disabled vehicles.
Managed Lanes	Highway facilities or a set of lanes where operational strategies are proactively implemented and actively managed to optimize traffic flow and vehicular and person throughput. These strategies typically involve pricing, vehicle eligibility, and access control (e.g. HOV, HOT, BOS).	Managed lanes and lanes designated for part-time shoulder use can be added at the same time to maintain the existing number of general purpose lanes. The shoulder may already need to be restricted to certain types of vehicles due to its width and other physical conditions.
Active Traffic Management (ATM)	A comprehensive collection of strategies to dynamically manage recurrent and non-recurrent congestion on the mainline based on prevailing and predicted traffic conditions. ATM includes the automation of dynamic deployment to optimize performance quickly and without delay that occurs when operators must deploy operational strategies manually. These include: dynamic speed limits, dynamic lane assignment, junction control, queue warning, among others.	Adjusting speeds and lane assignments to prevailing conditions and notifying drivers of congestion or other incidents can mitigate speed differentials, substandard geometry, and the loss of a shoulder breakdown lane.
Traveler Information	A combination of strategies for enabling better traveler decision making throughout the trip chain – before, during, and near the end of a trip. Includes: 511, apps on Smartphones and tablet devices, CMS.	Traveler information educates drivers on when shoulder is open and closed.
Commercial Vehicle Operations and Freight Management	A set of strategies tailored to the unique needs of commercial vehicle operation to promote efficient, seamless, and secure freight flows on the U.S. transportation system and across our borders.	Information makes truck drivers aware of shoulder lane status and whether or not they may use the shoulder.

CHAPTER 3. MOBILITY ANALYSIS

This chapter provides a brief overview of how to conduct an operations analysis and a reliability analysis of a freeway with static or dynamic part-time shoulder use.

In general, part-time shoulder use improves the peak period operation of an existing freeway, but to a lesser degree than an additional general purpose lane. The results of operations analysis are a key metric in a performance-based practical design (PBPD) alternatives analysis process and are also inputs into other evaluation processes such as noise analysis, air quality analysis, and life-cycle cost analysis. Estimating specific operational conditions such as delay, travel time, and reliability is also a key component of performance management as reflected in Moving Ahead for Progress in the 21st Century (MAP-21).[16] The ability to quantify the operational benefits of part-time shoulder use will provide the ability to rank and prioritize part-time shoulder use projects among a region's many other potential projects.

SHOULDER CAPACITY

Operations analysis of part-time shoulder use with any technique requires the selection of a capacity for the lane designated for part-time shoulder use. One previous Federal Highway Administration (FHWA) study collected operational data from four part-time shoulder use facilities, and another simulated different part-time shoulder use configurations. [17, 18] Collectively, the results indicate that utilization of the shoulder varies greatly and is influenced by the "quality" of the lane, as described below.

The following operational characteristics of part-time shoulder use facilities have been observed: [17]

- Virginia I-66 eastbound
    - The speed in the shoulder is approximately 5-10 mph lower than the speed in the adjacent general purpose lanes.
    - The capacity of the shoulder is the same as the adjacent general purpose lanes—approximately 2,000 vehicles per hour per lane.
    - The speed at capacity is approximately 55 mph.
- Minnesota I-35W northbound
    - The shoulder is priced, and it is unclear if volumes reach capacity.
    - The maximum observed volume in the shoulder is 1,100 vehicles per hour, and the speed at this volume is 55 mph.
    - There was no significant change in adjacent general purpose lane speed after implementation of part-time shoulder use, suggesting that volume on I-35W increased.
- Washington U.S. 2 eastbound
    - The volume using the shoulder when it is open is approximately one-third of the per-lane volume of adjacent general purpose lanes.

  - The typical operating speed of traffic in the shoulder is approximately 50 mph, and the typical operating speed of traffic in the adjacent general purpose lanes is approximately 55 mph to 60 mph.
  - Observed speed-flow curves suggest the shoulder has an operating speed of 40 mph at capacity, and the general purpose lanes have an operating speed of 50 mph at capacity.

- Massachusetts I-93
  - AM peak period volume is approximately 1,000 vehicles per hour in the shoulder and 1,500 to 2,000 vehicles per hour per lane in the general purpose lanes.
  - Speed at capacity is 35-40 mph in the shoulder and approximately 55 mph in the general purpose lanes.

The results indicate that design features influence shoulder capacity. The lane designated for part-time shoulder use on I-66 is 12 feet wide, has a paved shoulder several feet wide beyond it, has overhead dynamic lane control signs, and was observed to have the same capacity as adjacent general purpose lanes. The lanes designated for part-time shoulder use on I-93 in Massachusetts are less than 12 feet wide, have a one- to two-foot paved shoulder beyond the part-time shoulder use, use limited dynamic signs, and run through generally older-style interchanges with more constrained geometry than I-66. The shoulder on I-93 was observed to have only one-half to two-thirds the capacity of adjacent general purpose lanes. Additional background information on these part-time shoulder-use facilities can be found in the Appendix.

Researchers for another study used a simulation model of the I-90/I-290 corridor in Buffalo, New York, to assess various part-time shoulder use configurations.(18) I-90/I-290 does not have part-time shoulder use, but it was added to a bottleneck area in the simulation model. The simulation models were run with various part-time shoulder length, shoulder design, demand, and incident levels. The results from the part-time shoulder length and shoulder design scenarios, listed below, are most applicable to future part-time shoulder-use studies:

- Short, 1,000-foot part-time shoulder encompassing the length of the bottleneck.
- Long, 1.5-mile part-time shoulder encompassing the length of the bottleneck and the queue prior to it.
- A “low quality” part-time shoulder that is 10 feet wide, closed to trucks, and only willing to be used by 50% of drivers.
- A “high quality” part-time shoulder is 12 feet wide with “normal freeway lane design standards” that all drivers are willing to use.

Table 5 shows the simulated capacities of the four part-time shoulder use scenarios.

Table 5. Simulated part-time shoulder capacity.[18]

Part-time shoulder use Scenario	Shoulder Capacity (vehicles per hour)
Short and low quality	1,262
Long and low quality	1,334
Short and high quality	1,610
Long and high quality	1,687

The results are highly dependent upon simulation model settings selected by the researchers, but they suggest that part-time shoulder capacity varies greatly when a shoulder is substandard in width and other elements, making some drivers unwilling to use it. Length of a part-time shoulder use segment has a much smaller effect on utilization.

In general, it appears part-time shoulder utilization and capacity is highly dependent on design features, and dimensions meeting or exceeding the AASHTO criteria described in Chapter 7 should be provided when possible. Field-measured capacity ranges from 1,000 to 2,000 vehicles per hour, and a simulation study found capacity ranging from 1,250 vehicles per hour to 1,700 vehicles per hour. [17, 18] Right part-time shoulders that continue through interchanges and have adequate ramp merge distances were found to have a higher capacity than those that do not. Right part-time shoulders that meet or exceed the standard width of 12 feet have a higher capacity than narrower shoulder lanes. Data on left part-time shoulder use is limited.

The capacity of a standard width (12 feet) left part-time shoulder is expected to be similar to (and perhaps slightly lower than) that of the adjacent general purpose lanes. There may be some capacity reduction due to proximity to median structures, such as bridge piers and signposts, but there will be no effects of ramp traffic unless left-side ramps are present If the left part-time shoulder has limited access points connecting it to the general purpose lanes, then it will tend to have a capacity approaching that of a paint or barrier-separated high-occupancy vehicle (HOV) lane, which tends to be approximately 1600 vehicles per hour.[19, 20]

SYSTEM ANALYSIS

System analysis is usually done in the context of a regional travel-demand model or as part of a post-process analysis of the demand model outputs to obtain more-precise estimates of operational performance measures such as speed, delay, and reliability and environmental performance measures such as motor vehicle emissions. The NCHRP 7-22, *Planning Applications Guide* describes a post-processing approach for obtaining improved system mobility performance estimates that can be adapted for the analysis of the system performance effects of part-time shoulder use on individual facilities.[21]

For systems analysis purposes, the capacity of a part-time shoulder should be considered to be half to three-quarters of that of a general purpose lane, based upon capacities presented in the previous section.

For system analysis purposes, the congested speed and the free-flow speed of a part-time shoulder can be assumed to be virtually the same as that for the general purpose lanes. Congestion in the general purpose lanes will generally encourage drivers to use the shoulder until the speeds are better balanced, unless a different speed limit takes effect during part-time shoulder use.

OPERATIONS ANALYSIS

Operations analysis of freeways is typically conducted with the procedures of the Highway Capacity Manual or microsimulation. Both sets of tools can be adapted for analysis of part-time shoulder use.

Highway Capacity Manual

The Highway Capacity Manual (HCM) does not provide for lane-by-lane analyses, so the shoulder must be combined with the general purpose lanes for the purpose of capacity analysis and the estimation of speed and delay. However, it is known that the shoulder will generally have a lower capacity than general purpose lanes, so a capacity reduction should be applied to all freeway lanes to account for this. Suppose a freeway with two lanes in one direction has a part-time shoulder added, and based on the design of the part-time shoulder, the capacity is expected to be half that of a general purpose lane. If the capacity of the general purpose lanes is 2,000 vehicles per hour per lane, and the capacity of the shoulder is 1,000 vehicles per hour per lane, then the facility could be analyzed as three lanes with a capacity of 1667 vehicles per hour per lane.

If the shoulder has a lower posted speed limit or design characteristics that are likely to cause the free-flow speed in the shoulder to be more than 5 mph different than the general purpose lanes, then the speed and delay may be computed separately for the general purpose lanes and the shoulder. The results are then weighted by volume to obtain an average speed and delay for the entire cross-section of the freeway.

Analysis of long freeway facilities encompassing multiple interchanges becomes complicated due to the number of analyses involved (each basic segment, ramp freeway junction, and weave), as well as the potential for the effects of one segment to affect another and the potential for the effects of one time period to influence conditions at the start of the next time period. The FREEVAL software tool, developed by TRB, addresses these issues by allowing a user to input data for multiple segments and multiple time periods at once and accounting for relationships between them. However, the complexity of the tool makes it difficult for an analyst to make manual adjustments to for account different capacities in different lanes.

Microsimulation

Microsimulation is conducted with commercial software packages, and specific settings vary from one program to another. Many microsimulation programs enable parameters to be adjusted on a per-lane basis, and speeds, capacities, and driver behavior characteristics of lanes designated for part-time shoulder use and general purpose lanes can be set to different values.

Microsimulation settings could also restrict certain vehicles and certain drivers from using the shoulder.

In general, microsimulation is an order of magnitude more complex than HCM analysis. However, modifying a simulation model to account for the unique properties of lanes designated for part-time shoulder use is more straightforward than modifying HCM analysis.

RELIABILITY ANALYSIS

The travel-time reliability for a freeway with or without part-time shoulder use can be estimated using the methods provided in the NCHRP 3-115 Updated *Highway Capacity Manual* with the capacity and speed adjustments presented in the previous section.[19] There are no reliability analysis procedures that specifically account for part-time shoulder use.

In general, part-time shoulder use reduces congestion and would generally be expected to improve reliability. However, the degree to which this occurs will depend upon the frequency and duration of incidents that block the shoulder. Static and dynamic part-time shoulder use will have the same effect on peak-period reliability (assuming both are open during the peak-period), but dynamic part-time shoulder use will provide greater annual reliability because the shoulder can be opened on-demand in response to congestion.

For planning and systems analyses, the following equations adapted from SHRP2-C11 can be used to estimate link-level reliability.[22] First, the average annual travel time rate (hours/mile) including incident effects is computed:

$$TTI_m = 1 + FFS \times (RDR + IDR)$$

Figure 11. Equation. Average Travel Time Rate

where

TTIm = average annual mean travel time index (unitless)
FFS = Free-Flow Speed (mph)
RDR = Recurring Delay Rate (h/mi)
IDR = Incident Delay Rate (h/mi)[23]

$$RDR = \frac{1}{S} - \frac{1}{FFS}$$

Figure 12. Equation. Recurring Delay Rate.

$$IDR = \{0.020 - (N - 2) \times 0.003\} \times X^{12}$$

Figure 13. Equation. Incident Delay Rate.

Where

S = peak hour speed (mph)
N = number of lanes in one direction (N = 2 to 4)
X = peak hour volume/capacity ratio

Note: IDR equation is valid for X <=1.00.

The 95th-percentile travel time index (TTI_{95}) and percent of trips traveling at under 45 mph (PT_{45}) then can be computed from the average annual travel time index according to the following equations.

$$TTI_{95} = 1 + 3.67 \times \ln(TTI_m)$$

Figure 14. Equation. 95th-Percentile Travel Time Index.

$$PT_{45} = 1 - \exp(-1.5115 \times (TTI_m - 1))$$

Figure 15. Equation. Percent of Trips that Occur at Speeds Less than 45 mph.

where

TTI95 = the 95th percentile TTI;
PT45 = the percent of trips that occur at speeds less than 45 mph

BEFORE/AFTER STUDIES

Most before/after studies of facilities on which part-time shoulder use was implemented have identified positive operational outcomes. Data is primarily from Europe due to the limited number of recent U.S. installations.

- On U.S. 2 in Washington State, peak period, peak direction delays on the 1.55-mile segment with part-time shoulder use decreased from 8-10 minutes to 1-2 minutes.(24)
- On the M42 motorway in the UK, average travel times increased because the speed limit was reduced. However, the variability of travel times was decreased 27-34 percent.(25)
- In the Netherlands, part-time shoulder use increased capacity by seven to 22 percent, decreased travel times from one to three minutes, and increased through traffic volumes up to seven percent during congested periods.(26)
- In Munich, Germany, part-time shoulder use created a 20-percent increase in peak hour capacity.(26)
- In the Hessen state of Germany, part-time shoulder use reduced congestion by 30 percent.(27)

CHAPTER 4. SAFETY ANALYSIS

Reducing congestion by allowing part-time shoulder use allows for greater headways between vehicles and reduces stop-start activity that is generally known to contribute to rear-end crashes. However, implementation of part-time shoulder use requires a compromise of other geometric design elements, including shoulder width (when the shoulder is open to traffic) and sometimes others such as lane width and lateral offset to obstructions such as median barriers, guardrails, and bridge rails. Although limited research is currently available to quantify the specific effects of part-time shoulder use, the relationship between these variables and crash frequency provides insight into the potential safety effects of part-time shoulder uses.

The following sections draw on the best quantitative tools available and reference empirical studies in an effort to inform evaluations of future implementation.The first section of this chapter describes a general process for assessing the safety impacts of part-time shoulder use on a given facility. Subsequent sections present findings from past before/after safety studies of part-time shoulder use and crash prediction methods, both of which can be incorporated into the analysis of a specific facility.

ASSESSING PART-TIME SHOULDER USE SAFETY

Assessment of the safety impacts of part-time shoulder use on a given facility should begin with a review of three or more years of historical crash data. The review should consider the crash type, temporal factors (e.g., time of day, day of week), and location. Congestion-related crashes, such as rear-ends occurring during times the shoulder would be open, may potentially be reduced with part-time shoulder uses if congestion is reduced. Crashes related to erratic driver behavior or suboptimal geometry, such as run-off-road, fixed-object, or sideswipe crashes, may increase with part-time shoulder use. Crashes related to right-side ramp-freeway junctions may increase with right part-time shoulder use. The mere presence of crash types that may increase with part-time shoulder use should not prevent the application of part-time shoulder use, but a preponderance of those crash types indicates a given freeway may be a poor candidate for part-time shoulder use.

The design of ramps and interchanges also informs the potential safety impacts of part-time shoulder use. There may be safety issues associated with on-ramps with high convergence angles, small merge areas, weaving sections, and other characteristics of older freeways. Two-lane on- and off-ramps may also introduce safety issues. Additional information on the design of part-time shoulder use at ramp-freeway junctions is in the Geometric Design section of Chapter 7.

The Crash Prediction section of this chapter provides additional guidance on quantitatively assessing how implementing part-time shoulder use (and modifying freeway cross-section) influences crashes.

OBSERVATIONAL SAFETY STUDIES

Experience in the U.S. to date has not identified major safety issues with bus, static, or dynamic part-time shoulder use that led implementing agencies to discontinue their use. However, few empirical studies have been conducted to evaluate the specific changes in crash frequency and severity as a result of implementing part-time shoulder use. Crash frequency has increased following some part-time shoulder use projects and decreased following others, suggesting the safety impact of part-time shoulder use is influenced by site-specific operational and geometric conditions. The results of empirical studies appear to be heavily influenced by operational and geometric conditions. The following sections summarize the most reliable studies that have evaluated crash history associated with part-time shoulder use.

I-35W in Minnesota

A Federal Highway Administration (FHWA) Study used Empirical Bayes analysis to conduct a before/after comparison of I-35W in Minneapolis.[28] The Empirical Bayes analysis of total annual crash rates (at all times of day) on I-35W in Minnesota showed a 28.4-percent increase in crashes after implementation of a priced dynamic part-time shoulder use. MnDOT indicated the increase in crashes on I-35W after implementation was partially related to the removal of an upstream bottleneck around the same time shoulder running was introduced, effectively increasing congestion on the segment with part-time shoulder use.

SHRP 2 Project L07 related crash data to speed, volume, and density data from Seattle and Minneapolis/St. Paul. Density was identified as the independent variable. The SHRP 2 model indicates a non-linear increase in crashes as density increases, particularly at level-of-service (LOS) D or greater.

Researchers applied the SHRP 2 L07 models to I-35W in Minneapolis, which indicated an increase in crash frequency of 22 percent could be expected with the increase in congestion experienced on I-35W. Therefore, the researchers related the I-35W Empirical Bayes analysis to the SHRP 2 L07 model prediction to indicate as little as 6.4 percent of the increase in crashes observed on I-35W could be related to the part-time shoulder use.

Virginia

Virginia conducted a safety analysis of a portion of I-66 with a left-side high-occupancy vehicle (HOV) lane and a right-side part-time shoulder use. The study only included “after” data with the HOV lane and part-time shoulder use in place, and focused on crash frequency differences between the hours when the part-time shoulder use was open and closed to traffic. The study found no significant differences in crash frequency in the study area. A typical factor, high annual average daily traffic (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.[29]

Colorado

Kononov developed safety performance functions for freeways using data from Colorado and other states.[30, 31] Although the research did not specifically address part-time shoulder use, the findings have applications to the evaluation of other potential projects. On uncongested freeway segments, Kononov observed crash frequency increases only modestly as traffic increases until a critical traffic density is reached. Beyond this critical density, crash frequency increases much faster as traffic increases. When a lane is added to a freeway, there is a safety improvement due to the decreased density. However, if volume increases over time there is an increase in crash frequency. The additional lanes are able to process additional traffic, and Kononov also determined crash frequency increases more rapidly on freeways with more lanes. When considering part-time shoulder use, these findings suggest there will be a short-term crash reduction if part-time shoulder use decreases traffic density. If part-time shoulder use does not notably decrease traffic density [such as bus-on-shoulder (BOS) operation], then there may be no effect on crashes, or there may be an increase in crashes due to reduced shoulder widths, lane widths (if general purpose lanes were narrowed), and lateral clearances.

International Experience

Part-time shoulder use is more common in Europe than the U.S., and the European safety experience has been positive. A three-part study of the M42 motorway in the UK compared the following conditions:

- 3 lanes per direction and no Active Traffic Management (ATM) (60 months)
- 3 lanes per direction and variable speed limits (6 months)
- 3 lanes plus dynamic part-time shoulder use in each direction and variable speed limits (36 months)

The introduction of variable speed limits (without part-time shoulder use) decreased crashes per month from 5.08 to 3.17. The introduction of part-time shoulder use further reduced crashes per month from 3.17 to 2.25.[32] Variable speed limits are uncommon in the US at this time.

Two other studies from Europe have identified positive safety impacts of part-time shoulder uses:

- In the Hessen state in Germany, part-time shoulder use reduced congestion-related crashes.[27]
- A study of multiple part-time shoulder-use locations in the Netherlands with 3 years of “before” data and 2 years of “after” data found a reduction in crashes at most sites due to reduced congestion. Two sites with close ramp spacing had an increase in crashes.[26]

In Europe, part-time shoulder use is almost always accompanied by the construction of turnouts and a higher level of ATM than is typical in the U.S., including dynamic speed limits/lane assignment, full CCTV monitoring, and aggressive incident management.

CRASH PREDICTION

The 2014 Supplement to the Highway Safety Manual (HSM), 1st Edition, provides a structured methodology and specialized procedures to estimate the expected average crash frequency for various freeway facilities. It does not, however, explicitly model part-time shoulder use.

The HSM freeway chapters provide safety performance functions (SPFs) for 4- to 10-lane freeway facilities that account for several variables influenced by part-time shoulder use, including the following:

- Average Annual Daily Traffic (AADT),
- Proportion of AADT during high-volume hours,
- Number of through lanes,
- Distance to median barrier,
- Lane width, and
- Shoulder width (left and right).

The Enhanced Interchange Safety Analysis Tool (ISATe), developed by NCHRP Project 17-45, and the Interactive Highway Safety Design Model's Crash Prediction Module apply the methods and models from the HSM freeway crash prediction chapters. These tools can be used to assess how changes to freeway cross-section influence crash frequency.

The models reflect lane widths and shoulder widths and do not explicitly model shoulder use. Therefore, the predictive analysis assumes there is nothing inherent in a lane designated for part-time shoulder use that would change crash frequency relative to a general purpose lane of the same width, adjacent to a shoulder of the same width, on a freeway with the same AADT, and so forth.

In order to account for the influence of congestion on crashes, when average freeway speed tends to decrease and headway is reduced, the crash prediction methodology accounts for "the proportion of the AADT that occurs during hours where the volume exceeds 1,000 vehicles per hour per lane (veh/h/ln)."

Model Limitations

A number of challenges and limitations are associated with conducting a predictive safety analysis of part-time shoulder use with HSM freeway models, including the following:

- Models were developed with data collected on freeways with only full-time general purpose lanes. There is no differentiation between a general purpose lane and the shoulder, with all geometric dimensions being the same.
- Models do not capture changes to ramp-freeway junction areas that occur with part-time shoulder use.

- The HSM freeway model was calibrated only for right shoulder widths between 4 and 14 feet. When a shoulder is open to traffic, the resulting “shoulder” between the part-time travel area and the edge of pavement is usually less than 4 feet and the HSM cannot model this.
- Speed differential between vehicles in the shoulder and adjacent travel lane can vary depending on whether the shoulder is open to all traffic or restricted to specific users.
- Lane changes and weaving maneuvers associated with on- and off-ramps and speed-change lanes are not accounted for in the basic freeway analysis. They can be analyzed separately, but the separate models also lack an explicit means of accounting for part-time shoulder use.
- The HSM predicts crashes as a function of daily volumes and assumes a consistent cross-section throughout the day. Analyzing a shoulder in use for part of the day would require knowledge of the hours of operation and the percent of AADT during those hours. Models would be run twice, and a weighted average could be computed.
- The model will not account for the transfer of crashes from outside of the study area to within the study area, a phenomenon that has been observed if part-time shoulder use alleviates upstream bottlenecks.
- Improving freeway operation with part-time shoulder use may potentially transfer volume and crashes from adjacent alternate routes to the freeway. A slight increase in freeway crash frequency may accompany a larger decrease in network crash frequency.

Despite these limitations, the HSM freeway models reflect trends related to freeway cross-section that provide insight into when part-time shoulder use may have a positive or negative impact on safety. The following sections present these trends.

Model Evaluation of Number of Freeway Lanes and Shoulder Width

The HSM freeway crash prediction model can be used to assess the change in crash frequency and severity associated with increasing the number of freeway lanes while reducing shoulder width. This is the closest the HSM can come to modeling part-time shoulder use, although it only changes lane widths and shoulder widths, and does not explicitly model shoulder use. The scenarios presented below, then, must assume there is nothing inherent in a shoulder that would change crash frequency relative to a general purpose lane of the same width, adjacent to a shoulder of the same width, on a freeway with the same AADT, and so forth. Several example applications of the HSM models are provided to demonstrate their use.

The combined change in total crash frequency associated with increasing the number of freeway lanes while reducing right shoulder width from 14 to 4 feet, which is the range of right shoulder widths for which the model was calibrated, is shown in Figure 16.

Figure 16 shows the safety effects of adding part-time shoulder use to 4-lane, 6-lane, and 8-lane freeways. The point at which each line crosses the 0% mark on the y-axis indicates the AADT threshold at which part-time shoulder uses would be expected to increase or decrease crash frequency.

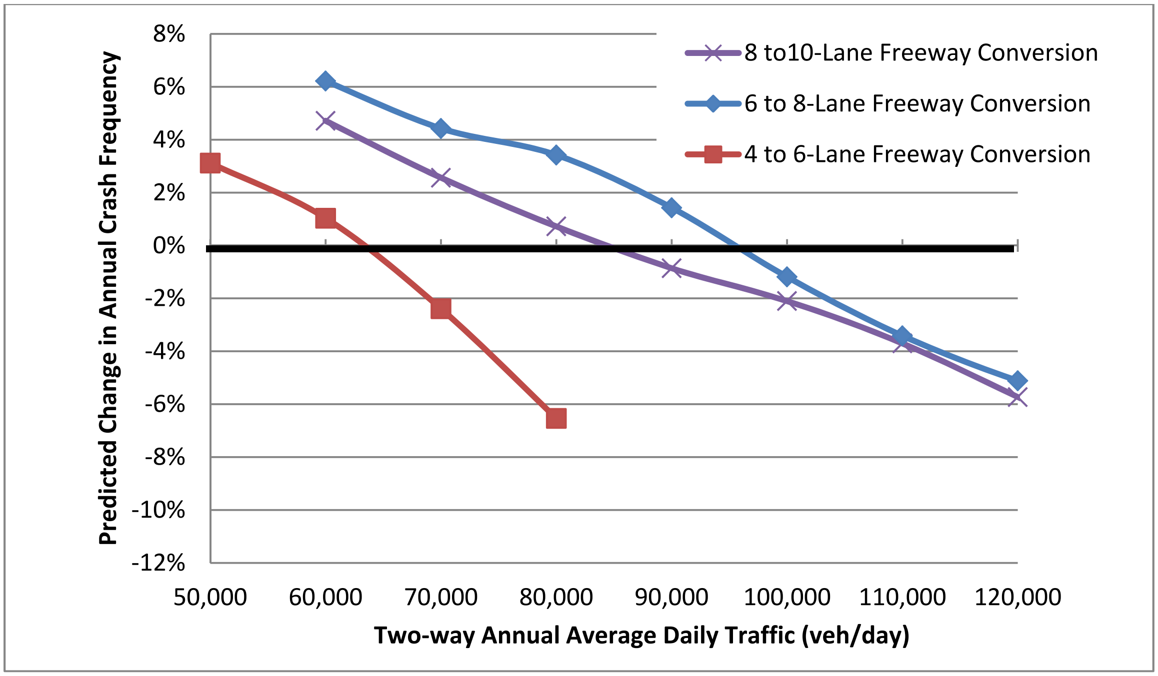


Figure 16. Graph. Predicted crash frequency associated with increasing number of freeway lanes and narrowing the right shoulder.

Figure 16, like others in this section, assumes shoulder use is actually the addition of a full-time lane. This is not the case with part-time shoulder use, so crash frequency changes associated with part-time shoulder use would be a fraction of those depicted in Figure 16.

The model predictions indicate that when congestion reaches a certain level (below the zero point on the y-axis in Figure 16), the crash reduction benefits of adding a lane are predicted to exceed the increase in crashes associated with reducing the width of the right shoulder.

It is noted the AADT threshold for achieving a reduction in crash frequency for a 6- to 8-lane conversion is lower than that for an eight- to ten-lane conversion. This reflects the model prediction that an eight- to ten-lane conversion is expected to have a greater reduction in crashes than a six- to eight-lane conversion, as described in the Model Evaluation of Number of Freeway Lanes section below.

Subsequent sections explore how number of lanes and shoulder width, individually without changing the number of lanes on the freeway, influence crash frequency and severity.

Model Evaluation of Number of Freeway Lanes

Using the HSM freeway models, the relationship between predicted crash frequency associated with converting an eight-lane freeway to a ten-lane freeway at various level of AADT was assessed. This is analogous to a conventional widening project where shoulder width remains the same after the addition of a lane. Figure 17 illustrates the predicted number of Fatal and Injury (FI) crashes and Property Damage Only (PDO) crashes associated with converting an eight-lane freeway to a ten-lane freeway at various level of AADT, while lane widths, shoulder widths, and all other model variables are held constant at default values.

Figure 17 indicates both FI and PDO crashes are expected to decrease with the conversion from an eight- to ten-lane freeway.

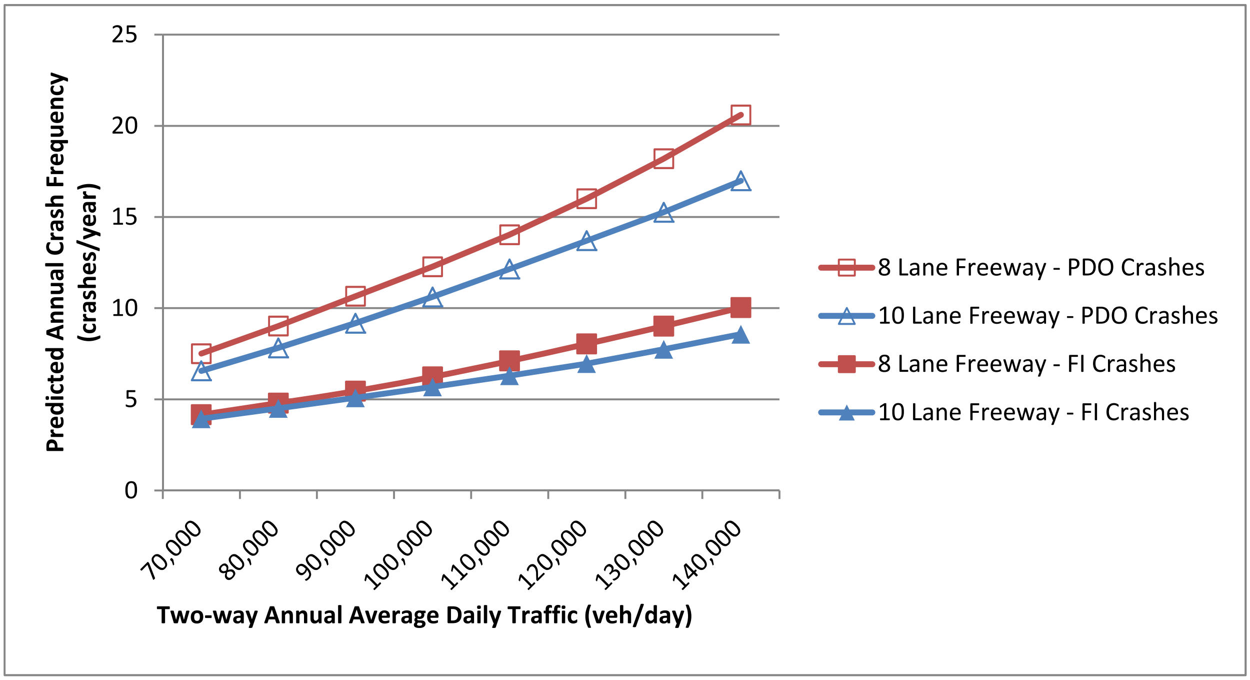


Figure 17. Graph. Predicted crash frequency on eight- and ten-lane freeways relative to Annual Average Daily Traffic, no change in shoulder width.

Figure 18 illustrates how total crash frequency is influenced by AADT and increasing the number of freeway lanes from four to six, six to eight, and eight to ten.

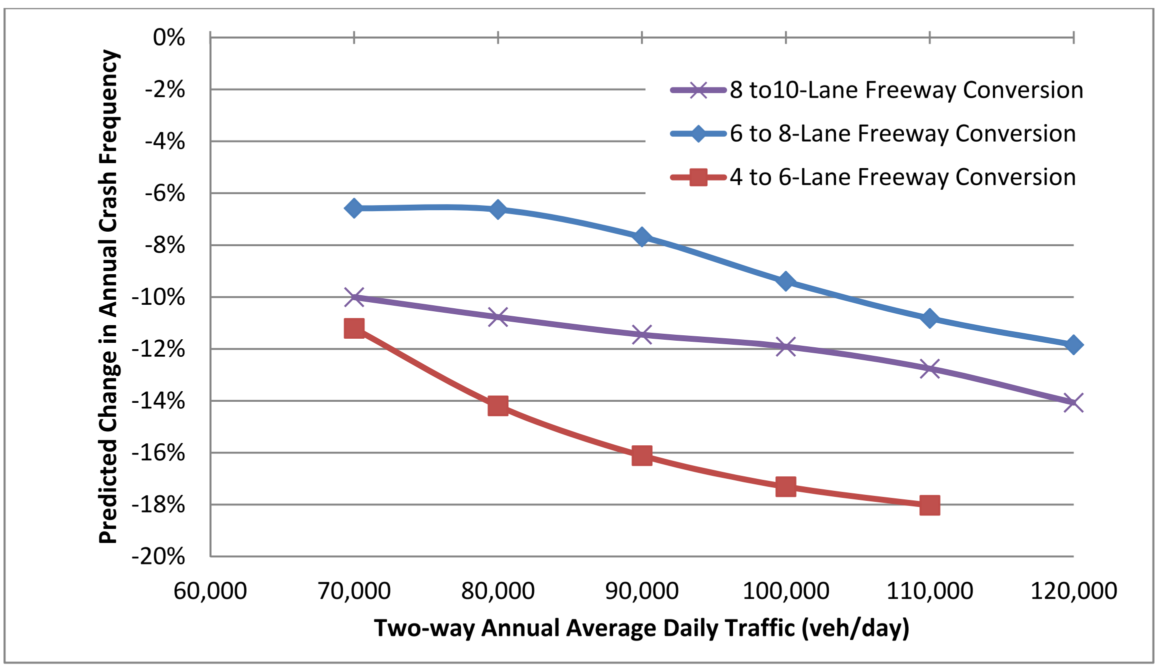


Figure 18. Graph. Predicted crash frequency relative to Annual Average Daily Traffic and Number of Freeway Lanes, no change in shoulder width.

As shown in Figure 18, the HSM freeway models predict a greater reduction in crash frequency for a 4- to 6-lane conversion than for an 8- to 10-lane conversion.

Model Evaluation of Shoulder Width

HSM freeway crash prediction models were applied to estimate the influence of reducing right shoulder width on 4-, 6-, and 8-lane freeways from 14 feet to the minimum model input of 4 feet, while holding all other model variables constant at default values. This isolates the effects of shoulder width from the effects of adding lanes. Figure 19 illustrates the predicted FI crash frequency associated with this change in right shoulder width on an 8-lane freeway. The trend is similar on 4- and 6-lane freeways. PDO crashes were omitted from Figure 19 because they are not sensitive to shoulder width in the 8-lane freeway model. The 4- and 6-lane freeway models predict slight increases in PDO crashes as right shoulder width decreases.

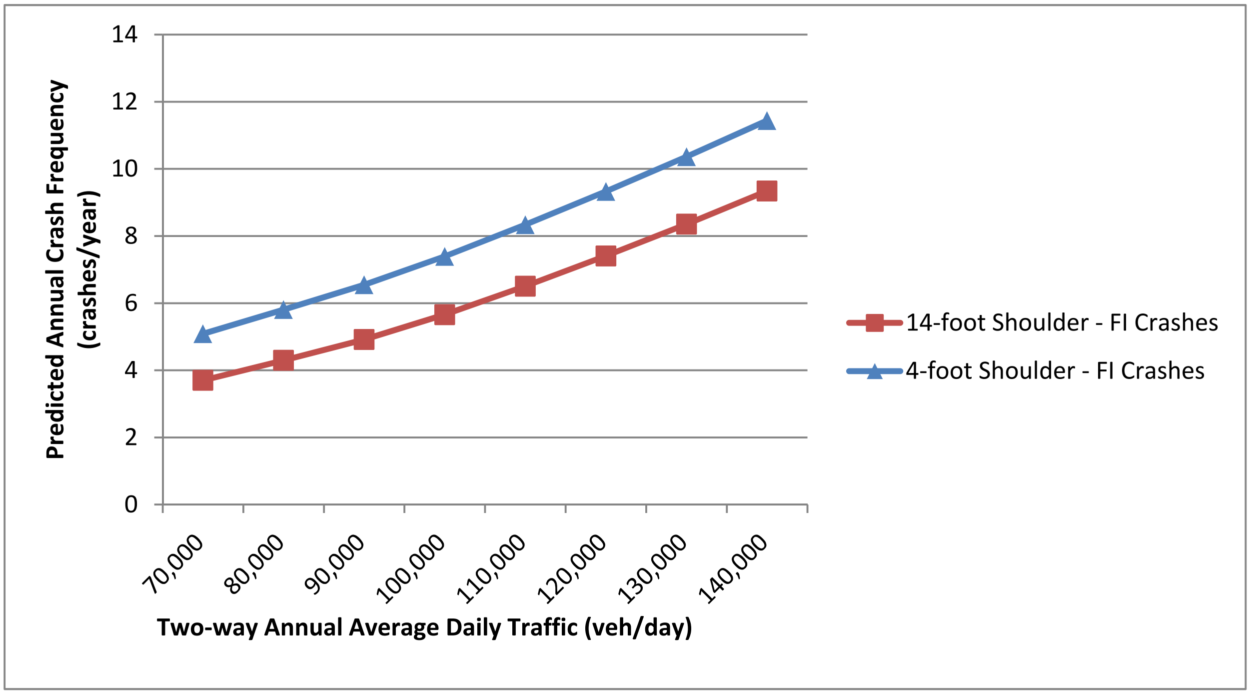


Figure 19. Graph. Predicted crash frequency on eight-lane freeways with 14- and 4-foot right shoulder width relative to Annual Average Daily Traffic.

As shown in Figure 19, reducing the shoulder width from 14 to 4 feet (without adding a lane) is expected to increase FI crash frequency, assuming volumes and other variables are kept constant.This reinforces the previous finding that part-time shoulder use is most appropriate if it relieves congestion and thus reduces congestion-related crashes.

Modelling Narrower Lanes and Narrower Shoulders

Most projects involving the implementation of part-time shoulder use have not modified general purpose lanes. However, part-time shoulder use could be implemented by narrowing general purpose lanes and widening the shoulder to make it a more viable for travel. This section presents the predicted safety effects of this change for the specific scenarios shown in Table 6.

The alternatives without part-time shoulder use reflect default values from the prediction models. The alternatives with part-time shoulder use assume width reductions from existing travel lanes and shoulders to provide for an 11-foot shoulder lane. Scenarios with part-time shoulder use are modeled with two more travel lanes (one per direction) than the existing freeway cross-section. Like the previous analysis presented in this chapter, the scenarios only changed lane widths and shoulder widths and did not explicitly model shoulder use.

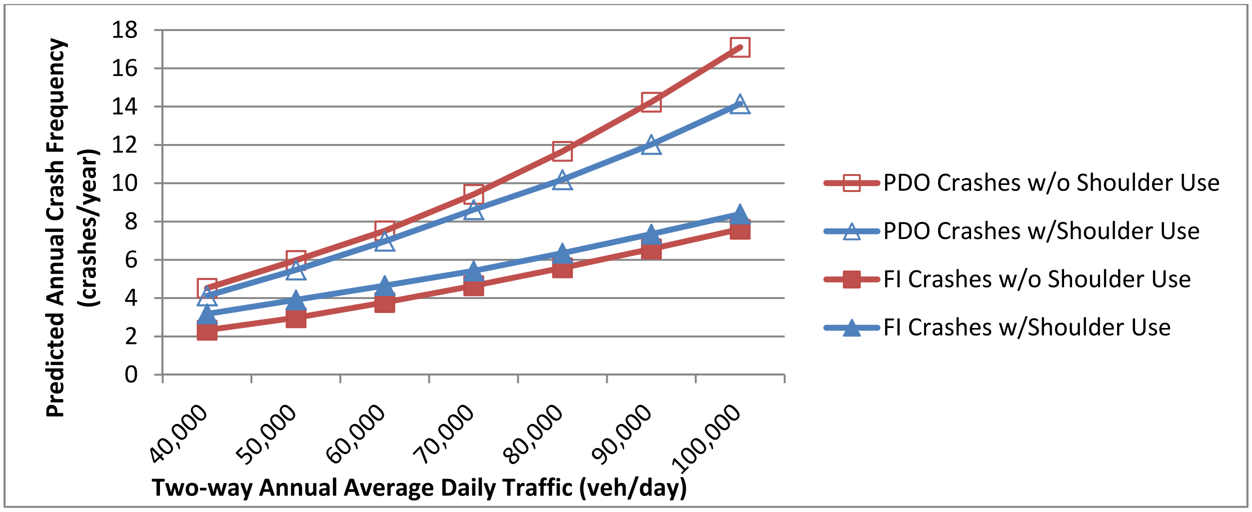
Table 6: Freeway part-time shoulder use scenarios and crash prediction inputs.

Variable	Alternative					
	4-Lane Freeway		6-Lane Freeway		8-Lane Freeway	
	without part-time shoulder use	with part-time shoulder use	without part-time shoulder use	with part-time shoulder use	without part-time shoulder use	with part-time shoulder use
Number of Lanes	4	6	6	8	8	10
Lane Width	12	11	12	11	12	11
Right Shoulder Width	10	4*	10	4*	10	4*
Left Shoulder Width	6	3*	6	4*	6	5*

* These are the narrowest shoulder widths for which the HSM has crash modification factors

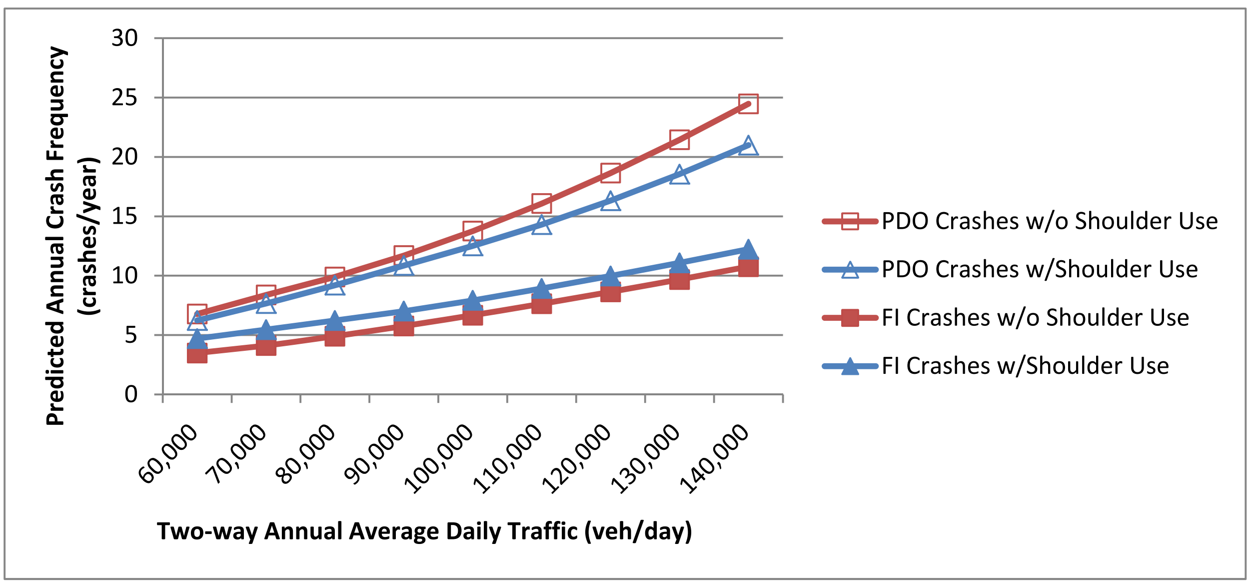
Note: Part-time shoulder use is modeled as six 11' general purpose lanes beside narrower shoulders, in use 24 hours a day.

Figure 20 through Figure 22 illustrate the predicted frequency of Fatal and Injury (FI) Crashes and Property Damage Only Crashes (PDO) for each freeway alternative shown in Table 6.



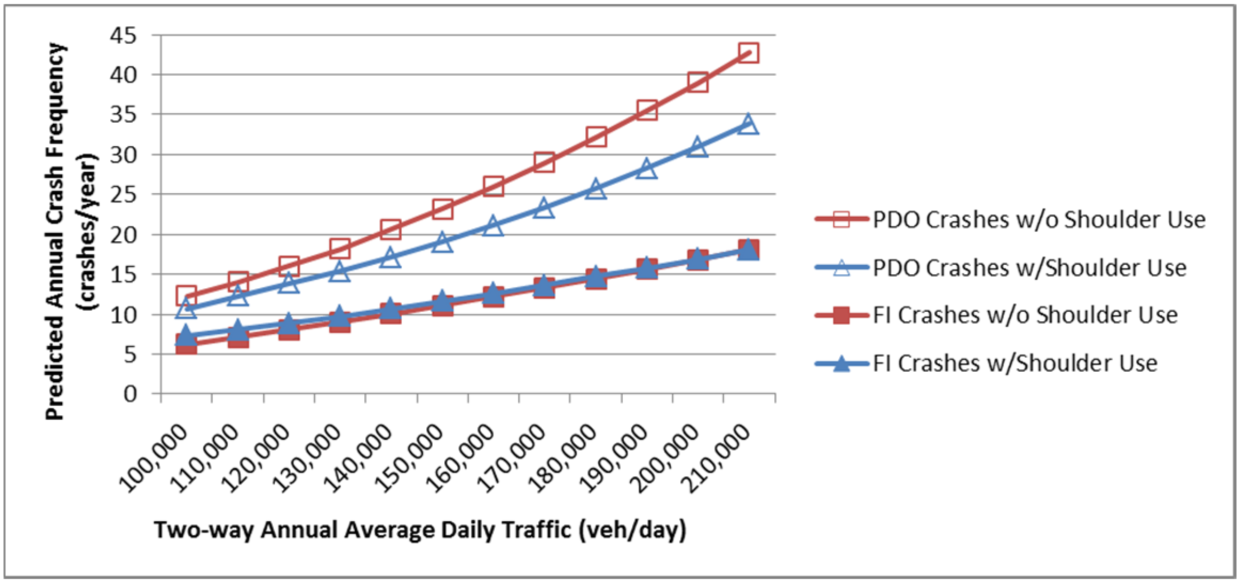
Note: Part-time shoulder use is modeled as six 11' general purpose lanes beside narrower shoulders, in use 24 hours a day.

Figure 20. Graph. Predicted crash frequency with and without narrow lanes and narrow shoulders on 4-lane freeways.



Note: Part-time shoulder use is modeled as eight 11' general purpose lanes beside narrower shoulders, in use 24 hours a day.

Figure 21. Graph. Predicted crash frequency with and without narrow lanes and narrow shoulders on 6-lane freeways.



Note: Part-time shoulder use is modeled as ten 11' general purpose lanes beside narrower shoulders, in use 24 hours a day.

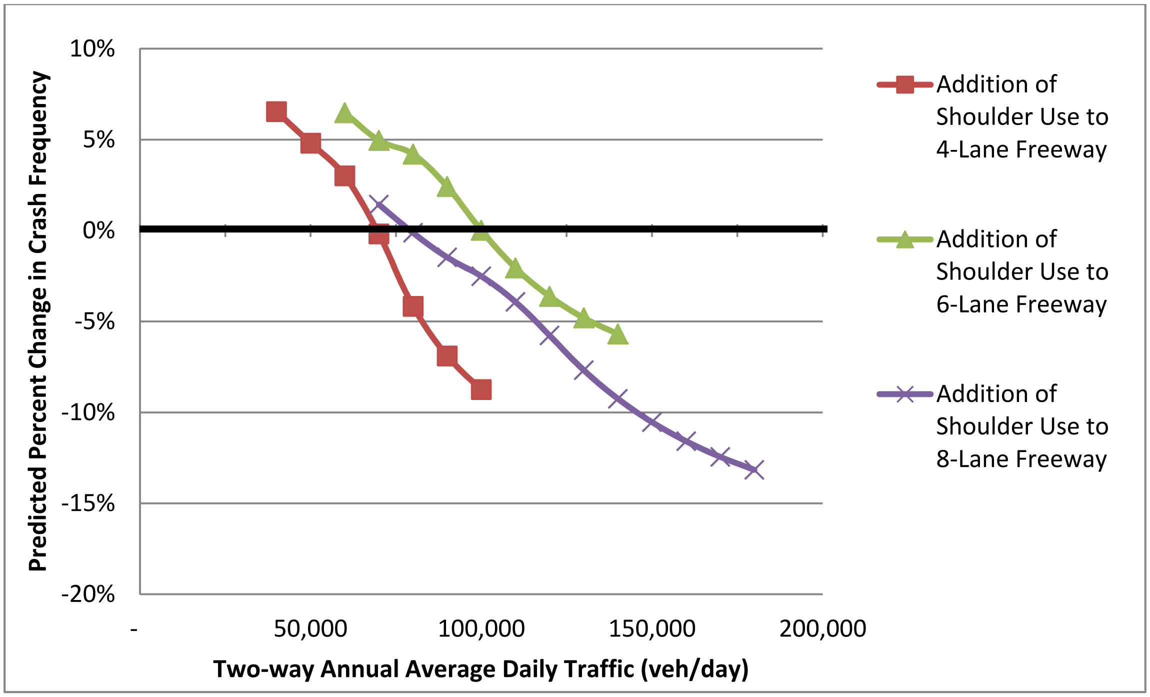
Figure 22. Graph. Predicted crash frequency with and without narrow lanes and narrow shoulders on 8-lane freeways.

The HSM freeway crash prediction models indicate that freeway part-time shoulder use, if similar to the three conversion scenarios presented in Figure 20 through Figure 22, could have the following influence on crash frequency and severity:

- Reduce PDO crashes
- Slightly increase FI crashes when converting existing 4- or 6-lane freeways
- Have little to no effect on FI crashes when converting existing 8-lane freeways

The analysis modeled part-time shoulder use as narrow general purpose lanes beside narrow shoulders and not explicitly as shoulder use because the HSM models do not explicitly include lanes designated for part-time shoulder use.

Figure 23 summarizes the scenarios shown in Table 6 and shows the safety effects of adding part-time shoulder use to 4-lane, 6-lane, and 8-lane freeways by narrowing general purpose lanes to 11 feet and reducing shoulder width. The point at which each line crosses the 0% mark on the y-axis indicates the AADT below which part-time shoulder use would be expected to increase crash frequency and above which part-time shoulder use would be expected to decrease crash frequency.



Note: Part-time shoulder use is modeled as a reduction in general purpose lane width, addition of an 11' general purpose lane, and reduction in shoulder width, in use 24 hours a day.

Figure 23. Graph. Predicted percent change in crash frequency when adding part-time shoulder use by narrowing all lanes.

CONCLUSIONS

An analysis of existing crash data, including crash type, time of day, and the location of crashes, should be the basis of a safety analysis of potential part-time shoulder use. Congestion-related crashes occurring during the hours part-time shoulder use would operate will likely be reduced by part-time shoulder use. Crashes related to erratic driver behavior, driver confusion, or suboptimal geometry may increase with part-time shoulder use.

Secondarily, the figures provided in this chapter provide ranges of AADT when part-time shoulder use is expected to have a positive or negative effect on crash frequency.

Overall, there appears to be a link between changes in congestion and changes in safety performance when shoulders are narrowed to implement part-time shoulder use. The application of the HSM freeway crash prediction models indicate reducing congestion (by increasing capacity) can offset the increase in crashes associated with increasing the number of lanes while reducing lane and shoulder width. This finding is consistent with research conducted by Kononov et. Al. on Colorado's freeways using a corridor-specific crash prediction model.(31)

The empirical studies show that additional variables not specifically accounted for in the HSM prediction models could increase crashes associated with part-time shoulder use. Those factors include any differences between narrow general purpose lanes and a narrow part-time "lane" on a shoulder, speed differential, influence of ramps, and upstream/downstream bottlenecks. Changes in barrier offset difference with and without part-time shoulder use can be modeled in the HSM, but were not included in the analysis presented in this chapter because of high dependence on site-specific conditions. There may be greater changes in crash frequency with part-time shoulder use if barriers are present and they cannot be moved further back from the roadway when part-time shoulder use is implemented.

CHAPTER 5. ENVIRONMENTAL ANALYSIS

Although the National Environmental Policy Act (NEPA) process is described earlier, this chapter highlights how to consider and conduct an analysis for the three most likely/typical/common environmental issues associated with part-time shoulder use:

- Air quality
- Greenhouse gas emissions
- Noise

This chapter describes how an agency could or should go about assessing their impact on the feasibility of the project during the planning and NEPA stages and, later, addressing them during the environmental clearance stage. This chapter describes how and when these environmental analyses are conducted and discusses the potential effects of part-time shoulder use on air quality, emissions, and noise. This chapter identifies standard guides on conducting these analyses, and points out special considerations when evaluating the use of an existing paved shoulder (possibly with minor improvements) to allow use by cars and/or buses during peak hours on a regular basis.

AIR QUALITY ANALYSIS

Given the variety of characteristics of shoulder use projects, it is difficult to generalize the effect of shoulder use on air quality. Shoulder use may reduce congestion, which is generally beneficial to air quality. Shoulder use also has the potential to increase volume, which generally worsens air quality. There may also be no net effect on traffic characteristics that would affect air quality pollution concentrations.

Nonattainment and Maintenance Areas

Air quality analysis of federal transportation projects is required by the Environmental Protection Agency (EPA) in areas that do not meet, or previously did not meet, federal air quality standards, identified as “non-attainment” and “maintenance” areas, respectively. The definition of a federal project is broad and includes “any highway or transit project which is proposed to received funding assistance or approval through the Federal Aid Highway program or Federal mass transit program, or required FHWA or FTA approval for some aspect of the project, such as connection to an Interstate highway or derivation from applicable design standards on the Interstate system” is subject to transportation conformity. This definition, particularly the “derivation from applicable design standards,” will encompass most part-time shoulder use projects. Projects in non-attainment and maintenance areas must be incorporated into the region’s Transportation Improvement Plan (TIP) and, per the Clean Air Act, must demonstrate their consistency with the regional conformity determination and address potential localized emissions impacts. Conformity requirements cover four pollutants for which federal standards are set—ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter ($PM_{2.5}$ and PM_{10}).

Areas that do not meet or previously did not meet federal air quality standards are identified as “non-attainment” and “maintenance” areas, respectively. Air quality analysis of federal transportation projects is required by the Environmental Protection Agency (EPA) in these designated areas for the transportation-related pollutants—ozone, nitrogen dioxide, carbon monoxide, and particulate matter per the transportation conformity rule. Shoulder-use projects are typically federal projects because they require design exceptions. Projects in metropolitan non-attainment and maintenance areas must be incorporated into regional emissions analyses associated with the region’s Transportation Improvement Plan (TIP) and long-range plan (MTP). Transportation conformity rules also require the analysis of potential localized emissions impacts where applicable. Non-attainment and maintenance areas have standing transportation conformity procedures in place that address how projects are handled to assess for conformity status (exempt/non-exempt) and whether a project-level analysis is required. These procedures may assist in assessing individual part-time shoulder lane projects.

More information on conformity can be found on these websites:

FHWA Conformity Website: http://www.fhwa.dot.gov/environment/air_quality/conformity

EPA Conformity Website: http://www.epa.gov/otaq/stateresources/transconf/index.htm

Other Areas

Outside of nonattainment and maintenance areas, air quality analyses may be conducted as part of a NEPA analysis. Agencies may consider the following questions when deciding whether or not to conduct air quality analysis in these areas:

- Is there concern about the project within the community?
- Is the shoulder only open to buses, or will a greater percentage of the fleet have access?
- If the shoulder is only open to buses, is service being added or will bus headways remain the same?
- For PM impacts, are diesel vehicles being moved closer to sensitive roadside receptors?
- Is the project in a dusty area where dust will be stirred up when the shoulder opens each day?

The degree of analysis conducted should be proportional to the project scope. Qualitative analysis without the use of modeling software is likely acceptable for low impact projects and more-complex analysis may provide useful information for projects with a higher potential for impact.

Analysis Tools and Techniques

For quantitative air quality analysis, conformity guidance should be used. Tools for quantitative analysis include the latest MOVES (Motor Vehicle Emissions Simulator) and EMFAC models. MOVES is used in all states, except California, which uses EMFAC. The models require inputs such as volumes and speeds, as shown in Table 7.

Table 7. Air Quality tools and data needs.

Tool	Inputs
MOVES (**Mo**tor **V**ehicle **E**missions **S**imulator)	Vehicle Operating Mode: vehicle speed, vehicle acceleration, road grade, rolling resistance, vehicle mass Service Hours Operating: actual time a vehicle spends within certain operating modes (captures emissions from idling)
EMFAC	VMT-based emission model: daily VMT by vehicle speed (at 5 mph increments) and vehicle class

More information on these tools can be found on these websites:

U.S. Environmental Protection Agency, Motor Vehicle Emissions Simulator (MOVES): http://www.epa.gov/OMSWWW/ngm.htm

California Air Resources Board, Emission Factor Model (EMFAC):

http://www.arb.ca.gov/msei/categories.htm

When analyzing part-time shoulder use, practitioners may consider two unique aspects that differ from a conventional widening project:

- During the hours the shoulder is closed to traffic, dust may accumulate on it, and this dust may be stirred up when the shoulder reopens each day.
- Use of the right shoulder will place emission sources (vehicles) closer to sensitive receptors, if any are present.

If a quantitative analysis is conducted for transportation conformity purposes, practitioners should follow EPA guidance for conducting hot-spot analysis for particulate matter and carbon monoxide, where applicable.

GREENHOUSE GAS EMISSIONS ANALYSIS

In some states—currently California, Massachusetts, New York, and Washington—analysis of greenhouse gas (GhG) emissions is required for some transportation projects. Part-time shoulder use projects in these states may require GhG analysis, depending on the circumstances.

Resources, such as the FHWA's *Handbook for Estimating Transportation Greenhouse Gases for Integration into the Planning Process*, provide information on how to analyze on-road greenhouse gas emissions at the state and regional level. The majority of greenhouse gas (GhG) emissions from transportation are carbon dioxide (CO_2) emissions from the combustion of petroleum-based products. Methods to reduce GhG emissions include improving traffic operating conditions, such as avoiding rapid acceleration and braking, reducing idling, and reducing travel demand. MOVES and EMFAC (described in the previous section) are used for GhG emissions analysis.

Similar to air quality, it is difficult to generalize the effect of part-time shoulder use on GhG emissions. A study of the M42 part-time shoulder uses pilot project in the UK captured this.[(25)] In general, regardless of part-time shoulder use, emissions on the M42 fall per mile as average speed increases from congested conditions to 40-50 mph where the fuel efficiency of engines is greatest and then rises as the average speed increases towards 70 mph and fuel efficiency falls. On a per-vehicle basis, the GhG emission benefit of part-time shoulder use was greatest in lower speed ranges when it reduced start-stop traffic. However, the effect is likely to be outweighed by additional emissions from higher speeds above the 40-50 mph range and changes in peak period traffic volume. The study concluded by stating "we expect that shoulder [use] will lead to an increase in traffic emissions compared to a 'do nothing' scenario. However, the impact of [part-time shoulder use] on traffic emissions is expected to be lower than the impact of road widening."

NOISE ANALYSIS

The level of highway noise primarily depends upon traffic volume, traffic speed, truck volume, and to a lesser extent it depends on other factors such as topography and pavement type.

The Federal noise regulation in 23 CFR 772 constitutes the Federal noise standard. For the purposes of meeting the requirements in 23 CFR 772, a noise analysis is required for all Federal or Federal-aid projects that are defined as Type I, per the regulation. Noise measurements are conducted to determine existing noise levels, and future levels are predicted using the FHWA Traffic Noise Model (TNM). A noise impact occurs when the predicted noise level approaches or exceeds the Noise Abatement Criteria (NAC) in 23 CFR 772, Table 1, or represents a substantial increase over existing noise levels. If noise impacts are determined, then noise abatement must be considered. If noise abatement is found to be feasible and reasonable, per 23 CFR 772 and that state's noise policy, then the noise abatement measure must be constructed. For the purposes of NEPA, a noise analysis may also compare the project noise level of a no-build or no action condition to the existing noise levels.

There are eight parts to the Type I definition, but there are only three that may encompass a part-time shoulder use project, depending on the type of shoulder and any restrictions and/or requirement for its uses. Those three parts include:

- "The physical alteration of an existing highway where there is…substantial horizontal alteration. A project that halves the distance between the traffic noise source and the closest receptor between the existing condition and the future build condition."
- "The addition of a through-traffic lane(s). This includes the addition of a through-traffic lane that functions as an high-occupancy vehicle (HOV) lane, High-Occupancy Toll (HOT) lane, bus lane, or truck climbing lane."
- "Restriping the existing pavement for the purpose of adding a through-traffic lane or an auxiliary lane."

Similar to air quality analysis, design exceptions required for part-time shoulder use projects will make these projects federal and, thus, subject to 23 CFR 772.

The level of noise analysis necessary will depend upon the type of part-time shoulder use. For bus-on-shoulder (BOS), noise analysis may be qualitative because the number of additional vehicles and changes in speed are small or nonexistent. For static and dynamic part-time shoulder use, noise analysis will typically be conducted in a manner similar to a conventional widening project. For the noise analysis, the location of the part-time shoulder use would affect the proximity to sensitive receptors. Left side part-time shoulder use is less likely to have noise impacts compared to right side part-time shoulder use, which places the traffic closer to sensitive receptors. Noise analysis and determination of noise mitigation needs is focused on peak noise conditions. This may or may not correspond to peak volume conditions (when shoulder lanes are typically open), and analysis will determine if part-time shoulder use affect peak noise or not. Predicted noise levels are determined by using the FHWA Traffic Noise Model.(4) If part-time shoulder use does increase peak noise, and there are impacts associated with it, then noise abatement must be considered and implemented if found to be feasible and reasonable.

Existing part-time shoulder use demonstrates the differences in noise analysis and mitigation needs. For example, part-time shoulder use on US 2 in Everett, Washington, was implemented on a bridge over wetlands. There were no sensitive receptors (i.e. land uses where noise would cause impacts) in the project area, so no noise analysis was conducted. Washington State is currently planning part-time shoulder use on another freeway—I-90 east of Seattle—and noise analysis was conducted because there were sensitive receptors. The analysis indicated the need for noise walls, which will be constructed as part of the part-time shoulder use project.(33)

CHAPTER 6. COSTS AND BENEFITS ANALYSIS

The previous chapters (3-5) address possible methods for estimating measures of part-time shoulder use performance in terms of mobility, safety, and environment, respectively. This chapter discusses how to compute the costs of part-time shoulder use over a project's life cycle, how to monetize the potential benefits (or dis-benefits) discussed in previous chapters, and how to combine costs and benefits into a benefit-cost (B-C) ratio to simultaneously compare these performance measures. The B-C ratio is a useful tool in comparing alternative approaches for implementing and operating part-time shoulder use.

A benefit-cost analysis is also an important consideration within the broader regional transportation planning process. Transportation planners and operations personnel will likely need to compare more traditional infrastructure projects (e.g., permanent widening, bottleneck removal) and Transportation System Management and Operations (TSM&O)-oriented strategies, including part-time shoulder use. Because both of these different types of projects are often competing for the same funds, a benefit-cost analysis provides a framework for prioritizing and ranking widely varying improvement types.

This chapter provides information for computing life-cycle costs and developing a Benefit-Cost Analysis (BCA). Additional details on some of the BCA activities and processes can be found in the Federal Highway Administration (FHWA) *Life-Cycle Cost Analysis Primer* and the *FHWA Operations Benefit/Cost Analysis Desk Reference*.[34, 35]

LIFE-CYCLE COSTS

Estimating the life-cycle costs of part-time shoulder use is often complex. This is particularly true of more-advanced part-time shoulder use, such as dynamic part-time shoulder use or static part-time shoulder use with dynamic signs. Compared with more traditional infrastructure improvements, TSM&O improvements such as part-time shoulder use typically incur a greater proportion of their costs as continuing operations and maintenance costs, as opposed to upfront capital costs.

Much of the intelligent transportation systems (ITS) equipment associated with part-time shoulder use also typically has a much shorter anticipated useful life than many traditional improvements and must be replaced as it reaches obsolescence. Costs include deployment, implementation, and operations and maintenance plans. Failure to recognize and accurately forecast these costs may result in future funding or resource shortfalls, or the inability to properly operate and maintain deployed part-time shoulder use.

The FHWA *Operations Benefit/Cost Analysis Desk Reference* recommends the following structure for organizing cost data:

- **Capital costs**. The upfront costs necessary to prepare the shoulder pavement for traffic flow, provide refuge areas, modify signing and pavement marking, and procure and install ITS equipment. These costs will be shown as a total (one-time) expenditure and will include the capital equipment costs, as well as the soft costs required for design, installation, and other systems engineering activities. Potential capital cost elements for part-time shoulder use are identified in Table 8.

- **Operations and maintenance costs**. Those continuing costs necessary to operate and maintain the deployed part-time shoulder use, including ongoing labor costs for activities such as emergency patrols, additional law enforcement, and TMC staffing. These costs do not include wholesale equipment replacement when the equipment reaches the end of its useful life. These operations and maintenance costs will be presented as annual estimates. Likely operations and maintenance costs are listed in Table 9.
- **Replacement costs**. The periodic cost of replacing and/or redeploying equipment as it becomes obsolete and reaches the end of its expected useful life.

Table 8. Potential capital cost components.

Component	Description
Activities associated with the systems engineering process	Concept of Operations and requirements documents, design and contract documents, testing and acceptance activities, construction engineering, and environmental assessments or environmental impact statements.
Shoulder reconstruction and widening	Repaving the shoulder, modifying drainage structures, adding/relocating guardrails, constructing turnouts, and complete reconstruction or minor widening of the shoulder.
Ramp treatments	Ramp widening and/or shoulder pavement improvement along ramps and in gore areas as may be required to provide continuity of the part-time shoulder use through interchanges.
Training	For existing / new operations staff, maintenance and law enforcement staff, and bus operators on Bus on Shoulder (BOS) facilities.
Emergency patrols	Typically increased to compensate for the loss of a breakdown area.
Public outreach and communications campaigns	Part-time shoulder use will likely be new to the motoring public and an extensive public outreach program may be required

Continuation

Component	Description
ITS	Most part-time shoulder use, except for BOS, has some degree of ITS. Major ITS cost components may include: ▪ **CMS and supporting sign supports and gantries –** Static part-time shoulder uses facilities are increasingly being equipped with CMS, and dynamic facilities by definition must have CMS. Costs for CMS can vary greatly depending on spacing, mounting (overhead or ground-mounted), design (gantry or mast arm if overhead). Part-time shoulder uses with other Active Traffic Management (ATM) elements such as dynamic speed limits, dynamic lane assignment, and / or queue warning will require larger and more frequent CMS, increasing cost. ▪ **Overhead lane-use control signals –** These are less expensive than CMS, but can only indicate whether a lane is open, closed, or (in some cases) about to close ▪ **Controllers –** for operating CMS and for processing detector data. ▪ **Detection and CCTV –** Dynamic part-time shoulder use or static part-time shoulder use that can be closed due to incidents will require some sort of detection and surveillance, up to full CCTV coverage of the shoulder and emergency refuge areas. If additional ATM elements such as dynamic speed limits, dynamic lane assignment, and queue warning are included, the system will likely require extensive detector subsystems. ▪ **Communications and power software –** Dynamic part-time shoulder use with automated decision-making on the opening and closing of the shoulder will likely require additional software algorithms, including decision support systems that can assist operators with quickly inputting necessary information (e.g., confirm that a lane is closed, confirm that the shoulder is clear of any vehicles) and approving opening/closing. ▪ **Central Hardware / TMC Enhancements –** Additional central hardware such as servers, communications modems, workstations, and video displays may be required at the TMC. This in turn may require alterations or enhancements to the TMC.
Mobilization and contingency costs.	

Table 9. Potential operations and maintenance cost components.

Component	Description
Compliance	It may be necessary to include the cost of additional police presence to help enforce the part-time shoulder use (e.g., not using the shoulder when closed) and related strategies such as variable speed limits.
Driver Training	Transit agencies using BOS facilities will need to conduct training for new bus drivers as they are hired or assigned to routes with BOS.
"Sweeps"	Many agencies with static or dynamic part-time shoulder use have a police or maintenance vehicle drive the length of the facility prior to each opening of the shoulder.
ITS	Most part-time shoulder use, except for BOS, has some degree of ITS. Major ITS operations and maintenance components may include: ▪ **On-going TMC Operation** – Depending on the size and complexity of the part-time shoulder uses system, and the degree of automation and accompanying ATM, existing TMC operators' workload might increase, and additional staff might be required. Training of new staff must also be included in the costing. ▪ **Updating and Maintaining Operating Procedures** – Besides the additional labor costs associated with operations, there are other costs tied to operation of ATM strategies. These include updating standard operating procedures and the system rules based on operating experience. ▪ **Maintenance** – This includes a consistent and continuing program of preventive and reactive maintenance of supporting ITS hardware in the field and at the TMC. This may require additional maintenance staff, spare parts, and on-going training.
Roadway Maintenance	Maintenance of lanes designated for part-time shoulder use is typically the same as maintenance of adjacent general purpose lanes and the incremental cost of maintenance (patching potholes, maintaining pavement markings, etc.) is minimal. Debris removal needs are more similar to regular travel lanes than regular shoulders. Snow removal is sometimes challenging in constrained areas such as under or on bridges after a major snowfall, and there may be costs related to this.

Within each of the capital costs (Table 8) and operations and maintenance costs (Table 9), there are items that increase proportionally to the length of the facility and items that are only minimally affected by facility length. Costs such as driver training, public education, and "backbone" ITS infrastructure in a TMC are generally incurred regardless of facility length. Costs such as pavement preparation, CMS, and emergency turnouts are incremental, and largely a function of facility length.

Structuring the cost data in this framework provides the ability to readily scale the cost estimates to the size of potential deployments. Presenting the costs in this scalable format provides the opportunity to easily estimate the costs of expanding or contracting the size of the deployment and allows the cost data to be reutilized for evaluating other corridors.

MONETIZING BENEFITS

The computation of potential operational, safety, and environmental benefits of part-time shoulder use was discussed in previous chapters. This section describes how to monetize those benefits. The estimated benefits will likely be expressed in terms of reduced travel times, reduced delays, reduced number of crashes, and so forth, relative to existing conditions or a future no-build scenario. It will, therefore, be necessary to convert these various measures into a dollar value. State DOTs typically have such conversion values, or national averages may be used. Table 10 shows the values used by the FHWA TOPS-BC tool for various benefit parameters.

TOPS-BC is a benefit-cost tool developed by FHWA for TSM&O projects. In addition to monetizing benefits, it can develop estimates of benefits—if they were not previously computed—using link volume (per analysis period) as a primary input, along with link length, number of lanes, link capacity, and free-flow speed.

Many advanced TSM&O strategies—including part-time shoulder use and particularly part-time dynamic shoulder lanes—have only been recently deployed in the U.S. Accordingly, estimates of the likely impacts and benefits resulting from these strategies may need to be based on limited empirical data of the actual benefits of the strategy within the analysis. Being conservative regarding the estimated benefits, and conducting a sensitivity analysis, should be considered. For part-time shoulder use, benefits are likely to be focused on improved operational performance. As discussed in previous chapters, there are no methods for reliably predicting crashes with part-time shoulder use, and environmental benefits may be positive or negative.

Table 10 shows some of the performance measures that would be used in a benefit-cost estimate, and the societal cost of each per TOPS-BC. Many agencies have their own valuations for these parameters as well.

Table 10. Benefit estimation parameters.

Benefit	Specific Condition	Valuation
Delay (per hour)	"On the clock" travel	\$ 30.91
	Other auto travel	\$ 15.46
	Truck travel	\$ 30.91
Crashes (per occurrence)	Fatality	\$ 9,936,727
	Injury	\$ 73,973
	Property damage only (PDO)	\$ 2,539
Fuel Use	Per gallon (excluding taxes)	\$ 4.05
Non-fuel Operating Costs (per VMT)	Auto	\$ 0.25
	Truck	\$ 0.37
Emissions (per ton)	CO	\$ 77
	CO2	\$ 41
	Nox	\$ 17,997
	PM10	\$ 145,518
	VOC	\$ 1,259
Noise (per VMT)	Auto	\$ 0.0012
	Truck	\$ 0.0364

Note: From TOPS-BC Tool, assuming 2015 dollars and a 2% inflation rate

The combination (e.g., mobility, safety, reliability, environmental) and subsequent monetization of benefits needs to be carefully planned and structured to avoid the double-counting of benefits. Double-counting can occur in situations in which there are overlaps in different benefits, or when a change to one benefit results in a direct change to another benefit.

Another critical aspect of monetizing benefits is to annualize them, and then estimate the total dollar value of the benefits over the life cycle of the system. This life-cycle period must be the same as the analysis period used for the estimating costs, as discussed below.

CONDUCTING A BENEFIT/COST ANALYSIS

Once the life-cycle cost of a project has been determined and the project's benefits have been monetized, a benefit-cost analysis can be conducted.

Analysis Period

It is essential that the analyses use the same period of time—the "analysis period"—to assess life-cycle costs and benefits, and to compare the resulting benefit-cost ratios for different alternatives and scenarios. The analysis period should be long enough to include the initial construction up to (and possibly beyond) the point where it becomes necessary to replace many of the ITS components, as these have a shorter lifespan than traditional infrastructure. The purpose of this approach is to spread out both the benefits and costs over an appropriate timeframe to allow for a meaningful analysis. For part-time shoulder use, a 10-, 15-, or 20-year time horizon should be considered. Shorter horizons may be appropriate if part-time shoulder use is being implemented as a temporary measure until a traditional widening project is completed.

Inflation and Discounting

An inherent issue in life-cycle benefit-cost analysis is the difficulty of making value comparisons among projects that are not measured in equal units. Even when values are stated in monetary units such as dollars, the values still may not be comparable, for at least two reasons:

- **Inflation**. Expenditures typically occur at various points in the past or future and are, therefore, measured in different value units because of changes in price (e.g., a 1990 dollar would, in general, have purchased more real goods and services in 1990 than would a 2010 dollar in 2010). A general trend toward higher prices over time, as measured in dollars, is called inflation. A general trend toward lower prices is called deflation. Dollars that include the effects of inflation or deflation over time are known as nominal, current, or data-year dollars. Dollars that do not include an inflation or deflation component (i.e., their purchasing power remains unchanged) are called constant or base-year dollars.
- **Discounting**. Costs or benefits (in constant dollars) occurring at different points in time—past, present, and future—cannot be compared without allowing for the opportunity value of time. The opportunity value of time as it applies to current versus future funds can be understood in terms of the economic return that could be earned on funds in their next best alternative use (e.g., the funds could be earning interest) or the compensation that must be paid to induce people to defer an additional amount of current year consumption until a later year. Adjusting for the opportunity value of time is known as discounting.

Analytically, adjusting for inflation and discounting are separate calculations. Future costs and benefits of a project should be expressed in constant dollars and then discounted to the present at a discount rate that reflects only the opportunity value of time (known as a real discount rate).

Through the use of a real discount rate, the following transformations can be performed to facilitate comparison of the constant dollar costs of alternative transportation projects:

- **Relocation in Time.** A single figure can be “moved” (transformed into an equivalent value) backward or forward in time, without altering its real value, known as its “present worth”.
- **Annualized Cost.** This is the average annual expenditure that would be expected to deploy, operate, and maintain the operations strategy and replace (or redeploy) any equipment as it reaches the end of its useful life. Within this cost figure, the capital costs

will be amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual operations and maintenance cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of TSM&O deployments.

- **Present Value.** Any combination of flows (finite or infinite) and lump sums can be summed into a single value at a single point in time.

TOPS-BC

A number of tools, many of them specific to certain agencies, exist for B/C analysis. The TOPS-BC tool, developed by FHWA for TSM&O projects including part-time shoulder uses, is described in this section.

TOPS-BC tool is a spreadsheet-based tool providing the following four key capabilities:

- The ability for users to investigate the expected range of impacts associated with previous deployments and analyses of many TSM&O strategies.
- A screening mechanism to help users identify appropriate tools and methodologies for conducting a benefit/cost analysis based on their analysis needs.
- A framework and default cost data to estimate the lifecycle costs of various TSM&O strategies, including capital, replacement, and continuing operations and maintenance costs.
- A framework and suggested impact values for conducting simple benefit/cost analysis for selected TSM&O strategies.

A desk reference was developed in parallel with the tool.

Part-time shoulder use is one of the strategies addressed by TOPS-BC—identified therein as "ATDM Hard Shoulder Running." The user will likely need to modify default values and add inputs to meet the specifics of any particular location and application, for example:

- The useful life, capital costs and annual costs for the "infrastructure-related components".
- The useful life, capital costs and annual costs for the "incremental deployment equipment".
- Additional cost items for the two categories. Examples were listed earlier in this chapter in Table 8.
- TOPS-BC calculates costs based on the user inputs of the "number of infrastructure deployments" and the "number of incremental deployments." The infrastructure deployments (i.e., hardware, software, staff at the TMC, public outreach) can likely be set up as a single deployment. Incremental deployments may be set up as a single ITS location (e.g., lane control sign, support structure, controller, detector, and communications), although a "per mile" approach may work better if new communications infrastructure and/or some sort of shoulder work is required. With the

per-mile approach, the cost per mile for new communications and shoulder work would be included, along with the number of signs, support structures, controllers, detectors, cameras, etc., per typical mile.

As was the case with estimating benefits, care should be taken to not double-count costs. For example, if part-time shoulder use is to be implemented with other ATM strategies (such as dynamic speed limits and dynamic lane assignment—what is shown in TOPS-BC as "speed harmonization"), then the supports, controllers, and communications for new signs may already be included in the other ATM costs, and should not be included for part-time shoulder use.

SELECTING THE OPTIMUM PROJECT(S)

Although a B-C analysis provides a robust and comprehensive framework for comparing the relative efficiency of different projects, strategies, and combinations of strategies, the resulting B-C ratios should not be the only piece of information that may be used in analyzing and prioritizing projects and strategies. Other considerations that should be addressed may include the following:

- **Regional goals and their relative priorities**. If improved transit is of great importance, a BOS approach may be given greater consideration even if it has a low B-C ratio. If congestion frequently occurs outside of traditional peak periods, widening—although costly—may be more appropriate than part-time shoulder uses.
- **Roadway Use**. Facilities that carry significant freight traffic, serve a large number of bus routes, provide access to and from special event venues, may be used for evacuations, and/or already have other types of ATM may have a higher priority for part-time shoulder uses.
- **Funding and time constraints**. There may be budget constraints that preclude some projects, regardless of the B-C ratio. Similarly, it may be easier and faster to construct and implement strategies along one roadway relative to others and allow benefits to start accruing as soon as possible.
- **Political will and public acceptability**.

CHAPTER 7. DESIGN CONSIDERATIONS

Part-time shoulder use typically utilizes an existing shoulder; therefore, the design of a part-time shoulder use implementation project is typically less involved than the design of a full-time added lane. However, the same elements of roadway design—geometry, pavement, drainage, and signing and pavement marking—are applicable to both full-time lanes and lanes designated for part-time shoulder use and require some level of attention prior to implementation. Preexisting pavement and drainage should be assessed before part-time shoulder use is implemented, and improvements or modifications may be necessary. Special signing and pavement markings are necessary for part-time shoulder use, and dynamic signs are often used.

Designing for operations is "the collaborative and systematic consideration of management and operations during transportation project design and development" [36]. In the context of part-time shoulder use, a designing for operations process incorporates design features needed for part-time shoulder use—full depth pavement, sufficiently wide shoulders and lateral offsets, space for turnouts, and so forth—into the design of a facility where there is a reasonable likelihood that part-time shoulder use would someday be implemented. Part-time shoulder use is typically implemented on older freeways in constrained environments, so the design project in which a designing for operations process is used may be a reconstruction project rather than a new facility.

This chapter presents design considerations for part-time shoulder use in the context of existing design practices for facilities without part-time shoulder use and the experiences of states that have implemented part-time shoulder use. There is little quantitative research on design elements of part-time shoulder use, and much will be learned in this area in the coming years as new facilities are built and existing facilities age.

GEOMETRIC DESIGN

From a geometric design perspective, freeway part-time shoulder use can be subdivided into three types of segments:

- Beginning and end segments
- Basic freeway segments
- Ramp-freeway junction segments

This section presents geometric design considerations for each of these segment types, as well as design considerations for arterials with part-time shoulder use and emergency turnout areas.

Part-time shoulder use may introduce design elements that are below the minimum criteria specified in AASHTO's *A Policy on Geometric Design of Highways and Streets* (Green Book)[37] and design exceptions may be required. If the facility is an Interstate Highway, design elements in AASHTO's *A Policy on Design Standards – Interstate System*[38] also apply. The Basic Freeway Segment section below presents design criteria that part-time shoulder use may affect and require design exceptions. The process for obtaining a design exception is covered in CHAPTER 9.

Beginning and End Segments

Logical termini should be established during project scoping and preliminary design consistent with National Environmental Policy Act (NEPA) guidance. Part-time shoulder use can begin and end along basic segments or at ramps. If the beginning or end of static or dynamic part-time shoulder use is along a basic freeway segment, then it is desirable for it to be located such that it is highly visible and comprehended by approaching drivers. Horizontal curves, crest vertical curves, and overpasses may limit a driver's visibility of a downstream roadway, and dropping any type of lane—including part-time shoulder use—within or immediately beyond these features, should be avoided if possible. Likewise, dropping any type of lane in or immediately beyond an area with extensive, complex signing or other features contributing to high driver workload should be avoided if possible.

There are fewer considerations associated with adding a general purpose lane in comparison to dropping a general purpose lane because it requires no action on the part of the driver. However, starting part-time shoulder use requires a series of signs to indicate use restrictions and the point at which use of the shoulder becomes allowable. Therefore, the desirable locations for lane drops described above are also desirable locations to start part-time shoulder use.

Beginning of Part-time Shoulder Use

Part-time shoulder use added along basic freeway segments should have pavement markings that guide drivers from the adjacent general purpose lane to the shoulder, but also maintain continuity of the general purpose lane. Typically, a diagonal solid edge line provides a transition from the edge of the general purpose lane to the edge of the shoulder, and a dotted edge line connects the edge line adjacent to the general purpose lane before and after the transition to the part-time shoulder use. Striping for the beginning of part-time shoulder use is shown below in Figure 24.

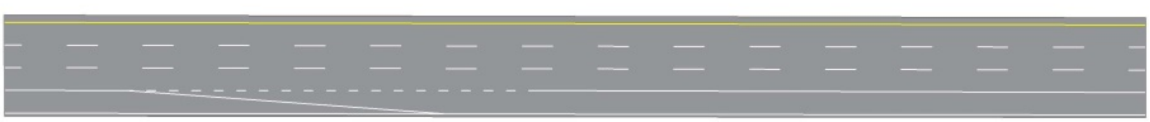


Figure 24. Illustration. Typical part-time shoulder use add.

(Source: Kittelson & Associates, Inc.)

Part-time shoulder use may also begin as an add "lane" from an on-ramp, with pavement markings supporting both ramp-to-general purpose lane and ramp-to-shoulder movements. At the end of the speed-change lane for a parallel style ramp, drivers from the on-ramp merge into the general purpose lane when the shoulder is closed and continue straight into the shoulder when it is open. This method of adding is most desirable at high-volume ramp locations where the merge of traffic from the on-ramp onto the freeway creates a bottleneck on the freeway. It is least desirable at locations where it is undesirable for a significant portion of on-ramp traffic to use the shoulder, such when the shoulder is restricted to high-occupancy vehicle (HOV) traffic or an on-ramp with a high percentage of truck traffic.

End of Part-time Shoulder Use

The end of part-time shoulder use along a basic freeway segment is designed similarly to the beginning of part-time shoulder use. A solid edge line is typically used to transition traffic from the shoulder back to the adjacent general purpose lane, shown in Figure 25.

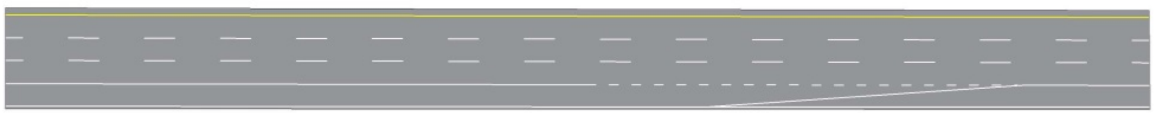


Figure 25. Illustration. Typical part-time shoulder use drop.

(Source: Kittelson & Associates, Inc.)

In general, basic freeway lanes should not be trapped onto exit ramps because this is unexpected to drivers, and the same applies to part-time shoulder use. However, at large system interchanges, it is more common to drop lanes onto ramps because a large percentage of the traffic is exiting. If exit ramps and the part-time shoulder use are on the same side of the freeway, dropping the shoulder use onto the exiting ramp may be reasonable depending on traffic patterns. Other strategies at system interchanges include ending the part-time shoulder use at the same location where a general purpose lane is added (because general purpose lanes are often added in advance of system interchanges) and carrying the part-time lane through the system interchange if the exiting and entering ramps have one or two lanes are designed in a manner that will not create conflicts (see ramp-freeway junction section of this chapter). Carrying part-time shoulder use through system interchanges is complex due to conflicts with exiting and entering traffic and the role part-time shoulder use serves on the freeway network, and should be done with caution. System interchanges often change volume (to a significant degree) or number of basic lanes on a facility, and there is often a not a need for part-time shoulder use both upstream and downstream of a system interchange.

At major forks, part-time shoulder use can be carried onto one of the forks. This is desirable if the ramps downstream of the fork have more lanes than the freeway approaching the fork. US 2 in Washington State and SR 29 in New Jersey both have part-time shoulder use in one direction that terminate this way. SR 29, for example, has three general purpose lanes upstream of the fork and two two-lane ramps downstream of the fork. Figure 26 shows an example of part-time shoulder use used to remove a bottleneck upstream of a major fork. The part-time shoulder use in Figure 26 is on the right side and provides the second lane to the right side fork, terminating into a general purpose lane on the ramp.

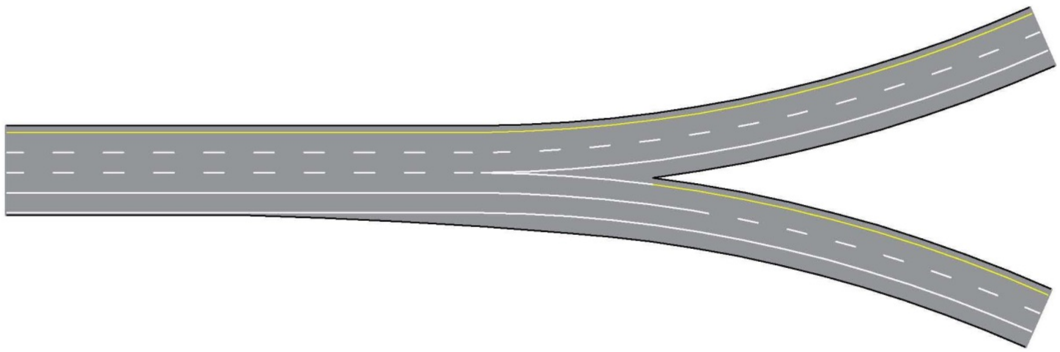


Figure 26: Illustration. Part-time shoulder use approaching major fork.

(Source: Kittelson & Associates, Inc.)

Shoulder Use Between Interchanges Only

Georgia and Hawaii use static part-time shoulder use between (but not through) adjacent interchanges to effectively create part-time auxiliary lanes and mitigate the effects of closely-spaced entrance and exit ramps. In this case, the shoulder is not functioning as a basic freeway lane, and a drop onto a service interchange is necessary and inherent in the design.

Basic Freeway Segments

Controlling design criteria and their minimum values from the AASHTO *Green Book*(37) and AASHTO's *A Policy on Design Standards – Interstate System* are presented in Table 11.(38) When the *Green Book* has different values for different types of facilities, only the freeway values are presented because part-time shoulder use is typically implemented on freeways. Minimum values from both AASHTO publications are the same for many of the criteria, and are only noted separately if they differ. In one or both documents, some minimum criteria are required ("shall") as opposed to desired ("should"). A design exception is needed if required minimum values are not met (on roadways on the National Highway System). States should work with their Federal Highway Administration (FHWA) Division Office when considering design exceptions on the National Highway System.

Existing design features often dictate part-time shoulder use dimensions. However, as discussed in 0, higher quality geometry meeting or exceeding AASHTO criteria, when possible, generally leads to higher utilization and capacity of the shoulder, compared to more constrained geometry.

Table 11. Controlling criteria, minimum AASHTO values, and relationship to part-time shoulder use.

Controlling Criteria	Minimum AASHTO Values(37, 38, 39)	Affected by Part-time shoulder use
Design Speed	Chosen by agency. Shall be at least 50 mph in urban areas, should be 70 mph in rural areas, may be 50-60 mph in mountainous areas	No, unless agency choses to reduce it
Lane Width	Shall be 12 feet	Possibly
Shoulder Width (values for paved width presented)	4-lane freeways – Right shoulder shall be 10+, left shoulder shall be 4+ feet 6+-lane freeways – both shoulders should be 10+ feet Truck traffic exceeds 250 DDHV – 12+ foot shoulders on both sides should be considered	Always
Bridge Width	Less than 200 feet long – Shall equal full paved width of approach roadway 200+ feet long, Green Book – provide approach shoulder widths and median barrier if single structure. 200+ feet long, Interstate Standards – offsets to parapet, rail, or barrier shall be 4+ feet from travel lane	Likely
Horizontal Alignment	Varies based on design speed and maximum superelevation (see Green Book Table 3-7)	Possible
Superelevation	Maximum of 6 to 12 %, should consider maximum of 6 to 8 % where snow and ice are a concern	Possible
Vertical alignment	Varies based on several elements (see Green Book Figure 3-43 for sag curves and 3-44 for crest curves)	Never
Grade	Varies 3 to 6% by type of terrain and design speed (See Green Book Table 8-1)	Never
Stopping Sight Distance	Varies based on design speed and grade (See Green Book Table 3-1 and 3-2)	Possibly
Cross slope	Green Book – 1.5 to 2 % Interstate Standards – Shall be 1.5% minimum, desirably 2%, may be 2.5% in areas of intense rainfall. Shoulder slopes should be in range of 2 to 6 %	Possibly

Continuation

Controlling Criteria	Minimum AASHTO Values[37, 38, 39]	Affected by Part-time shoulder use
Vertical clearance	Green Book – Shall be 16+ feet over lanes and shoulders in rural areas and at least a single freeway route through highly developed urban areas, shall be 14+ feet on other highly developed urban freeway routes Interstate Standards – Shall be 16+ feet over lanes and shoulders in rural areas and at least a single Interstate through urban areas, shall be 14+ feet on other urban Interstate routes	Possibly
Lateral offset to obstruction	Green Book – refers to AASHTO Roadside Design Guide, which specifies a minimum width of 1.5 feet. Interstate Standards – Shall be consistent with shoulder width requirements	Likely
Structural capacity	Green Book – Minimum HL 93 design loading structural capacity Interstate Standards – New bridges – HS 20, existing bridges – assess operating rating capacity for additional 20 year service life	Unlikely

Discussion of how part-time shoulder use may affect these minimum values is presented in the following sections. Minnesota has developed state standards for bus-on-shoulder (BOS); these standards have been used by other states with BOS operation and they are presented in the following sections as well.[40]

Design Speed

The selected design speed influences several geometric design criteria. The implementation of part-time shoulder use does not inherently change the design speed of the overall freeway facility. A lane designated for part-time shoulder use may have dimensions that are slightly below the minimum values set by the design speed (some of which may require a design exception), and the design speed could be reduced. This is rare and would occur in a situation such as a road with existing horizontal curves at the minimum radius and the shoulder having a radius that is 10 to 12 feet less than the minimum.

Lanes designated for static and dynamic part-time shoulder use typically have the same speed limit as the rest of the facility on which they are located. If the shoulder is assigned a lower speed limit, or the shoulder is only open to traffic when facility operating speeds fall below posted speeds, then adjustments to selected design values may be acceptable. A variable speed limit could also be used to maintain the existing speed limit when the shoulder is closed and to lower the speed limit when the shoulder lane is open. Minnesota and some other states limit the speed of buses travelling in BOS lanes to 35 mph, and MnDOT has adopted 35 mph as the design speed of BOS lanes.

Lane Width

A shoulder width of 12 or more feet is generally preferred for part-time shoulder use. A 12-foot shoulder creates a “shoulder lane” that is the same width as a typical general purpose lane. This dimension refers to the distance from the general purpose lane edge line to the edge of pavement. A second edge line is sometimes added near the edge of pavement to guide drivers on the shoulder and increase the delineation of the edge of pavement; however, pavement on both sides of a second edge line constitutes part of the shoulder. Research summarized in Chapter 3 of this guide has shown drivers are more likely to use 12-foot shoulders than narrower shoulders.

Shoulders less than 12 feet wide may be adequate for shoulder use depending upon the type of vehicles using the shoulder when it is open and depending on the availability of lateral offset to obstructions beyond the edge of pavement. If trucks are prohibited from using the shoulder, then shoulder widths as narrow as 10 feet may be adequate. Shoulders less than 10 feet wide are not recommended for part-time shoulder use.

A 10-foot shoulder may be inadequate if the lateral offset to obstructions is less than 1.5 feet or a high volume of larger vehicles, such as buses, is anticipated. Opening the shoulder only when congestion is present and reducing the speed limit when the shoulder is open are likely to improve the safety of a narrow shoulder during part-time shoulder use.

Minnesota standards for BOS specify a minimum “shoulder lane” width of 10.0 feet and a minimum total shoulder width of 12.0 feet (implying a two-foot paved area between the second edge lane and edge of pavement). A lane width of 12.0 feet is required “in areas of new construction or reconstruction”. Massachusetts design criteria specify a width of 11 feet for “shoulder lanes” and also require a one- to two-foot paved area beyond the travelled portion of the shoulder (implying a minimum total shoulder width of 12-13 feet).(41)

Shoulder Width

Designating the paved freeway shoulder for part-time travel use will typically require a design exception since there will typically be little or no untraveled shoulder beyond the portion of the shoulder used for part-time travel, and this will not meet the minimum width requirements.

Bridge Width

Many bridges have narrower shoulders than the approach roadways. The minimum width of a shoulder on a bridge that should be used as a travel lane is 11.5 feet. This dimension enables vehicles to remain 1.5 feet from the bridge rail and still have 10 feet of shoulder on which to maneuver. It is not necessary for the shoulder to be the same width on a bridge as on the approaching roadway, however, it does need to be 11.5 or more feet wide. Design exceptions may be needed for the narrow lane width.

Minnesota standards for BOS lanes specify a minimum bridge [shoulder] width of 11.5 feet and a desirable bridge [shoulder] width of 12.0 feet. A width of 12.0 feet is required “in areas of new construction or reconstruction”. These standards effectively maintain a 10.0 foot shoulder lane and a 1.5-foot paved lateral offset to the bridge rail, which is consistent with MnDOT's BOS design standards.

Horizontal Alignment

A shoulder on the inside of a horizontal curve will have a smaller radius than the adjacent general purpose lane. However, the difference in radii is small, and it is unlikely to result in a radius below AASHTO minimum values. If AASHTO minimum values are not met, then a design exception could be obtained. In practice, states have not reported issues with horizontal curvature when implementing part-time shoulder use.

Superelevation

Through horizontal curves, the superelevation of shoulders may differ from the superelevation of adjacent general purpose lanes to facilitate drainage. In some cases, there may be a cross slope break on the shoulder, or the entire shoulder may be superelevated in the opposite direction of general purpose lanes to direct water to inlets. In practice, states have reported issues with this on left shoulders with concrete median barriers. Roadways designated for part-time shoulder use should not have superelevation breaks and shoulders on these roads should generally have the same superelevation as adjacent general purpose lanes. Small superelevation differences of 2% or less may be acceptable, with the break occurring on the edge line between the shoulder and general purpose lanes.

Stopping Sight Distance

On the inside of horizontal curves, traffic using the shoulder will be closer to guardrails or barriers if they are present. This may reduce sight distance, and it may reduce it below AASHTO minimum design values. If this occurs, it may be appropriate to relocate the barrier causing the sight distance obstruction or obtain a design exception. Minnesota addresses this issue by basing SSD of BOS lanes on 35 mph, the maximum speed at which buses are permitted to operate.

Cross Slope

Cross slopes on shoulders are sometimes greater than adjacent general purpose lanes to facilitate drainage, creating two potential issues. First, the algebraic difference between the shoulder and the adjacent travel lane may be too abrupt to safely accommodate vehicles transitioning between them. If it exceeds seven to eight percent, then an agency should consider rounding the grade break or prohibiting lane changes to and from the shoulder in the affected area.[(42)] Prohibiting movement between the shoulder and general purpose lanes would be most effective for BOS operation, with a small number of professional drivers needing to obey the restriction. Second, regardless of algebraic difference, if shoulder cross slopes are greater than the travel lane values in Table 11, then it is necessary to reduce shoulder cross slope by adding pavement on top of existing pavement to modify the cross slope or obtaining a design exception. If existing or modified cross slopes and the current drainage system create ponding on the shoulder and there is no feasible means of addressing it, then the freeway is a good candidate for dynamic part-time shoulder use that can be closed during and after heavy rainfall or snowmelt.

Vertical Clearance

As shown in Table 11, AASHTO vertical clearance requirements are the same for travel lanes and shoulders. However, many bridges have lower clearances over shoulders because they pre-date current AASHTO policies or previously obtained design exceptions. In these cases, it is still necessary to ensure there is adequate vertical clearance for vehicles using the shoulder.

Part-time shoulder use generally prohibits trucks, which effectively eliminates the tallest vehicles from using the shoulder. During the preliminary engineering stage, a state DOT's permitting group can typically provide information on the vertical clearance of bridges because they maintain an inventory for the purpose of providing permits for oversize/overweight trucks. Prior to implementing part-time shoulder use, agencies typically field measure the height of bridges along a route, and any substandard vertical clearances dictate additional vehicle restrictions beyond trucks.

Lateral Offset to Obstruction

Lateral offset to obstruction, called horizontal clearance in previous editions of the Green Book, is the distance from the edge of the traveled way to the nearest physical obstruction such as a median barrier, guard rail, bridge support, or bridge rail. The minimum width of 1.5 feet is automatically met on a full-standard freeway because minimum shoulder widths are greater than 1.5 feet. However, the lateral offset between the edge of a shoulder and an obstruction may be less than 1.5 feet. In this case, it is necessary to move the obstruction or obtain a design exception.

In practice, states have relocated guardrails and other obstructions (sign and lighting structures), and obtained design exceptions for segments adjacent to bridge rails/barriers and abutments, or other concrete barrier, where less than 1.5 feet or lateral offset is available.

Other Criteria

Vertical alignment, grade, and structural capacity are unlikely to be affected by part-time shoulder use.

Ramp Freeway Junctions

Ramp-freeway junctions are the locations at which ramps merge with and diverge from the mainline freeway. The types of ramps and their specific geometric characteristics will influence the details of part-time shoulder use design in these areas. This, in turn, influences the overall quality of operation, including the capacities of ramps and the shoulder lane.

One-lane Ramps

Part-time shoulder use is generally compatible with one-lane ramps. Typical designs for the two basic types of ramp-freeway junctions—parallel and taper—are shown in the sections below.

Parallel Ramps: With parallel entrances and exits, entering and exiting traffic drives on a short speed change lane beside the outermost freeway lane (for right-side ramps) for several hundred feet before an exit gore or after an entrance gore. The speed change lane is essentially a striped portion of the shoulder.

When part-time shoulder use is added to a facility with parallel ramps and open to traffic, the shoulder lane can tie into the existing speed change lanes. This effectively converts the parallel ramp into a taper ramp during the hours the facility is open. Figure 27 shows the path of ramp traffic on a parallel-style on-ramp. If the shoulder lane is closed, ramp traffic uses speed change lane and then maneuvers to the adjacent general purpose lane, as shown with shading in Figure 27. If the shoulder lane is open, the speed change lane is part of the shoulder lane and on-ramp traffic no longer has an unimpeded path onto it. The ramp is effectively converted to a taper-style. At the end of speed change lane, on-ramp drivers may maneuver into the adjacent general purpose lane or continue straight into the shoulder lane. Similar changes occur at parallel-style off-ramps, as shown in Figure 28.

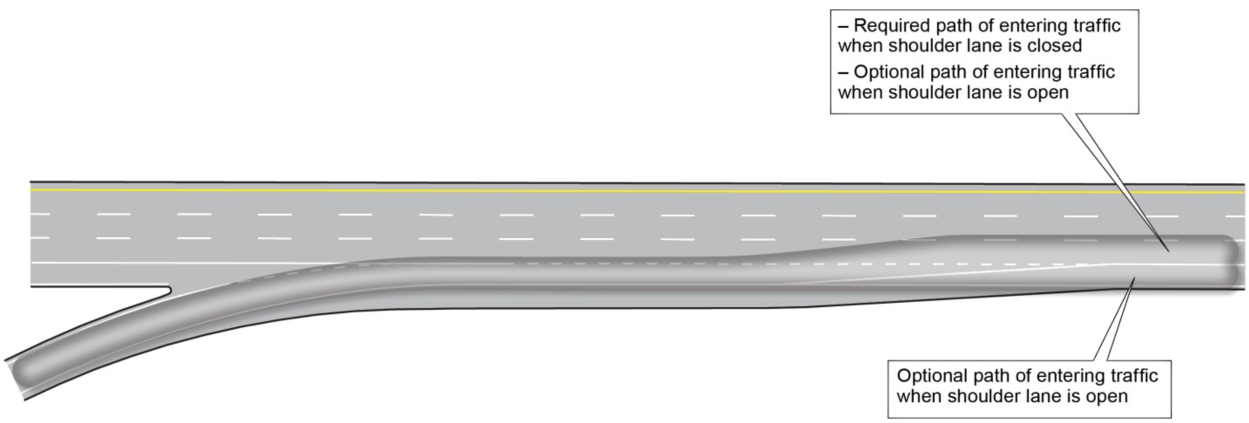


Figure 27. Illustration. Path of parallel-style on-ramp traffic with part-time shoulder use.

(Source: Kittelson)

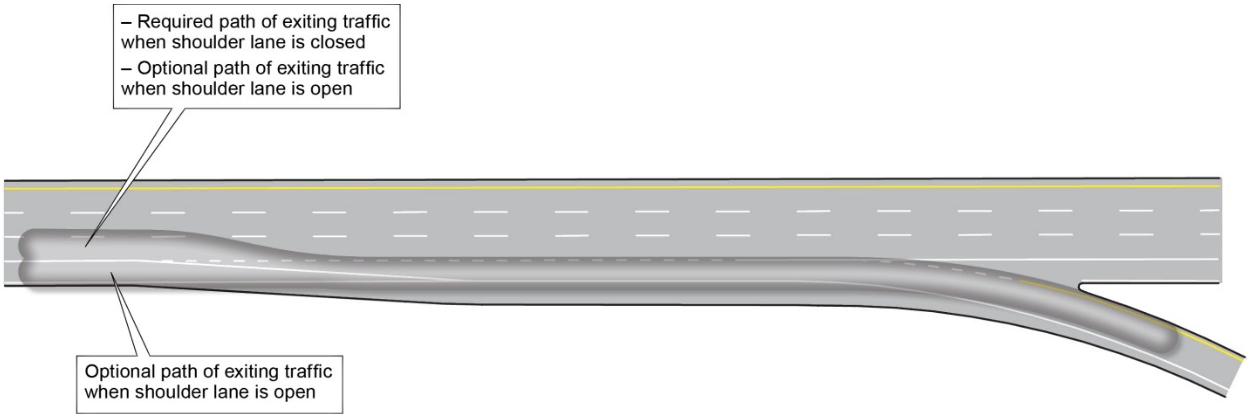


Figure 28. Illustration. Path of parallel-style off-ramp traffic with part-time shoulder use.

(Source: Kittelson)

The operational effects of a part-time conversion of a parallel-style ramp to a taper-style ramp vary based on the geometric characteristics of the ramp and gore area. For example, a gore with a relatively large convergence angle will result in a short maneuver area at the end of an on-ramp when the shoulder lane is open, likely reducing capacity of the on-ramp and shoulder lane. A gore with a relatively small convergence angle will result in a longer maneuver area and have lesser impacts on capacity. This is shown in Figure 29 and Figure 30.

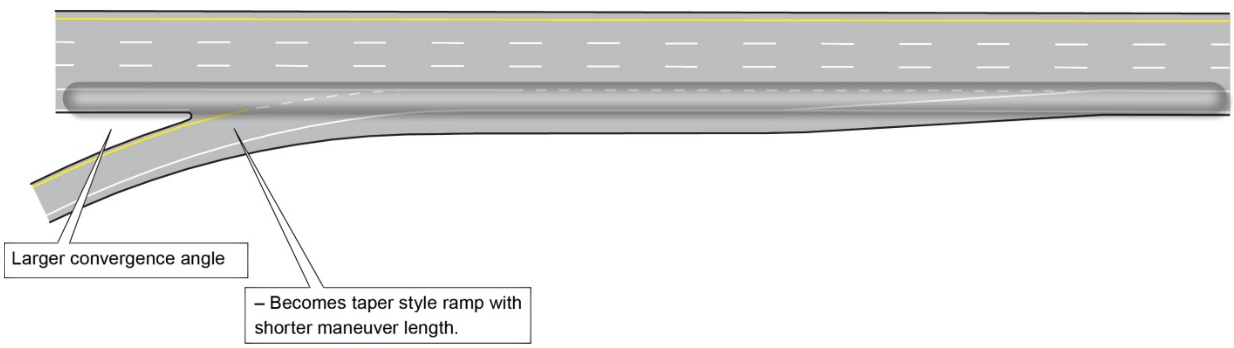


Figure 29. Illustration. Parallel-style ramp with large convergence angle. Shoulder lane shaded.

(Source: Kittelson)

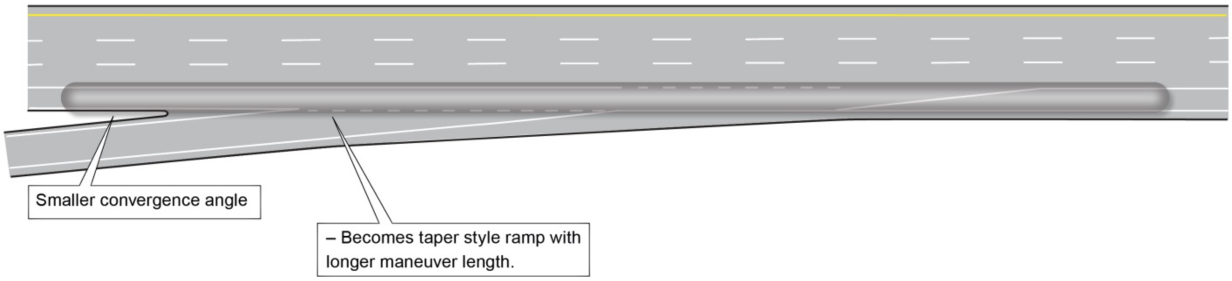


Figure 30. Illustration. Parallel-style ramp with small convergence angle. Shoulder lane shaded.

(Source: Kittelson)

Taper Ramps: Taper-style ramps do not have speed change lanes, and ramp traffic effectively "crosses" the shoulder in a single maneuver. If a shoulder was opened to traffic and this configuration was kept in place, it would result in a conflict between shoulder lane traffic and ramp traffic, as shown for an off-ramp in Figure 31.

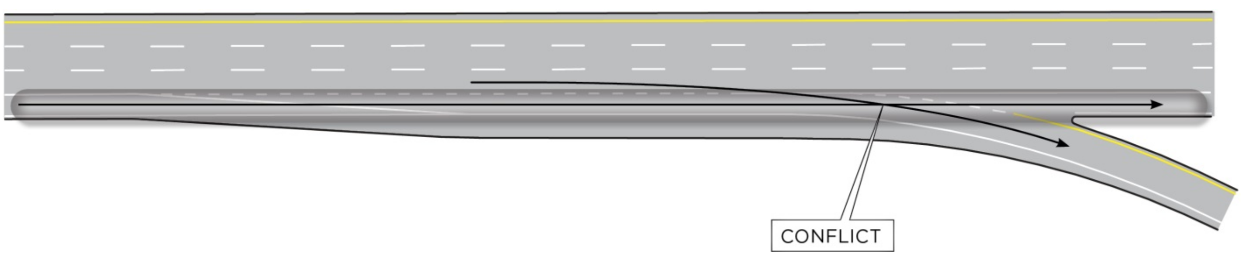


Figure 31. Illustration. Conflict between ramp and shoulder traffic with taper-style ramp. Shoulder lane shaded.

(Source: Kittelson)

To remove the conflict, the ramp should be converted into a parallel-style ramp with a speed-change lane. For an off-ramp, exiting traffic will maneuver onto the combined speed-change lane/shoulder lane prior to the exit as shown in Figure 32. Implementing shoulder use will already require that the shoulder be physically capable of carrying traffic, so the addition of the speed-change lane will typically require only pavement marking changes.

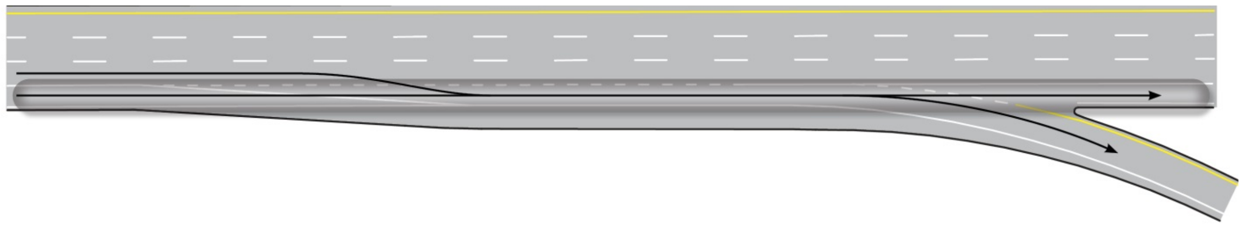


Figure 32. Illustration. Conversion of taper-style ramp to parallel-style ramp to remove conflict between ramp and shoulder traffic. Shoulder lane shaded.

(Source: Kittelson)

Two-lane Ramps

Design of shoulder lanes through two-lane ramps is more complex than one-lane ramps, and some types of two-lane ramps are not compatible with shoulder use without major modifications.

Parallel ramps: A parallel-style two-lane on-ramp has two speed-change lanes downstream of the entry gore that receive ramp traffic. Typically, they are different lengths, with the outer lane terminating before the inner lane. With shoulder use, the inner speed change lane will become part of the shoulder lane, as shown in Figure 33. When the shoulder lane is open, this will effectively create a taper-style two-lane on-ramp with an inside merge. Inside merges reduce ramp capacity and should be used with caution because they may be unexpected to drivers. They are most appropriate to use at locations where ramp and freeway drivers have good visibility to the gore and adequate time to prepare for the merge.

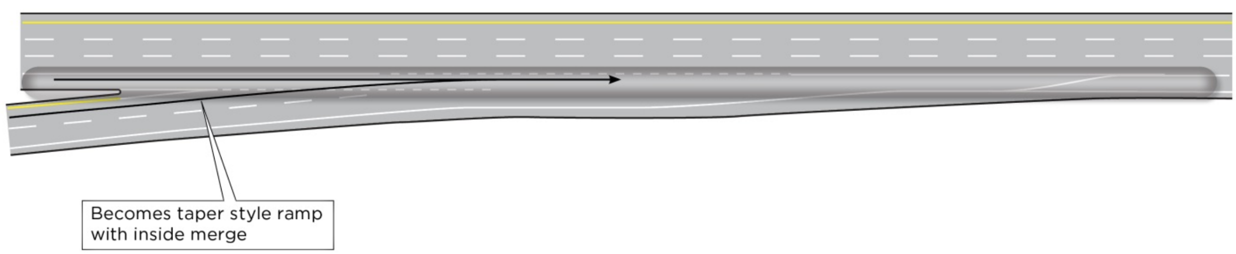


Figure 33. Illustration. Creation of inside merge with parallel-style two-lane on-ramp. Shoulder lane shaded.

(Source: Kittelson)

Design of a shoulder lane through a parallel-style off-ramp is similar to the design of the on-ramp shown in Figure 35. There are generally no issues associated with the loss of the inside speed-change lane when the shoulder lane is open and the creation of an "inside diverge".

Taper ramps: A taper-style two-lane on-ramp typically has an inside merge, and shoulder use will create a conflict between shoulder lane traffic and inside lane ramp traffic as shown in Figure 34. A similar conflict exists with taper-style two-lane off-ramps. Removal of this conflict is more complex than with single-lane ramp, and would typically involve adding a second speed-change lane downstream of the entry gore. In these cases, consideration should also be given to terminating the shoulder lane project upstream or downstream of the two-lane ramp, reducing the ramp to a single lane, or implementing junction control to vary the lane configuration in response to traffic conditions.

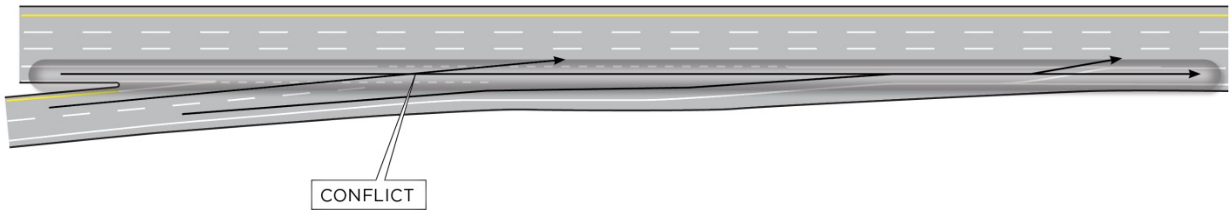


Figure 34. Illustration. Conflict between ramp and shoulder traffic with two-lane taper-style ramp with inside merge. Shoulder lane shaded.

(Source: Kittelson)

Turnout Placement/Design

Based on experience in Massachusetts, Virginia, and the UK, refuge spaces for disabled vehicles should be located approximately every half-mile along a facility with static or dynamic shoulder use.[(2)] At this distance, a vehicle in the process of breaking down is generally able to reach the refuge.

Sometimes, gore areas or ramp shoulders at entrances and exits provide a refuge space large enough to store a vehicle. When this is not the case or when ramp spacing exceeds a half-mile, emergency turnouts should be constructed. Turnouts should be long enough and wide enough that a vehicle with poor control and in the process of breaking down can enter it and be out of the shoulder lane. They should also be long enough to enable a tow truck to park and load a broken down vehicle. Turnouts should be a minimum of 16 feet wide to provide separation between a broken down vehicle and moving traffic in the shoulder, and additional width is desirable. Massachusetts uses turnouts that are 16 feet wide, 110 feet long, and have 300-foot tapers.[(41)] Virginia’s turnouts are approximately the same width and have approximately the same taper length, but are several times longer than 110 feet. Virginia does not limit turnout lengths to a maximum distance, and paves existing flat areas along the roadside, if present, to increase turnout length. The UK uses shorter tapers, approximately 80 feet for the entrance and 150 feet for the exit.[(2)]

Turnouts should be used exclusively as refuge areas for disabled vehicles, and not for other purposes such as overnight truck park. States have not reported issues with this, but if they occur they should be addressed quickly with signing and law enforcement.

If turnouts cannot be constructed, such as on bridge or other constrained areas, then part-time shoulder use can still be implemented, but there is a greater probability the shoulder will be blocked by disabled vehicles. Dynamic lane control signs should be given greater consideration on these facilities to enable closure of the shoulder in response to a disabled vehicle. Turnouts have fewer benefits and are generally not constructed on BOS facilities because buses can reenter a general purpose lane to pass a disabled vehicle without greatly affecting traffic flow on the freeway or bus travel time. Figure 35 and Figure 36 show turnouts from the UK and Massachusetts, respectively.

Figure 35. Photo. Emergency Turnout, UK.

(Source: FHWA ATM Screening Guidelines)

Figure 36. Photo. Emergency Turnout, Georgia.

(Source: Georgia Department of Transportation)

Arterial Part-Time Shoulder Use

There are few unique design considerations for part-time shoulder use on arterials. Arterials, particularly those in urban and suburban areas with recurring congestion, are less likely to have shoulders that are wide enough to be used as travel lanes, and increasing the shoulder width may be less feasible than on a freeway due to the potential presence of curb and gutter, roadside objects, or right-of-way constraints.

All known arterial part-time shoulder use in the U.S. to date have been BOS. Similar to freeways, arterial shoulder lane widths of 10 or 11 feet are adequate on an open section for a low volume of buses at lower, congested speeds and a 12-foot shoulder lane is desirable. A 10-foot lane should not be used if the lateral offset to obstructions is less than the 1.5-foot AASHTO standard or if curbs are present. If curbs are present, then vehicles should be able to remain entirely in the shoulder and maintain a 1.5-foot separation between right side tires and the face of curb.

Examples of signing and pavement marking treatments to accommodate right-turn lanes are shown later in this chapter.

PAVEMENT DESIGN

Part-time shoulder use places vehicles on a portion of the roadway that was not necessarily designed to carry through traffic instead of an occasional stopped vehicle, and an agency should assess shoulder pavement conditions prior to implementing part-time shoulder use. The first step in assessing the adequacy of existing pavement is to estimate the volume and type of vehicles that will use the shoulder. Part-time shoulder use is typically limited to certain hours of the day, reducing volume compared to adjacent general purpose lanes. Shoulders open only to passenger cars will result in only lighter vehicles using the shoulder, while shoulders open to buses will result in heavy vehicles using the shoulder. Bus volumes are relatively straightforward to estimate using known service schedules and expected hours of operation for the shoulder. Structural pavement needs for buses are related to the passenger load, and fully-loaded buses may have as much effect on pavement as a truck. The second step is to conduct a review of the existing shoulder pavement structural section and field assessment of pavement conditions to determine if the available pavement is adequate or if improvements are needed.

If part-time shoulder use is intended to be temporary, such as until a widening project occurs or during construction on an adjacent route, then an agency may find it more economical to routinely conduct maintenance on a shoulder with pavement in poor condition rather than rebuild the shoulder. This strategy is less viable for longer-term part-time shoulder use.(42)

Rumble strips, if used, are typically placed in a position where the tires of a vehicle traveling on the shoulder would track over them. It will generally be necessary to remove existing rumble strips areas prior to implementing part-time shoulder use by milling and resurfacing, and relocate them if they are still desired. MnDOT reinstalled rumble strips on some freeways with BOS operation and placed them on the edge line or in the middle of the shoulder such that buses straddle them.(30)

Minnesota's experience is that BOS operation typically does not damage shoulder pavement. As of 2007, only one shoulder replacement in Minnesota was due to BOS operation, although others had been repaved, reinforced, or widened. Minnesota now requires a shoulder pavement depth of seven inches for BOS operation. Buses are limited to 35 mph on shoulders in Minnesota to minimize the speed differential with general purpose lanes, and Minnesota reports this also reduces wear and tear on pavement compared to higher speed operation.[(42)] More generally, the effects of bus speed on pavement wear and tear may vary depending on pavement type and condition.

DRAINAGE DESIGN

Like pavement condition, existing drainage conditions and facilities will need to be assessed prior to implementing part-time shoulder use. On open, uncurbed roadway sections it is unlikely drainage modifications would be needed prior to part-time shoulder uses. On closed section roadways with curb and gutter or other structures such as retaining walls or concrete median barriers that prevent water from running off the road, there are several issues that may be encountered.

Catch basins located in the shoulder not only create potential safety issues and are uncomfortable to drive over, but most are not designed to handle a high volume of traffic driving over them. Minnesota encountered both of these issues after implementing BOS operation, and in response developed a catch basin design specifically for BOS operation.[(42)] The design brings the inlet flush with pavement and reinforces it with a concrete apron. Massachusetts moved inlets to the edge of pavement,[(2)] and Virginia relocated inlets on the BOS portion of I-66 that began operation in 2015.[(43)]

Some portions of a shoulder may have depressed areas to direct water towards catch basins or drainage channels (on open sections). These sections may be uncomfortable to drive over and require resurfacing and relocation of the associated drainage features to provide a smooth ride.

Finally, ponding may occur on shoulders unintentionally (due to pavement imperfections or rutting of pavement[(42)]) or intentionally due to a design that stores water from a design rainfall on the shoulder. In most climates, these issues should be corrected by improving pavement or adding drainage structures prior to implementing part-time shoulder uses, especially part-time shoulder use by passenger cars. San Diego, which is located in a dry climate, had a BOS pilot project in the mid-2000s that did not improve the pavement, but instead did not allow use of the part-time shoulder use during heavy rain.

In general, many drainage issues associated with part-time shoulder use are most likely to occur on arterials or older freeways. Freeways built in recent decades are less likely to have curbs, catch basins on shoulders, or other unusual drainage features that would require modification.

TRAFFIC CONTROL DEVICE DESIGN

Signing and pavement marking needs vary greatly depending on type of part-time shoulder use. BOS, at one end of the spectrum, is typically implemented as unobtrusively as possible with minimal signing and no pavement marking. Extensive signing and pavement marking is detrimental to overall BOS operation because it leads some passenger car drivers to believe the shoulder is also open to them. Dynamic part-time shoulder use, at the other end of the spectrum, requires changeable signs to notify drivers when the shoulder is open. Static part-time shoulder use has been successfully implemented and operated for decades with static signs, but dynamic signs are becoming increasingly common on these facilities and have been added to several established part-time shoulder use facilities that previously had only static signs to give a higher degree of acknowledgement to drivers of the current operating condition on the shoulder.

This section presents best practices for signing and pavement marking of part-time shoulder use, based on what states have done to date. The Manual on Uniform Traffic Control Devices (MUTCD) does not contain signs or pavement markings specifically intended for roadways with part-time shoulder use, but the principles of the MUTCD can be used to guide the development of such signs and pavement markings.

Bus on Shoulder

Signing and pavement marking needs for BOS facilities are minimal. States such as Minnesota and Virginia that have implemented BOS operation on multiple roadways at different times have determined fewer signs than initially anticipated are needed for BOS operation.[43, 44] Later implementations within these states have used fewer signs than the initial implementations. Limiting signing and pavement marking helps to make BOS operation inconspicuous and reduces the likelihood of the general public believing that they may use the shoulder.[45] TCRP Report 151 provides additional details on signs and pavement markings for BOS facilities. [42]

Signing

Signing on roadways with BOS operation is generally limited to static, ground mounted signs. Most agencies have used black on white, rectangular regulatory signs similar to the R3-10 through R3-12 series of preferential-only lane signs in the MUTCD. Such signs should be installed along a roadway with BOS operation at regular intervals (Minnesota uses one mile spacing) and near on- and off-ramps. They may be supplemented with “begin” and “end” banner plaques at the beginning and end of segments where part-time shoulder use is permitted. Most agencies with BOS operation allow buses to use the shoulder in response to traffic conditions rather than limiting use to certain times of day, so there is typically no need for signs specifying hours of operation. Minnesota experimented with several signs before settling on the sign shown in Figure 37. The word “authorized” is often used for BOS regulatory signs because part-time shoulder use is typically limited to certain transit agencies and/or certain bus drivers who have undergone training.

Figure 37. Photo. MnDOT, regulatory sign for Bus-on-shoulder operation.

(Source: Minnesota Department of Transportation)[42]

Along a route, buses sometimes must merge back into a travel lane to avoid a narrow section of shoulder, often on or beneath a bridge. Black on yellow warning signs should be used if this is necessary.

Along on-ramps, some agencies use a "watch for buses on shoulder" warning sign prior to the merge point. On arterials with BOS operation, some agencies use supplemental plaques on stop signs and yield signs on cross streets stating "stop for buses on shoulder" or "yield to buses on shoulder". Use of warning signs on freeway on-ramps and arterial cross streets is recommended for BOS facilities. Additionally, when a portion of an arterial shoulder is striped as a right-turn lane, a warning sign or a regulatory sign instructing buses to yield to right turn traffic should be considered.

Pavement Marking

BOS operation can be implemented on many freeways with no additional pavement markings being added. Since the mid-1990s, Minnesota has not used any special pavement marking for BOS operation.

The 2009 MUTCD limits use of diamond pavement marking symbols to high-occupancy vehicle (HOV) lanes, and they should not be used on shoulders open only to buses. Previous editions of the MUTCD allowed diamond pavement markings on other types of managed lanes. Minnesota installed diamond pavement marking symbols on shoulders open only to buses in the early 1990s, but removed them because some passenger car drivers believed they indicated the shoulder was open to HOVs and began to use the shoulder as a lane. Word pavement markings such as "bus only", "transit buses only", and "transit only" may be placed on the shoulder.

Arterials with BOS operation have greater pavement marking needs than freeways due to bus stops, side streets and driveways, right turn lanes, and other elements of access not present on freeways. Access may also increase the probability of a driver incorrectly believing the shoulder is open to general traffic. Arterial BOS operation is less common than freeway BOS operation, with the majority of US facilities located in Washington State, New Jersey, and Minnesota. Pavement marking needs on BOS arterials is highly facility-specific, and examples from Washington State and New Jersey are highlighted in the Appendix.

Static Part-time Shoulder Use

Signing and pavement marking needs are greater with static part-time shoulder use than with BOS operation because the shoulder is open to the general public. Some static part-time shoulder use facilities utilize dynamic signs, and others have successfully operated with static signs. Signing and pavement marking of static part-time shoulder use is typically supplemented with some degree of ITS, although sometimes ITS is only used to deliver information to facility operators and not drivers. ITS is covered later in this chapter.

Signing

The key signing needs of a static part-time shoulder use facility are to notify drivers that the shoulder is sometimes used as a lane, and to provide the specific times the shoulder is open. Both needs can be met with static signs. However, dynamic signs offer two primary advantages over static signs. First, they can use words or symbols such as a green arrow or red ‘x’ to communicate whether or not the shoulder is open. This reduces the workload on drivers, who otherwise have to read a schedule on a sign, determine the current day and time, and then determine whether or not the shoulder is open. Second, dynamic signs allow facility operators to open or close the shoulder outside of scheduled hours. It is occasionally desirable to do this with a shoulder that is otherwise static in event of disabled vehicles on the shoulder, planned special events generating off-peak traffic, closures of some general purpose lanes for construction or maintenance, or inclement weather. If the project timeline and budget can accommodate dynamic signs, then they should be strongly considered due to the reduction in driver workload, reduced potential for lane status confusion, and flexibility to modify hours of operation.

There are several factors to consider when choosing between static and dynamic signs for a new static part-time shoulder use installation:

- Who uses the roadway? Is it primarily a commuter route or long distance travel route?
- How complex is the part-time shoulder use segment? Are there system interchanges, other managed lanes, or features creating high driver workload?
- How familiar are drivers with part-time shoulder use? Is it the first installation in the region, or are there others?
- How quickly does the project need to be implemented? Is there time to install dynamic signs and communication to them?
- What is the cost of dynamic signs?

Primary static signs regulating part-time shoulder use, or the static portions of the dynamic signs, should be black on white. They may be supplemented with black-on-yellow warning signs.

Signs—static or dynamic—should be provided at the following locations:

- At the start of the part-time shoulder use
- At exit ramps, to manage the conflict of exiting traffic from permanent lanes and through traffic in shoulder lanes
- At and on entrance ramps:
    - To notify entering drivers that the shoulder may be used as travel lane
    - To manage the conflict between entering traffic and through traffic in shoulder lanes
- At recurring intervals between interchanges
- At the end of the part-time shoulder use

Table 12 lists current static part-time shoulder use facilities in the U.S. and the type of signing used. Georgia plans to convert static signs on GA 400 to dynamic signs and is planning a second set of part-time shoulder use facilities that will initially have dynamic signs. Massachusetts used static signs on their part-time shoulder use facilities for nearly 25 years before adding small dynamic panels to them. Images of signs on the facilities listed in Table 12 are included in Appendix C.

Table 12. Signing of static part-time shoulder use in US.

State	Facility	Type of Signing
CO	I-70	Overhead dynamic
GA	GA 400	Ground-mounted static (planning conversion to dynamic)
HI	I-H-1	Ground-mounted static (Overhead dynamic signs on facility for adjacent reversible lane but not shoulder lane)
MA	MA 3, I-93, I-95	Ground-mounted static with dynamic panels
NJ	NJ 29, NJTPK NBE	SR 29: ground-mounted static and portable dynamic, NJTPK NBE: overhead dynamic
TX	TX 161	Overhead dynamic
VA	I-66, I-264	Overhead dynamic and ground-mounted static
WA	US 2	Overhead and ground-mounted static

NJTPK NBE – New Jersey Turnpike Newark Bay Extension

Similar to exit ramps on a freeway, a series of signs provided in advance of a turnout and at the turnout itself is recommended to increase driver awareness of its existence. In 2007, Virginia modified turnout signing on I-66 from one small sign at the turnout itself to a sequence of typical freeway size signs, and this change has led to increased use of turnouts.[(43)] Turnouts can be signed with black on white regulatory signs (generally consistent with other signs related to part-time shoulder uses) or green guidance signs (consistent with exits). Preference will likely be determined in the next edition of the MUTCD.

Pavement Marking

Pavement markings for static part-time shoulder use should provide effective guidance to drivers when the shoulder is both open and closed to traffic. On basic segments away from ramps, this is straightforward and there is consistency across states:

- The solid edge line typically used between the shoulder and adjacent travel lane remains in place.
- A second solid line is used on the outside of the shoulder beside the edge of pavement. This line functions as an edge line for traffic using the shoulder. The second solid line should be continuous even when the shoulder narrows or has a physical barrier beside it, such as a bridge rail.
- The two solid lines should be the same color—white for part-time use of the right shoulder and yellow for part-time use of the left shoulder.

Pavement markings at the start and end of part-time shoulder use segments and through ramp freeway junctions were discussed in the Geometric Design section of this chapter. Pavement markings at on- and off-ramps are more complex, and example markings were previously shown in Figure 27 through Figure 34. They vary based on the types of entrance and exit configurations described in the geometric design section of this chapter, and existing state ramp-freeway junction marking practices. In general, pavement markings in the vicinity of a ramp-freeway junction should provide a clear means for drivers on the mainline shoulder to pass through the ramp freeway junction, and they should also provide a means to transfer from the freeway to ramp or vise verse. Striping can create parallel or taper style merges and diverges.

Colored Pavement

The Section 3G of the 2009 MUTCD and an interpretation letter specify the use of colored pavements for the following situations:

- Yellow pavement for median islands separating traffic flows in opposite directions or left shoulders of divided highways or one-way streets or ramps[5]
- White pavement for channelizing islands or right-hand shoulders[5]
- Green pavement for bicycle lanes[6]
- Red pavement for streetcar and/or bus-only lanes on an experimental basis[6]

No color is designed for part-time shoulder use, and none should be used at this time unless a request to experiment is submitted to and approved by the MUTCD team.

Dynamic Part-Time Shoulder Use

Dynamic part-time shoulder use requires dynamic signs to communicate whether or not the shoulder is open to traffic. Pavement marking needs for dynamic part-time shoulder use is no different than static part-time shoulder use. In both cases, pavement markings need to provide sufficient guidance to drivers when the shoulder is open and when it is closed.

ITS DESIGN

Most part-time shoulder use facilities are accompanied by ITS, and dynamic part-time shoulder use requires it. ITS includes:

- Speed sensors and cameras to help agencies monitor and manage the facility in real time
- Electronic lane control signs (LCS)
- Changeable message signs (CMS)
- Driver information ITS treatments to communicate information such as when the shoulder is open to traffic
- Regulatory and warning signs that must be turned on and off as the shoulder opens and closes

The 2006 FHWA scanning tour of ATM systems in Europe identified several recommendations for active traffic management strategies on facilities with part-time shoulder use:(46)

- Changeable message signs to provide guide sign information and regulatory signs to adapt to the addition of the shoulder as a travel lane. The signing should be uniform, with adequate installation of sign gantries to provide operational information and to ensure it is in sight at all times.
- Closed-circuit television cameras with sufficient coverage to verify the clearance of the shoulder before deployment.
- Comprehensive incident management program, including advanced incident detection capabilities.

This section addresses the potential ITS design treatments and associated issues.

Signs

Lane-Use Control Signals for Shoulder Use

Dynamic part-time shoulder use requires electronic lane-use control signals (LCS) to display whether the shoulder is opened or closed to traffic or, optionally, transitioning from being open to closed Static part-time shoulder use facilities can benefit from LCS as well, as they allow occasional deviation from operating hours due to disabled vehicles, off-peak special events, or other nonrecurring events.

The MUTCD (Section 4M.02 – Meaning of Lane Use-Control Signal Indications) identifies the following displays for lane control:

- A steady DOWNWARD GREEN ARROW signal indication shall mean that a road user is permitted to drive in the lane over which the arrow signal indication is located
- A steady RED X signal indication shall mean that a road user is not permitted to use the lane over which the signal indication is located.

- A steady YELLOW X signal indication shall mean that that a road user is to prepare to vacate the lane over which the signal indication is located because a lane control change is being made to a steady RED X signal indication.

The MUTCD requires lane-use control signals to remain on and not be dark. In general, the YELLOW X has not been used for part-time shoulder use or for the broader dynamic applications. The initial applications of ATM in the United States—Seattle, Washington and Minneapolis, MN—have used other yellow displays. Use of yellow displays other than an X is not consistent with the MUTCD and requires a request for experiment. Additional information on this process is included in CHAPTER 9. An ongoing FHWA study has been evaluating ATM sign displays and to identify potential gaps in the MUTCD in this regard.

Changeable Message Signs

In addition to lane control signs, changeable message signs (CMS) can be used to reinforce the open/closed status of shoulder or provide other information to drivers. High volume, urban freeways on which part-time shoulder use is typically implemented often already have CMS signs.

Dynamic Speed Limits with Part-Time Shoulder Use

Depending on the lane widths (both the shoulder and mainline), the types of vehicles allowed to use shoulder, the possible reduced sight distance around curves (as seen from the part-time shoulder use), the potential for reduced clear zone distances when part-time shoulder use is in operation, and the configurations of the mainline and ramp shoulders in the vicinity and through interchanges, it may be appropriate to reduce the speed limits during part-time shoulder use operation. If a state does not have the legal authority to vary speed limits, legislative changes may be needed so dynamic speed limits can be implemented. Enforcement of dynamic speed limits also presents challenges because the police must be informed in real time of the speed limit and have a record of speed limits used at all times for court purposes.

Mainline Dynamic Lane Assignment and Dynamic Speed Limits

The UK's "Smart Motorway" concept (formerly known as "Managed Motorway") includes the use of dynamic speed limits and dynamic lane assignment (with lane-use control signals) across all lanes, in addition to dynamic part-time shoulder uses. In Europe, dynamic part-time shoulder use is almost always deployed in conjunction with dynamic speed limits and dynamic lane-use control signals for all lanes along with queue warning.

While this has not been the practice to date in the U.S., consideration should be given to this approach if dynamic part-time shoulder use is being installed, particularly along segments experiencing high frequencies of rear-end or side-swipe crashes. Additional information on identifying roadway segments where the application of dynamic speed limits and dynamic lane assignments may be cost effective can be found in the FHWA document *Active Traffic Management (ATM) Feasibility and Screening Guide*.[47]

CMS Spacing – Static Part-time Shoulder Use

States with static part-time shoulder use are increasingly using changeable signs to supplement the static signs regulating the hours of operation of the shoulder lane. This reduces driver workload by clearly communicating whether the shoulder is open or closed, and it provides flexibility to occasionally deviate from normal operating hours. If used, supplemental dynamic signs should be placed at the same locations as static regulatory signs displaying operating hours of the part-time shoulder use. Typically, this is at the start of the part-time shoulder uses segment and after on-ramps.

CMS and LCS Spacing – Dynamic Part-Time Shoulder Use

The effectiveness of any ATM approach requires that drivers recognize and understand they are driving on an actively managed facility. How this "continuum of information" is provided has a significant impact on dynamic part-time shoulder use costs, particularly if other ATM treatments are also provided.

The initial deployments of ATM in the United Kingdom used gantries spanning the entire roadway with LCS displaying speed limits and lane control over each lane—including the shoulder, where applicable. Larger CMS on the side displayed queue warning messages and other information. These gantries were spaced such that drivers could see the next gantry immediately after passing under a gantry, resulting in a gantry spacing of 600 meters (0.37 miles) to 1,000 meters (0.62 miles). The concern was that compliance would be less if gantries were spaced too far apart. The spacing of gantries for the Washington State and Minnesota ATM systems followed suit and are located at roughly 0.5-mile intervals on average. If only part-time shoulder use operation is implemented—with a cantilever sign and LCS over the shoulder—then this approach (sign approximately every 0.5 miles) is appropriate. However, if other ATM treatments such as mainline lane assignment and variable speed limits are deployed, then placing a LCS over every lane requires a gantry structure like the ones in Figure 38, and this significantly increases project cost. In these cases, sign spacing greater than every 0.5 miles may be appropriate.

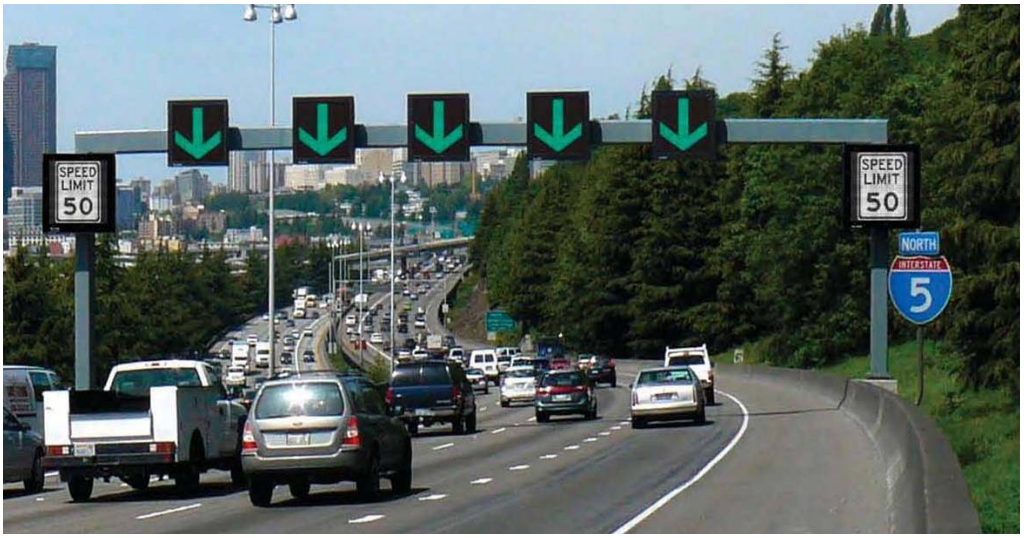


Figure 38. Photo and Illustration. Example of full gantry ATM deployment in Washington State (no part-time shoulder use).

(Source: CH2M)

In the U.K., gantry spacing of 600 to 1000 meters used on early ATM facilities is now considered conservative, and experience indicates that greater gantry spacing may be adequate. The current U.K. philosophy is that spacing needs to be sufficient so that drivers know they are still on a controlled roadway.

Cantilever signs that diagrammatically indicate lane status and gantry signs similar the one in Figure 38 were determined through a driver simulator trial to be comprehended equally well by U.K. drivers. The overall results suggested that cantilever signing is equal to gantry-mounted signing at instructing drivers to move out of a particular lane.

The latest Smart Motorway design concepts from the U.K. Highways Agency for dynamic speed limits, dynamic lane assignment (including shoulders) and queue warning consist of the following:(48)

- Driver information, including speed limits, lane availability and closures, and text legends (e.g., queue warnings) and pictograms is provided at intervals not exceeding 1,500 meters (0.93 mile). This can be provided via gantry or cantilever signs (referred to as “verge-mounted”.
- The first sign display downstream of an on-ramp is a gantry with lane signs (for displaying dynamic speed limit and dynamic lane assignment messages) over each lane and a CMS for other messages of a strategic nature.

Based on the U.K. work, a “hybrid” approach has been developed for planned installations of dynamic part-time shoulder use and other ATM treatments in New Jersey and Pennsylvania consisting of gantries every mile, with cantilever dynamic speed limit signs (located on both sides of the roadway) between each set of gantries.

CCTV and Detection

The aforementioned Smart Motorway design concepts from the UK Highways Agency also calls for full coverage of CCTV equipped with pan, tilt, and zoom. This allows viewing the entire length of the shoulder prior to initiating shoulder operations (i.e., verifying the clearance of the shoulder before deployment) and to identify and verify roadway conditions during incidents and other events. Many static part-time shoulder use facilities in the U.S. are manually inspected by police driving the corridor prior to the opening of the shoulder each day. This approach is less feasible for dynamic part-time shoulder use with varying hours of operation, and full CCTV coverage is recommended for dynamic part-time shoulder use.

With dynamic part-time shoulder use, the software algorithms at a TMC determining when to open and close the shoulder will likely require a high density of detectors, measuring volumes (including the part-time shoulder use) and spot speeds (for each lane including the shoulder) at each gantry/sign location. These data are also used to vary speed limits and provide queue warnings if this is done on the facility.

If there are weather-related concerns about part-time shoulder use, such as ponding of water, buildup of snow and ice, or reduced visibility due to fog, then consideration should also be given to the installation of road weather information sensors to determine the condition of the pavement and air. This information can be used to help determine whether the shoulder should be opened to traffic and to determine appropriate speed displays if variable speed limits are in place.

CHAPTER 8. IMPLEMENTATION PROCESS

This chapter presents "how to" information to help agencies implement part-time shoulder use once a decision to use it has been made. The chapter will also help agencies still in the planning stages understand the steps generally taken to implement part-time shoulder use.

DESIGN EXCEPTION PROCESS

States are required to obtain design exceptions from Federal Highway Administration (FHWA) if the minimum values of the controlling criteria presented in the Geometric Design section of Chapter 7 of this Guide are not met on roadways that are part of the National Highway System. Part-time shoulder use may impact a number of the controlling criteria, and by definition it impacts shoulder width when the shoulder is open. AASHTO standards require a minimum freeway lane width of 12 feet and a minimum freeway shoulder width of 10 feet (except the left shoulder of 4-lane freeways, which has a minimum width of 4 feet). Therefore, unless an existing shoulder is at least 22 feet wide (or 16 feet wide in the case of a left shoulder on a 4-lane freeway), a design exception will be required when static or dynamic part-time shoulder use is implemented. Design exception practices for bus-on-shoulder (BOS) vary.

The key piece of a design exception request is an explanation of why it is infeasible to meet AASHTO standards. Meeting standards on part-time shoulder use is equivalent to conventional widening, and part-time shoulder use is likely being considered because conventional widening is infeasible in terms of cost or right-of-way (ROW) requirements.

Design exception requests should also include an evaluation of the implications of substandard features and how they are mitigated on a specific facility. In the case of part-time shoulder use, the following may mitigate substandard geometry:

- Reduced speeds, achieved through lower speed limits of periods of shoulder operation coinciding with congestion.
- Annual average daily traffic (AADT) in ranges where Highway Safety Manual (HSM) analysis, summarized in CHAPTER 4, predicts a reduction in crashes with narrowing of the shoulder and addition of a lane.
- Use on commuter facilities during commuting periods with a high percentage of familiar drivers.
- Prohibition of trucks from the shoulder.
- Extensive monitoring of the facility with ITS and/or patrol vehicles.
- Variable lane controls allowing closure of the shoulder if it is blocked by a disabled vehicle.
- Emergency turnouts.

- The potential for a performance-based practical design (PBPD) approach where the savings associated with not constructing a conventional lane are used on other projects that improve network operations and safety.

The specific requirements of design exception requests vary by state. Design exceptions are typically submitted to and approved by FHWA Division Offices, although they may allow approval on their behalf by state departments of transportation (DOTs) or local agencies.[(50)] Part-time shoulder use may have a relatively short implementation timeframe compared to conventional projects, so a design exception request should be prepared and submitted to FHWA as early as possible in the planning process. Design exception requests are typically reviewed in conjunction with the overall review and approval of the plans, specifications, and estimates, which may be relatively minor for part-time shoulder use.[(50)]

FHWA approval process for part-time shoulder use has varied. In Massachusetts, approval was granted on a temporary basis when part-time shoulder use was first implemented in 1985 and renewed several times before permanent approval was granted in 2009.[(49)]

Most part-time shoulder use projects that have recently been implemented or are currently in the planning process are long-term implementations. Temporary approval is not recommended because it creates the need for re-approval.

Many states also have design standards, manuals, or laws that may need to be updated prior to implementing part-time shoulder use. Minnesota, which has nearly 300 miles of BOS facilities, developed standards for BOS facilities in the 1990s with input from their FHWA Division Offices.[(44)] The standards were incorporated into MnDOT's design manual. Washington State, which is planning several part-time shoulder use and Active Traffic Management (ATM) installations, is developing an urban freeway retrofit guide with the help of their FHWA Division Office.[(33)]

LEGAL ISSUES

In some states, driving on the shoulder is prohibited by law, and implementation has required legislative action or new rulemaking and agreements to interpret existing laws. For example:[(42)]

- Minnesota amended their statutes in 2005 to "formalize" BOS operation. Previously, there was an agreement between the state patrol, Metro Transit, and the DOT.
- Florida DOT created an inter-local agreement with the Miami-Dade Transit in which BOS was treated as a pilot project.
- California defined shoulders as transit lanes to legally enable a BOS pilot project in San Diego in the mid-2000s (the project has since ended).
- Georgia DOT authorized BOS as a demonstration project.

MUTCD EXPERIMENTAL APPROVAL PROCESS

If "a new traffic control device or a different application of an existing device" is "not compliant with or not included in the MUTCD", the state DOT considering its installation should submit a request to experiment to FHWA MUTCD team, and FHWA must approve the experiment before the control device is installed.

Most part-time shoulder use projects have not used experimental traffic control devices. Control devices commonly used on part-time shoulder uses facilities that do not require experimental approval include the following:

- Regulatory signs indicating the hours of operation of a shoulder lane
- Warning signs on on-ramps or along part-time shoulder use segments that notify drivers of part-time shoulder uses
- Signs indicating vehicle restrictions of part-time shoulder uses, such as no trucks or buses only
- Green arrow and red "x" dynamic lane control signs
- A second edge line between the outside of the shoulder and edge of pavement or median barrier
- Dotted pavement markings at ramp-freeway junctions and the start and end of part-time shoulder use segments to guide drivers when the shoulder is open and closed

However, more-complex part-time shoulder use projects, such as those with other ATM elements, may require a request for experimentation.

The request for experimentation should originate with the State DOT and be sent to FHWA Headquarters with a courtesy copy to the FHWA Division Office. The FHWA must approve the experiment before it begins. All requests should include the following:[(51)]

- A statement of the nature of the problem, including data that justifies the need for a new application.
- A description of the proposed change, how it was developed, and how it deviates from the current MUTCD.
- Any illustration(s) that enhances understanding of the device or its use.
- Supporting data that explains how the experimental device was developed, if it has been tried, the adequacy of its performance, and the process by which the device was chosen or applied.
- A legally binding statement certifying that the concept of the traffic control device is not protected by a patent or copyright.
- The proposed time period and location(s) of the experiment.
- A detailed research or evaluation plan providing for close monitoring of the experimentation, especially in the early stages of field implementation. The evaluation

plan should include before and after studies as well as quantitative data enabling a scientifically sound evaluation of the performance of the device.

- An agreement to restore the experimental site to a condition that complies with the provisions of the MUTCD within 3 months following completion of the experiment. The agreement must also provide that the sponsoring agency will terminate the experiment at any time if it determines that the experiment directly or indirectly causes significant safety hazards. If the experiment demonstrates an improvement, the device or application may remain in place until an official rulemaking action occurs.
- An agreement to provide semi-annual progress reports for the duration of the experimentation and a copy of the final results to the FHWA's Office of Transportation Operations within three months of the conclusion of the experiment.

STAKEHOLDER ENGAGEMENT

Successful deployment of part-time shoulder use requires a well-planned, interdisciplinary collaboration with a variety of different stakeholders, including planning, operations, design, maintenance, and executive leadership staff within a DOT; law enforcement; emergency responders; bus operators; MPO staff; and FHWA Division Office staff.

A state DOT will typically be the agency that decides if part-time shoulder use is feasible, possibly in collaboration with a transit agency if BOS is under consideration. As soon as this determination is made, the state DOT should reach out to the stakeholder groups noted above and form a working group. Most agencies that have successfully implemented part-time shoulder use have formed working groups to ensure the needs of all stakeholders are incorporated into the concept of operations. Stakeholder involvement and education—assuming that some stakeholders may not be aware of the benefits and potential issues associated with part-time shoulder uses—is an ongoing process and working groups should continue to meet during the early years of a part-time shoulder use facility's operation. Engaging executive leadership early is critical because policies may need to change and laws potentially prohibiting driving on the shoulder may need to be interpreted or changed.

For stakeholders who do not have a working knowledge of part-time shoulder use, implementing an education and outreach program during the early stages of the effort will help build trust in the proposed investments. This education and outreach effort can include peer exchanges, involving counterparts from other states or countries with shoulder running experience, as well as FHWA.

The traveling public is also an important stakeholder, and their engagement is discussed later in this chapter.

Incorporating and Mitigating Emergency Response and Incident Management Concerns

Emergency responders frequently drive on shoulders to reach incident scenes and use shoulders to park while responding to incidents. Concerns over the potential loss of the ability to bypass congested traffic and remain out of the travelled way when responding to incidents need to be addressed before part-time shoulder use is implemented, particularly for longer part-time shoulder use sections spanning multiple interchanges.

Incident response plans developed during the planning of part-time shoulder use can mitigate these concerns. "Sweeps" of the shoulder before it opens and the construction of turnouts reduce the likelihood of the shoulder being blocked. A fleet of dedicated incident response vehicles positioned at multiple locations along the facility can also decrease incident response times.

If dynamic signs are used, additional incident management and response options are available. Local emergency response agencies should be given the authority to order the closure of the shoulder and have a clear line of communication to the TMC for doing so. Closing the shoulder clears it of vehicles and provides emergency responders with an uncongested path to incident scenes.

Incorporating and Mitigating Maintenance Concerns

Maintenance concerns with part-time shoulder use typically relate to how the lane designated for part-time shoulder use should be maintained—more similar to a shoulder or more similar to a travel lane, how existing maintenance activities will be impacted, and what new maintenance activities will be required.

Agencies with part-time shoulder use have generally come to the conclusion that shoulders should be maintained in the same manner as other lanes, and nothing outside of typical maintenance operations needs to be done with regard to filling potholes, plowing snow, and so forth. Existing maintenance activities requiring stopping on the shoulder cannot occur when the shoulder is open but are otherwise unaffected.

New maintenance needs vary greatly depending on the type of part-time shoulder use. BOS and static part-time shoulder uses with no additional ITS have virtually no additional maintenance needs beyond maintaining the shoulder as a lane. Extensive ITS hardware used for dynamic part-time shoulder use and other ATM systems likely require additional maintenance staff and staff training with regard to the specifics of the technology.

Incorporating and Mitigating Bus Operator Concerns

Minnesota began widespread implementation of BOS operation in the Twin Cities metropolitan area in the 1990s. Their methods of mitigating bus operator concerns are well-established and have served as a model for many other states that have subsequently implemented BOS.

On routes designated for BOS, Minnesota limits BOS speed to 15 mph faster than adjacent traffic and an absolute maximum of 35 mph. This ensures BOS occurs in a relatively low-speed environment with low speed differentials. The choice to use the shoulder is up to each driver, although passengers sometimes complain if speeds are low enough to permit part-time shoulder use and drivers choose not to use it. Metro Transit, the largest bus operator in the Twin Cities, allows drivers who are uncomfortable driving on the shoulder to request transfers to other routes. The primary requirement for a bus using the BOS lanes is for the driver to have received training. Transit agencies using the BOS lanes offer training several times a year, and new drivers are assigned to routes without BOS if they have not yet been trained.

PUBLIC INVOLVEMENT

Similar to other innovative transportation projects, public outreach is a critical part of part-time shoulder use implementation. Successful implementation of the first part-time shoulder use project in a metropolitan area includes explicit and proactive outreach and education to the general public and should be undertaken consistent with state public information guidance. This would create opportunities to familiarize others with the concept of part-time shoulder use and the details of how it will work on a specific facility. How will drivers know if the shoulder is open or closed? What special signs will be used? Will the speed limit change? What should drivers do if they break down? Creating multiple forums to engage the public (including presentations at local council or board meetings, briefs at community organization functions, and project-specific open house meetings) results in opportunities to listen to community interests and share objective information about part-time shoulder use.

Public outreach conducted during planning a part-time shoulder use project can inform and educate the public about proper use and benefits. Media campaigns through local newspapers, television, and public meetings can be effective methods of keeping the community informed. Once the part-time shoulder use project is open to the public, monitoring driver behavior and using law enforcement as necessary to promote proper use of the part-time shoulder use can aid driver acclimation. Figure 39 shows a postcard handout that has been used at public meetings in Michigan in preparation for an ATM installation.

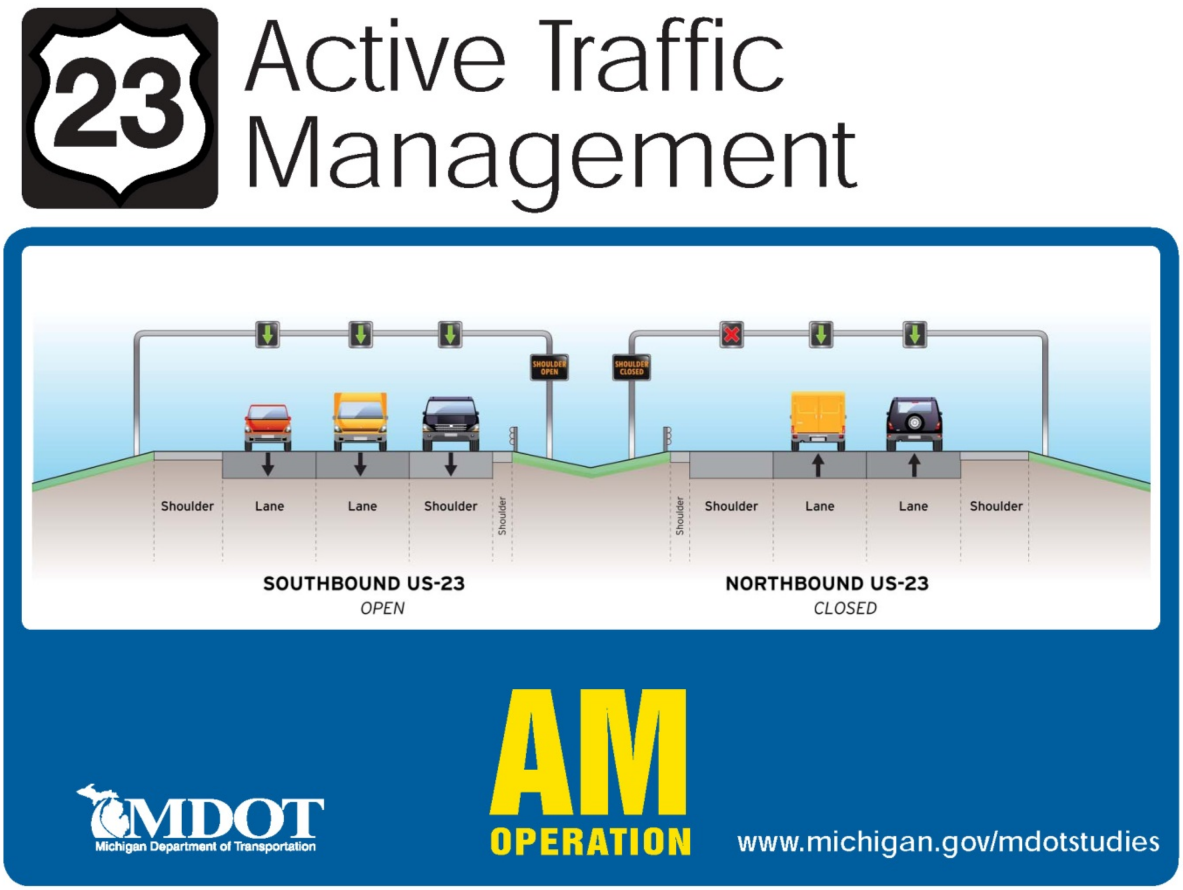


Figure 39. Example Dynamic Part-time Shoulder Use Public Information Material

(Source: Michigan Department of Transportation)

The following communications and public involvement elements may be considered as part of the public outreach:

- Expect opposition and confusion
- Understand your non-technical audience
- Define and identify success
- Manage expectations
- Demonstrate public accountability
- Tell an engaging story

CHAPTER 9. DAY-TO-DAY OPERATION

Part-time shoulder use has unique maintenance, incident management, and law enforcement needs. Early applications of part-time shoulder use in the U.S. were done with little or no intelligent transportation systems (ITS) support. As ITS technology has advanced, it has been increasingly integrated into part-time shoulder use operations.

MAINTENANCE

Maintenance of lanes designated for part-time shoulder use is more similar to maintenance of general purpose lanes than maintenance of a shoulder. Over time, agencies with part-time shoulder use have found it is most efficient to maintain the shoulder at the same level as general purpose lanes. There is no need to clean the shoulder with street sweepers, as the presence of traffic on the shoulder moves debris off of it similar to a general purpose lane. Conducting maintenance on part-time shoulder use segments that requires maintenance vehicles to stop on the shoulder will need to be conducted at times the shoulder is closed to traffic. On high volume freeways where part-time shoulder use is most commonly used, there may already be restrictions on maintenance during peak period when the shoulder lane would be open.

After snowfall, part-time shoulder use is typically plowed after all general purpose lanes on the freeway have been plowed. This creates the potential for the shoulder to be closed during a period when it is scheduled to be open, although this usually has little effect on traffic operations due to reduced traffic volume during snow. Minnesota has found it beneficial to open the I-35W dynamic part-time shoulder use segment throughout the duration of a snowstorm because vehicles driving in the shoulder help to distribute salt that has been spread there.

Reduced lateral offsets to obstructions may not provide sufficient space to push and store snow beside the shoulder. Minnesota and Massachusetts have not experienced issues with this, but Virginia has on I-66. On average, less often than once a year a storm produces enough snow that it cannot be fully plowed off of the shoulder in several constrained areas. Loaders and dump trucks are used to remove the snow from these areas in nighttime hours. The time and cost associated with this are high enough that it would not be feasible if Virginia received more snow and it was necessary to remove snow several times per year.

INCIDENT MANAGEMENT

Part-time shoulder use is typically implemented on some of the highest volume and most congested freeways in a region. These roadways typically have incident management plans and infrastructure in place that can be adapted for part-time shoulder use. Strategies for enhanced incident management on part-time shoulder use facilities include the following:

- Emergency turnouts, discussed in the Geometric Design chapter, constructed approximately every half-mile unless other turnouts such as ramps are present.
- Service patrols, especially for longer part-time shoulder use spanning multiple interchanges.

- CCTV coverage of shoulder lanes and turnouts.
- Devices to detect slow or stopped traffic on shoulder lanes or in turnouts.
- Dynamic lane control signs:
    - A shoulder can be closed for safety reasons if a disabled vehicle stopped on the shoulder
    - A shoulder can be closed to traffic so emergency responders can drive on it to rapidly reach a crash scene anywhere on the facility.

Most static and dynamic part-time shoulder use facilities employ some of these strategies. Bus-on-shoulder (BOS) facilities, including those in Minnesota, typically do not have additional incident management specifically associated with BOS.

LAW ENFORCEMENT

The success of part-time shoulder use depends on the extent to which drivers comply with posted hours of operation or lane-use controls, as well as any vehicle restrictions. In Europe, agencies often use automated enforcement for temporary lanes. Such automated enforcement in the U.S. is uncommon outside of school and work zones, and there are legal restrictions on automated enforcement in many states. Accordingly, an increased traditional law enforcement presence will likely be needed on facilities with part-time shoulder use. Enforcement of BOS lanes is focused on use of the shoulder by non-buses, and enforcement of static and dynamic part-time shoulder use is more focused on use of the shoulder outside of hours of operation.

With the increased likelihood of vehicles on the shoulder, including violators when the shoulder lane is closed, police conducting routine enforcement may want to target areas with downstream pull over opportunities such as exit ramps, emergency turnouts large enough for two vehicles, and so forth. Ultimately, law enforcement personnel should be engaged in the planning and design of shoulder lanes and specific design needs for local enforcement entities should be incorporated into the facility.

Even without automated enforcement, installation of some of the hardware associated with it, such as presence and speed detectors, may be helpful to track compliance on a system level and help target areas for enforcement by police. On dynamic part-time shoulder use facilities, lane control technology may include mechanisms for providing real-time information to police officers in the field about the status of the shoulder, when it was opened/closed, and the current lane assignment displays (for patrol vehicles in locations where displays are not visible). This technology can also be used on a static shoulder lane facility with a high level of ITS infrastructure.

On BOS facilities, shoulders can still be used by police to pull over vehicles, and bus drivers are trained to reenter general purpose lanes when a shoulder is obstructed. Police and bus operators in Minnesota have determined buses should reenter travel lanes approximately 500 feet upstream of a police car stopped on the shoulder, and bus drivers can estimate this distance in Minnesota based on the standard spacing of light poles along freeways.[44]

OPENING AND CLOSING PART-TIME SHOULDER USE FACILITIES

The opening and closing of part-time shoulder use facilities in the U.S. open to more than buses is a largely manual process. A shoulder should be inspected in entirety before each opening by "sweeping" (driving) the length of the facility or viewing CCTV if there is full camera coverage of the facility. Any debris or disabled vehicles should be cleared prior to the scheduled opening time of the shoulder. If dynamic lane use control signs are present, then they can be used to keep the lane closed past the scheduled opening time if additional time is needed to clear the shoulder. Additionally, if an incident occurs while the shoulder lane is open and the shoulder becomes blocked, then the shoulder should be closed as soon as possible if dynamic lane assignment signs are present. Interagency agreements should be prepared prior to the implementation of part-time shoulder use to determine which agencies have the authority to instruct the TMC to close the shoulder.

BOS lanes do not need to be inspected before opening, and most are not. If buses encounter obstructions on the shoulder, then they can merge into traffic to avoid them, and dispatchers can alert buses on part-time shoulder use routes of known obstructions. Additionally, many BOS lanes are used on an as-needed basis and there are no fixed hours of operation.

The extensive ITS requirements and variable hours of operation of dynamic part-time shoulder use facilities make them well-suited for more automated opening and closing processes. Some of these processes may also be used for static part-time shoulder use if sufficient ITS infrastructure is in place. Agencies should be cautious with introducing too much variability into the operating hours of dynamic part-time shoulder use. For example, if a shoulder needs to be opened in the morning peak period for congestion reduction purposes nearly every weekday, it will be more predictable to drivers if it is opened at the same time every weekday (such as 7 a.m.) rather than different times (such as 6:50, 7:10, 7:15, etc.) based on minor variations in traffic from day to day. In this case, the benefits of dynamic over static part-time shoulder use would still be realized by the ability to extend the operating hours if high traffic volume was still present at the end of the typical a.m. peak period or occasionally open the shoulder at other times such as weekends.

The long-term costs of an increased number of operators to continuously monitor dynamic part-time shoulder use and other ATM features, if they are present, may be greater than having software to assist with part-time shoulder use (and general ATM) operation. In Europe, some facilities with ATM are controlled by "an expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention."[(46)] Opening or closing a shoulder as a fully automated process is not recommended for the U.S. at this time because ATM is less common than in Europe. However, expert systems can be used to provide recommendations to human TMC operators, who then ultimately decide whether to open or close a shoulder based on the recommendation. Although expert systems can electronically, rather than manually, sweep a facility, it is still necessary to have incident response vehicles on standby in the event that debris or disabled vehicles are identified and need to be cleared.

An expert system—also known as a Decision Support System (DSS)—continuously monitors data and other performance parameters collected from the field devices (e.g., speeds and volumes; status of shoulder (blocked / clear); confirmed incidents, location, severity, number of lanes blocked, anticipated duration; scheduled events; weather and pavement conditions; equipment status; and time of day and day of week). Inputs from field devices will need to be supplemented with inputs from TMC operators, such as schedules of special events and police reports of incidents. Through a series of IF, AND, OR, and THEN logical statements, this DSS implements or recommends the most appropriate response plan.

The logical statements typically involve comparisons of real-time parameters with various threshold parameters, such as comparisons of speeds and volumes with the time of day and known special events. Examples of outcomes from an automated system include:

- Providing advisory messages to TMC operators
- Switching sign displays
- Switching text messages and contents on CMS
- Sending a notification to others (e.g., State Police)
- Automatically resetting signs to normal once an incident clears

APPENDIX A – CASE STUDIES OF SUCCESSFUL APPLICATIONS IN THE UNITED STATES

A list of known part-time shoulder use applications can be found in Table 13. Though the application of part-time shoulder uses has been rather limited in some cases, it can be seen that this Active Traffic Management (ATM) strategy has been employed across most regions in the United States. The various examples highlighted in this section, which features corridors from all over the country and of vastly different implementation scales, evidence that under the appropriate conditions, part-time shoulder use is an effective strategy in reducing travel times and increasing overall network reliability and performance.

Though part-time shoulder use is more-widely implemented in Europe, it is difficult to establish comparisons between ATM strategies employed in Europe versus those employed in the United States due to differences in driver behavior, political support, and transportation networks as a whole. No effort was made to inventory European facilities with part-time shoulder use, but noteworthy practices from Europe were provided through this guidance document.

Table 13. Part-Time Shoulder Use Facilities in US.

Strategy	Location	Corridor	Length (miles)	Year Deployed	Vehicle Type	Usage Criteria	Maximum Allowed Speed	Lane Width (feet)	Note
Bus-on-shoulder	Minneapolis Metro Area	Multiple	290	1991	Buses only	24/7, when main line speed is under 35 mph	Maximum of 35 mph, and no more than 15 mph faster than mainline	10-12	Freeway application and a few arterials
	Wilmington, Delaware	US 202	0.3		Buses only	24/7			Arterial queue jump application
	Miami, Florida	SR 826	16	2005	Buses only		35 mph	10-12	Freeway application
	Miami, Florida	SR 836	18	2005	Buses only		35 mph	10-12	Freeway application
	Miami, Florida	Turnpike			Buses only	General purpose speeds drop below 25 mph	Maximum of 35 mph, and no more than 15 mph faster than mainline	10-12, depending upon truck volumes	Freeway application
	Miami, Florida	SR-874, SR-878	9	2007	Buses only	General purpose speeds drop below 25 mph	Maximum of 35 mph, and no more than 15 mph faster than mainline	10-12, depending upon truck volumes	Freeway application
	Montgomery County, Maryland	US 29	4		Buses only	M-F, 6-9am (SB), 3-8pm (NB)			Arterial queue jump application
	Mountainside, New Jersey	US 22 EB	1		Buses only				Arterial application

Continuation

Strategy	Location	Corridor	Length (miles)	Year Deployed	Vehicle Type	Usage Criteria	Maximum Allowed Speed	Lane Width (feet)	Note
Bus-on-shoulder (con'd)	Middlesex County, New Jersey	US 9	4	2006	Buses only	M-F, 5-9am (NB), SB pm peak period	35 mph		Arterial application
	Falls Church, Virginia	SR 267 EB	1.3		Buses only	M-F, 4-8pm	25 mph	12	Freeway queue jump
	Columbus, Ohio	I-70	10	2006	Buses only	General purpose lane speeds drop below 35 mph	35 mph		Minneapolis-St. Paul Twin Cities area model was followed
	Cleveland, Ohio	I-90/SR 2	10	2008	Buses only	General purpose lane speeds drop below 35 mph	45 mph		Freeway application
	Cincinnati, Ohio	I-71	10	2007	Buses only	General purpose lane speeds drop below 35 mph	45 mph	12	Freeway application, left shoulder
	Chicago, Illinois	I-55	14	2011	Buses only	General purpose lane speeds drop below 35 mph	45 mph		Freeway application,
	Raleigh, North Carolina	I-40	12	2012	Buses only	General purpose lane speeds drop below 35 mph	35 mph		Similar features as the Twin Cities network, freeway application

Continuation

Strategy	Location	Corridor	Length (miles)	Year Deployed	Vehicle Type	Usage Criteria	Maximum Allowed Speed	Lane Width (feet)	Note
Bus-on-shoulder (con'd)	Kansas City, Kansas	I-35	12	2012	Buses only	General purpose lane speeds drop below 35 mph	35 mph		Freeway application
	Seattle, Washington	SR 522	2.2	1970	Buses only	24/7	Buses allowed to operate at full posted speeds		Arterial application
	Seattle, Washington	SR 99							Arterial application
Static	Alpharetta, Georgia	GA 400	12	2005	All	General purpose lane speeds drop below 35 mph	35 mph max, speed differential with general purpose lanes below 15 mph		Previously buses use only, freeway application
	Boston, Massachusetts	I-93, I-95, SR 3	45	1985	Passenger vehicles only	M-F, 5-10am, 3-7pm	65 mph (60 mph on SR 3)	10-12	Freeway application, shoulder running has been eliminated on several miles of I-95 after road widening
	Fairfax County, Virginia	I-66	6.5	1992	All	M-F, 5:30-11am (EB), 2-8pm (WB)	55 mph	12	Freeway application

Continuation

Strategy	Location	Corridor	Length (miles)	Year Deployed	Vehicle Type	Usage Criteria	Maximum Allowed Speed	Lane Width (feet)	Note
Static (con'd)	Virginia Beach, VA	I-264	3.5	1992	All	M-F, 6-8am (EB), 4-6pm (WB)	55 mph	10	Freeway application
	McLean, Virginia	I-495	1.5	2015	All	7-11 am, 2-8pm	55 mph	11	Planned left-shoulder application
	Everett, Washington	US 2 EB	1.22	2009	All	M-F, 3-7pm	60 mph	14	Arterial application
	Honolulu, Hawaii	I-H1			All	Morning peak period			Temporary condition until high-cost capacity improvements are implemented, freeway application
	Seattle, Washington	US 2	1.55		All	Evening peak period	Same as general purpose lane		Permanent application, capable to accommodating growth
	Idaho Springs, Colorado	I-70 EB	13	2015	Passenger vehicles only	Weekend peak periods			Dynamically-priced lane, left shoulder
	Irving, Texas	SR 161	3	2016	All	M-F 6-10am, 2-7 pm			Freeway application

Continuation

Strategy	Location	Corridor	Length (miles)	Year Deployed	Vehicle Type	Usage Criteria	Maximum Allowed Speed	Lane Width (feet)	Note
Static (con'd)	Trenton, New Jersey	NJ 29	1		Cars only	M-F, 7-10am	Same as general purpose lane	13	Additional exit lane to NJ 129 (creating 2 lane exit)
	Newark, New Jersey	I-78 EB	7	2014	All	Peak periods	Variable, but same as general purpose lane	12	Temporary due to closure of adjacent freeway for reconstruction
Dynamic	Minneapolis, Minnesota	I -35W	2.5	2009	Dynamic priced		Freeway free-flow speed	17-19	Freeway application
	Fairfax County, Virginia	I-66	6.5	2015	All		variable	12	Was static from 1992-2015

MINNEAPOLIS-ST. PAUL, MINNESOTA – BUS ON SHOULDER

Perhaps the foremost part-time shoulder use network in the country, the bus on shoulder (BOS) program in Minneapolis-St. Paul has allowed transit vehicles to travel on more than 290 miles of shoulder throughout the region since 1991. Though all 290 miles of shoulder have not been open since the program's inception, the extent to which the program has grown has made it—without a doubt—the most-extensive system in the United States. While many BOS systems arise out of the desire to increase transit reliability (and therefore its appeal to potential riders), the BOS system in Minnesota germinated out of a rather unique situation.

In May of 1991, major flooding forced officials to close one of the bridges on I-35W, a primary means of travel in and out of the Twin Cities. In a state of emergency, the governor called a summit to help develop strategies for increasing throughput on the adjacent bridges while repairs were made to the I-35W bridge. Ultimately, it was decided that buses would temporarily be allowed to travel on the shoulder to improve subsequent traffic congestion. The quick turnaround and immediate success of the strategy prompted officials to begin testing bus shoulder running on other congested roadways in the Twin Cities area. The result was the development of a designated task team consisting of key stakeholders, such as Metro Transit and suburban bus operators, MnDOT officials, state police officers, and the Metro Council of Governments. Several central staff members at the DOT were selected to act as advocates for the program.

Over the past decade, the task team has successfully advocated for the inclusion of BOS operations on hundreds of miles of freeways, primarily as part of larger construction or shoulder maintenance projects. MnDOT now has an overall program that looks annually at where shoulder running can be added on freeways.(42). A 1998 survey of the program estimated that the BOS system resulted in a bus travel time savings of 5 to 15 minutes depending on levels of congestion and route length. Respondents also saw the shoulders as a way to minimize their stress sitting in congestion and increase individual trip reliability. While safety has been identified as a primary concern by program officials and other key stakeholders, the most-concerning safety issues for buses in the shoulders have been sideswipe crashes and mirror hits, which tend to be less severe crash types.(24)

In 2009, MnDOT converted the right shoulder (previously used for BOS) into a general purpose lane on a section I-35W to maintain lane continuity into downtown as other portions of I-35W were widened. The left shoulder was converted to a dynamic priced lane. Buses and high-occupancy vehicles can use the lane for free, and single-occupant vehicles pay a variable toll.(52)

FAIRFAX COUNTY, VIRGINIA

At the same time that a BOS system was being developed in Minneapolis-St. Paul, VDOT was establishing an alternative part-time shoulder use strategy for one of its most-heavily congested roadways. I-66, which extends radially outward from the Capital Beltway (I-495) in Northern Virginia, suffers from recurring congestion both during and outside of peak hours. To help aid peak-direction travel, VDOT converted the leftmost general purpose lane to an high-occupancy vehicle (HOV) lane and allowed general purpose traffic to use the shoulder to offset the decrease in general purpose capacity. Static part-time shoulder use was opened in 1992 and was available for use by all traffic during specified peak periods on a 6.5-mile section of I-66 between I-495 and US 50. These periods have been revised over the years to respond to changes in traffic, and, in 2015, a more-advanced active traffic management system with dynamic part-time shoulder use was installed. The shoulder is now opened whenever warranted by traffic conditions. A 2007 investigation into system performance revealed that these shoulders operate at near capacity (V/C ratios: 0.90-1.0 eastbound, and 0.83-1.0 westbound), indicating the part-time shoulder use is able to help significantly augment throughput during the peak periods. A similar investigation was completed with regards to the safety effects of the part-time shoulder use; a negative binomial regression analysis using several years of crash data indicated the part-time shoulder use did not have any statistically significant effect on crash frequency.(24)

ALPHARETTA, GEORGIA

In the northern suburbs of Atlanta, nearly 12 miles of part-time shoulder use has been developed on GA 400. The project has incrementally grown from BOS in one direction to static part-time shoulder use in both directions. Part-time shoulder use was initially operated only in the southbound direction during the AM peak and was only open to buses. Opened on September 12, 2005, the project was championed by the GDOT and Georgia Regional Transportation Authority (GRTA), which operates express bus services in the area. The program was modeled after the successes of the Minneapolis-St. Paul BOS program but initially considered a temporary solution until the roadway could be permanently widened. The project development process included a bus ridership estimate using the regional travel demand model, benefit forecasts, and a field assessment of shoulder conditions. Both GRTA and Metropolitan Atlanta Rapid Transit Authority (MARTA), which operate four and eight buses per hour (respectively) on the BOS section of GA 400, report averages of five to seven minutes of travel time savings on their commuter bus routes. The routes end at a heavy rail station with direct access from GA 400. During peak congestion, up to 25 minutes were saved through the 12-mile corridor. The disparity of travel times between buses and general traffic later decreased due to the widening of GA 400. TCRP Report 151 states, as of 2012, no crashes related to BOS were reported in Georgia; no further safety information is provided in the report.(42) More recently, the southbound BOS was converted to general purpose part-time shoulder use, and northbound part-time shoulder use was opened. The part-time shoulder use only occurs on auxiliary lanes between interchanges and does not extent through interchanges.

SAN DIEGO, CALIFORNIA

The San Diego Association of Governments (SANDAG) implemented BOS along five miles of I-805/SR 52, used by express bus route 960 in the mid-2000s. SANDAG agreed to a two-year pilot program with Caltrans to test BOS; it was initially envisioned as a temporary improvement until managed (i.e., HOV and HOT) lanes could be deployed or until the roadway was widened. In collaboration with SANDAG and local transit operators, BOS on I-805/SR-52 was opened in December 2005 by Caltrans. Several key findings were determined with a six-month assessment of the program: (42)

- Safety
    - No crashes [As stated in TCRP Report 151—presumably this refers to shoulder-running buses only, as crashes in general likely happen on a freeway in a six month period of time].
    - No issues related to enforcement or Caltrans maintenance.
- Bus Travel Time and Reliability
    - Route 960 buses have 99 percent on-time performance.
    - Up to 5 minutes travel-time savings for buses during heavy congestion.
- Freeway Level of Service and Maintenance
    - California Highway Patrol and Caltrans report no changes in freeway levels of service.
    - Transit operator indicates need for additional maintenance to remove debris on shoulders.
- Structural Changes
    - 10-foot shoulder width is optimal.
    - Buses can safely operate in narrower shoulders, but it does slow operations.
- Perceptions
    - 72 percent of bus drivers feel use of shoulders is safe.
    - 86 percent of bus drivers believe use of shoulders is a good idea.
    - 91 percent of passengers feel use of shoulders provides travel time savings.
    - 90 percent of passengers feel safe with buses on shoulders.

The pilot program has since ended. However, another demonstration project is currently planned in the San Diego area on I-805/SR 94 from SR 54 to downtown.(53)

MIDDLESEX COUNTY, NEW JERSEY

Due to the success of BOS along US 22 in Mountainside, New Jersey (which is limited in scale and has existed for decades), New Jersey DOT opened a second BOS corridor along four miles of US 9 in Middlesex County. Opened in November 2006, the BOS was designed to serve over 400 buses and 6,800 passengers during peak commute periods. The plan was a key element of the NJDOT's Enhanced Bus Improvement Program, which is tasked with reducing delays and increasing travel-time reliability of bus services. Feedback from the program has been overwhelmingly positive from both passengers and bus operators alike; the latter responded positively to the use of 12-foot shoulder priority treatments. As of 2012, no crashes have been reported [As stated in TCRP Report 151—presumably this refers to shoulder-running buses only, as crashes in general are likely to happen on an arterial in a six year period of time], and travel time savings on the order of three to four minutes have been seen during peak trips along the 4-mile corridor.(42)

SEATTLE, WASHINGTON

In order to help improve travel time, reduce the impacts of bottlenecks, and relieve congestion at a critical interchange, the Washington State DOT began opening the shoulder to all traffic along a 1.55-mile segment of US 2 near Seattle. WSDOT employed outreach efforts prior to implementation, which aided significantly in the development of the part-time shoulder use concept. It was determined the shoulder would only be open to traffic during the evening peak period, and restriping was undertaken to reduce weaving throughout the corridor. As a result of the additional throughput with part-time shoulder use, WSDOT considers it a permanent solution (at least for the near future) to solve the aforementioned issues along the corridor. Average delays for all vehicles have been reduced from 8-10 minutes to 1-2 minutes along the 1.55 mile stretch of US 2.[24]

MIAMI, FLORIDA

In 2002, residents of Miami-Dade County (MDC) developed the People's Transportation Plan, which sought to improve mobility and reduce congestion throughout the county. Seventeen million dollars was committed under the plan to improve local bus services through the addition of routes, increased efficiency of service, and expansion of rapid transit services. Complementing this plan, the MDC MPO conducted an extensive, two-phased investigation into the feasibility of special-use lanes in the county. Phase I provided a high-level assessment of the applicability of various types of special-use lanes along several of MDC's most-congested corridors. The primary outcome of this phase was the identification of rapid transit corridors comprised of Expressway Core routes. In Phase II of the study, these Expressway Core routes were further vetted for potential use with shoulder running schemes by the Center for Urban Transportation Research at the University of South Florida. The study outlined key operational characteristics required for the successful implementation of shoulder running in MDC. Based on several factors, including roadway characteristics, programmed corridor improvements, and proposed express transit, five corridors were ultimately identified as holding the most potential for a pilot bus on shoulder program.

After further investigation by the MDC MPO, the SR 874 and SR 878 corridors were selected for the first BOS project. Consisting of approximately nine miles of freeway, buses were allowed to begin operating on the shoulders of these routes when the speed of general traffic fell below 25 miles per hour. Four years after their opening in 2007, a 50-percent reduction in the number of late buses running along the BOS corridor was found. Key stakeholders in the program included the MPO, Office of the County Manager, Miami-Dade Transit, Miami-Dade Expressway Authority, Florida DOT and Turnpike Enterprise. Key stakeholders noted bus shoulder running was not the ideal solution to congestion, but it served as an effective means to help improve mobility and transit reliability throughout Miami-Dade County.[40]

MINNEAPOLIS, MINNESOTA – DYNAMIC SHOULDER LANE

Focused on reducing traffic congestion in the I-35W corridor and downtown Minneapolis, the Minnesota Urban Partnership Agreement (UPA) developed the first dynamic part-time shoulder use application in the United States on I-35W. Opened in 2009, the “priced dynamic shoulder lanes” (PDSL) allow buses, vanpools, carpoolers (2+), and MnPass users to utilize the 17-19 foot left-shoulder during congested periods; it previously operated as BOS. The 2.5-mile length of shoulder features both static and changeable message signs every 0.5 miles to inform drivers when the shoulders are open, as well as the price per segment to utilize the PDSL.

To implement this innovative system, the UPA relied on more than traditional technical analyses (e.g., operations, transit, and safety analyses); it also maximized the benefits of the institutional arrangements used to manage and guide the development of the initial proposal and implementation of the UPA projects, outreach activities, media coverage, and political and community support. The multi-agency organizational structure was essential for the initial implementation of this shoulder running application, and the subsequent processes, structures, media coverage, and staff competencies supported its development. Table 14 summarizes the non-technical success factors that were vital to the implementation of the PDSL, as well as other UPA projects on the I-35W corridor.

Table 14. Non-Technical Success Factors of the I-35W Priced Dynamic Shoulder Lane.

Questions	Results	Evidence
What role did the following areas play in the success of the Minnesota UPA project deployment?		
1. People	Effective	Key elements included the multi-agency organization structure, support throughout the agencies, and neutral conveners.
2. Processes	Effective	Forums, workshops, meetings, presentations, and newsletters were used to communicate with different groups.
3. Structures	Effective	The strong agency working relationships supported the implementation of the UPA projects.
4. Media	Effective	Played role of informing the public, rather than attempting influencing public opinion.
5. Competencies	Effective	Agency personnel had the technical expertise and project management skills needed to successfully deploy the UPA projects.
Does the public support the UPA strategies as effective and appropriate ways to reduce congestion?		
	Supported	The reports from the various surveys of bus riders, commuters in the I-35W South corridor, and I-35W MnPASS customers indicate general support for the UPA strategies as effective and appropriate methods to reduce congestion.

Opened in both the northbound and southbound direction on I-35W, the PDSL have helped reduce congestion, improve travel-time reliability, and increased throughput along the corridor. A year after implementation, the PDSL (in conjunction with the I-35W HOT lanes) pulled an average of 50,000 to 60,000 month trips from the general purpose lanes and generated $74,000 to $102,000 in monthly revenue. Preliminary safety studies have shown that the addition of the PDSL do not appear to negatively affect safety.(54)

IDAHO SPRINGS, COLORADO

Serving as the only east-west interstate in Colorado, the I-70 Mountain Corridor provides critical access for both localized and regional traffic from Denver to the mountains of West Colorado. As such, the corridor experiences heavy traffic demand, resulting in severe congestion and traffic delays in the eastbound direction. The 13-mile stretch of I-70 between Empire Junction and Idaho Springs, in particular, suffers from severe recurring congestion during peak periods. This four-lane section of highway would potentially benefit from traditional capacity improvements (e.g., road widening); however, strict physical constraints resulting from the surrounding mountainous terrain have forced the Colorado Department of Transportation (CDOT) to consider more context sensitive solutions.

As a part of the CDOT's comprehensive plan to improve travel along this corridor, a task force began investigating alternative solutions to help alleviate recurring congestion along I-70. Coordinating with representatives from the local community, including key community members, county and city officials, law enforcement, and historical and environmental protection advocates, CDOT formed Project Leadership and Technical Teams to gather valuable insights during the planning phase all the way through to final construction. These teams helped develop the guiding core principles for the alternatives analysis; this ultimately led to the development of a peak period shoulder running alterative in the eastbound direction.

After fully vetting the operational and environmental viability of shoulder running between Empire Junction and Idaho Springs, CDOT proceeded with a plan to develop an optional, dynamically-tolled third lane on I-70. This scheme not only aims to alleviate congestion, reduce travel times, and increase throughput of the critical corridor, but it does so without expanding the existing roadway. Slated for completion in the fall of 2015, CDOT will open the left-shoulder for use during the peak periods, promoting a more-reliable travel experience for drivers by actively displaying prices for the tolled-shoulder via variable message signs. Though a static operation, the dynamic pricing of the lane will help maintain the travel time savings expected under shoulder use.(55)

BOSTON, MASSACHUSETTS

One of the earliest part-time shoulder use operations in the country opened on several miles of I-95 and SR-3 in 1985 outside of Boston. Prior to implementation, standstill traffic along these corridors prompted drivers to begin using the shoulder, despite a lack of permitted use. To help alleviate congestion along these corridors, the Massachusetts Department of Transportation (MassDOT) developed a static part-time shoulder use scheme on I-95 and SR-3 during the peak travel periods (5 a.m. to 10 a.m. and 3 p.m. to 7 p.m. on weekdays) for passenger cars and trucks. Before this could be introduced, however, these corridors required a few minor improvements to accommodate the safe and efficient flow of traffic on the existing shoulders.

Prior to implementation, MassDOT strengthened and relocated drainage structures on the shoulder, conducted minor repairs to pavement, widened shoulders to meet a 10-foot minimum (12-foot desired), and developed emergency breakdown turnouts at 0.5 mile intervals to facilitate incident management and emergency response. MassDOT also employed the assistance of the Massachusetts State Police, who travel the lanes each day prior to opening the shoulder for use to ensure motorists will be safe from debris. Though no specific performance measures are collected on the effect of the shoulder lanes, the early success of the shoulder lanes increased travel speeds along these corridors, prompting MassDOT to extend shoulder operations to additional sections of roadway.

Since opening in 1985, part-time shoulder use in the Boston area have expanded to over 45 miles of roadway, including sections of I-93 north of the city. The infrastructure of these operations have also expanded, as pavement markings have been updated to reflect lessons learned, and signing plans have evolved to include both static and changeable message signs at the beginning and end of operations, as well as at freeway entrance ramps. The implementation of part-time shoulder use on these corridors, however, is only temporary. Prior to 2009, MassDOT was required to reapply for approval from Federal Highway Administration (FHWA) to implement the strategy every five to seven years until funding for permanent road widening was obtained. Since then, MassDOT has eliminated part-time shoulder use on half of the I-95 corridor after recent widening; it has plans to eliminate part-time shoulder use on the other half of I-95 within the next few years.[24]

APPENDIX B – SIGNING AND PAVEMENT MARKING EXAMPLES

This appendix provides examples of signing and pavement marking from U.S. part-time shoulder use facilities. They are not necessarily compliant with the Manual on Uniform Traffic Control Devices (MUTCD) and are provided as examples of what states have done rather than guidance. CHAPTER 7 of this guide provides guidance on signing and pavement marking for agencies designing new part-time shoulder uses facilities, developed in part from the examples presented here.

BUS ON SHOULDER

Signing

Figure 40 shows the layout of signs used for bus-on-shoulder (BOS) operation on freeways and arterials in Minnesota.

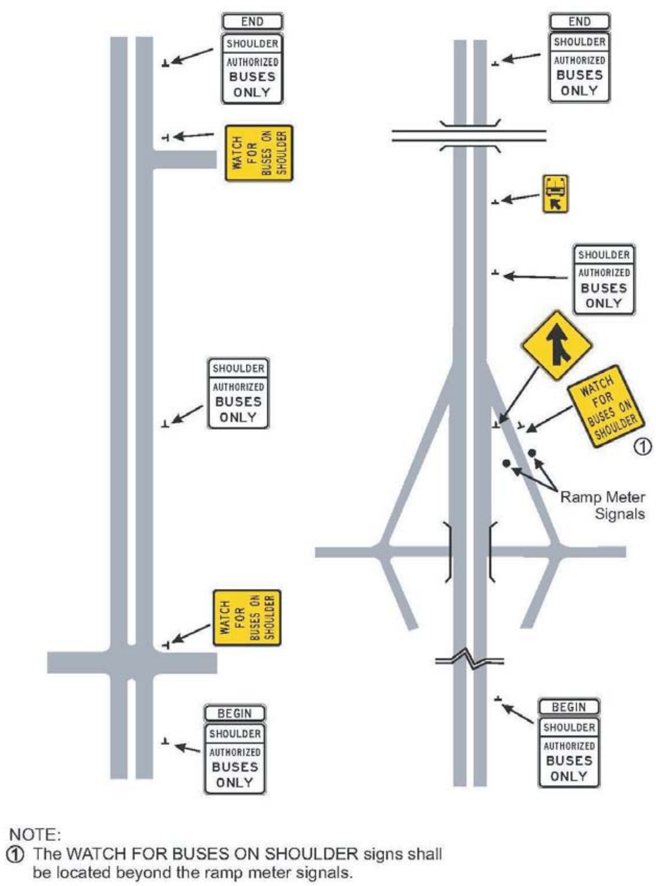


Figure 40. Bus-on-shoulder sign placement, Minnesota.

(Source: TCRP Report 151)

Figure 37 and Figure 41 show regulatory signs for BOS operation used in Minnesota and Miami, respectively. Miami's signs have since been modified to remove the diamond symbol, which is now exclusively for high-occupancy vehicle (HOV) lanes per the 2009 MUTCD.

Figure 41. Photo. FDOT regulatory sign for Bus-on-shoulder operation.

(Source: TCRP Report 151)

Figure 42 shows a typical MnDOT on-ramp warning sign for BOS operation. The white-on-black sign on the left side of the photo is a standard regulatory sign used on Minnesota regardless of whether or not the freeway has part-time shoulder uses.

Figure 42. Photo. MnDOT on-ramp Bus-on-shoulder warning sign, right side of photo.

(Source: TCRP Report 151)

Figure 43 shows a sign from the US 29 arterial in Montgomery County, Maryland, instructing buses to yield to right-turn vehicles at the start of a right-turn lane.

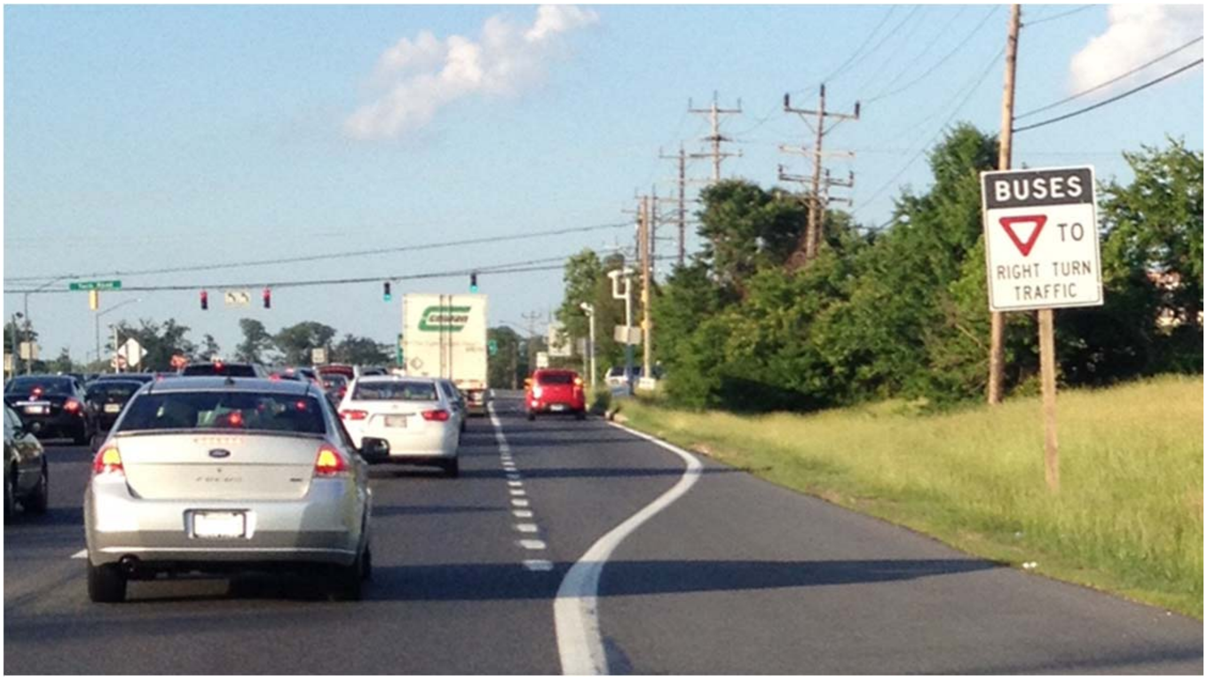


Figure 43. Photo. Maryland SHA sign to manage right-turn lane conflict.

(Source: Kittelson and Associates, Inc.)

Pavement Marking

Figure 44 and Figure 45 show optional word pavement markings from a freeway in California and an arterial in New Jersey, respectively.

Figure 44. Photo. Caltrans word pavement markings for BOS operation.

(Source: TCRP Report 151)

Figure 45. Photo. NJDOT word pavement markings for BOS operation.

(Source: TCRP Report 151)

Arterials in Washington State and New Jersey are highlighted below to present examples of arterial BOS pavement markings in different contexts.

SR 522 in Kenmore, Washington, is a highly developed arterial with numerous access points. A dotted edge line is used to indicate to passenger car drivers the shoulder is available as a right-turn lane in areas with many access points, and solid edge line is used in areas with fewer access points. Upstream of major access points, right-turn arrows are placed on the shoulder. Downstream of major access points, transverse white pavement markings are placed on the shoulder for approximately 50 feet followed by “transit only” word pavement markings. Figure 46 shows pavement markings on SR 522, with red arrows pointing to markings noted above.

Figure 46. Photo. SR 522 arterial Bus-on-shoulder pavement markings, Washington state.

(Source: TCRP Report 151)

US 9 in Old Bridge, New Jersey, is a higher order roadway than SR 522, with fewer access points and a mixture of intersections and interchanges. A solid white edge line is used along the majority of the roadway. Approaching major intersections, the edge line transitions into the curb using dotted white pavement markings and the shoulder space becomes a right-turn lane, with lane line markings separating the right turn lane and through lanes. Downstream of major intersections, dotted white pavement marking transitioning from the curb to a solid white edge line is used to reestablish the shoulder lane.

Figure 47 shows these pavement markings. The specific intersection shown in Figure 47 has jughandles, which provides space for a bus stop and turnout upstream of the intersection. This is a relatively unique configuration that cannot be easily replicated on many arterials.

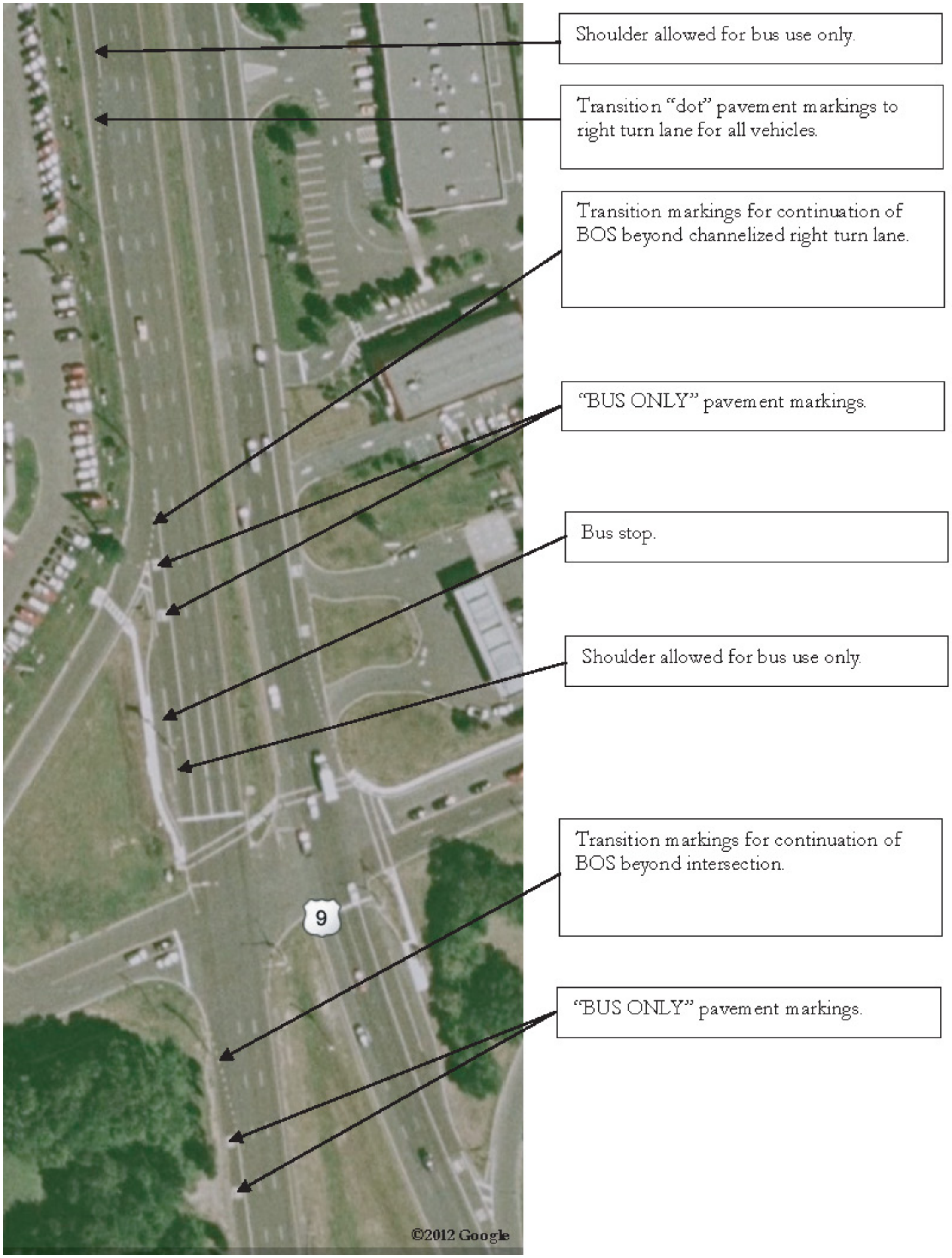


Figure 47. Photo Illustration. US 9 arterial Bus-on-shoulder pavement markings, New Jersey.

(Source: TCRP Report 151)

STATIC PART-TIME SHOULDER USE

Signing

Georgia

Georgia 400 is a commuter freeway connecting Atlanta and its northern suburbs. BOS operation was implemented in the mid-2000s, and in 2012 and 2014, the southbound and northbound shoulders between three interchanges, respectively, were opened to all vehicles during peak periods. Part-time shoulder use does not extend through any interchanges and instead functions as an auxiliary lane between interchanges. GA 400 has black on yellow and white signs at the start of part-time shoulder uses segments noting the hours of operation (see Figure 48), and black on yellow warning signs along the part-time shoulder uses segments with the message "shoulder lane" and a 45 mph advisory speed limit plaque (see Figure 49). A black on white regulatory sign with the message "shoulder lane begins 1000 feet" is placed near the end of on-ramps, as shown in Figure 50.

Figure 48. Photo. Sign at start of part-time shoulder use segment, GA 400.

(Source: Georgia Department of Transportation)

Figure 49. Photo. Warning sign along part-time shoulder use segment, GA 400.

(Source: Georgia Department of Transportation)

Figure 50. Photo. Regulatory sign on on-ramp, GA 400

(Source: Georgia Department of Transportation)

GDOT has a project underway to add dynamic signs to GA 400, and is planning another part-time shoulder use facility on I-85 that will open with dynamic signs. GDOT is adding dynamic signs to enable closure of the shoulder when disabled vehicles are stopped on it, and to more easily modify the set hours of operation.

Hawaii

Interstate H-1 in Hawaii employs static part-time shoulder use in the eastbound direction that operates during the a.m. peak period. Like Georgia's shoulder lane, it functions as an auxiliary lane between interchanges and does not run through interchanges. Ground mounted, two-section black on white regulatory signs with the messages "shoulder lane 5 AM – 8 AM exc. Sat Sun Hol" and "no trucks or buses" are used along the route; an example is shown in Figure 51.

Figure 51. Photo. Regulatory sign, I-H-1 mainline.

Similar signs are used at the start and end of segments and along ramps. Figure 52 shows signs on on-ramps and off-ramps. On I-H-1, signs are used on off-ramps because shoulder traffic is directed onto off-ramp shoulders to form a second exit lane rather than remaining on the freeway through interchanges.

Figure 52. Photo. Regulatory sign, I-H-1 on-ramp.
(Source: Google Maps)

Figure 53. Photo. Regulatory sign, I-H-1 off-ramp.
(Source: Google Maps)

In addition to eastbound part-time shoulder use, I-H-1 also has a moveable zipper barrier that is used to reduce westbound lanes and increase eastbound lanes during the a.m. peak hour. I-H-1 has dynamic signs to regulate use lanes created with the moveable barrier, but they do not communicate information related to part-time shoulder use.

Massachusetts

Massachusetts uses a mix of black on white regulatory signs and black on yellow warning signs. MassDOT initially implemented part-time shoulder use in 1985 with static signs at the start of part-time shoulder use segments, after on-ramps, and at the end of part-time shoulder uses segments. In the early months and years of operation, warning signs were added to on-ramps and "Mon - Fri" was added beneath the hours of operation; an example is shown in Figure 54. Prior to the addition of "Mon – Fri", some drivers were using the shoulder on weekends.

Figure 54. Photo. Updated regulatory sign, I-95 breakdown lanes.

(Source: Massachusetts Department of Transportation)

In 1999, MassDOT replaced the static signs, which were nearly 25 years old, on two of the three part-time shoulder use facilities. As part of the replacement, MassDOT added a dynamic panel to some of the static signs that displays "open" or "closed". The primary purpose of adding the dynamic panel was to provide a clearer message to drivers. The dynamic panel also creates the opportunity to open shoulders outside of regularly scheduled hours, and MassDOT has done this when construction closes general purpose lanes. Figure 55 illustrates the signing detail of the new dynamic signing.

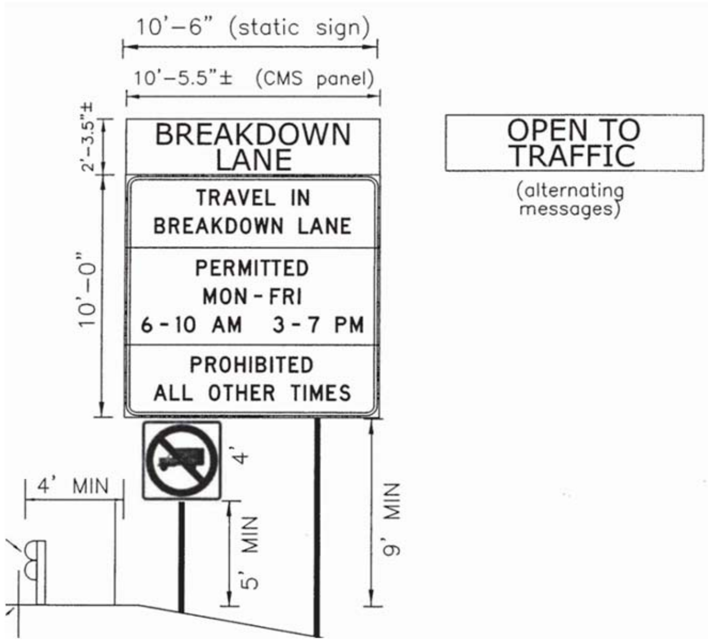


Figure 55. Illustration. Dynamic part-time shoulder use sign detail, I-95 breakdown lanes.

(Source: Massachusetts Department of Transportation)

These hybrid signs are located at the start of the permitted part-time shoulder uses lanes and after every on-ramp to the freeway where shoulder running is authorized. The dynamic messaging at the top of the sign is controlled remotely by the Incident Management Division in MassDOT's Highway Operations Center.

The varied messaging that can be displayed on these dynamic signs to inform travelers about the lane's current functionality are shown in Figure 56 and Figure 57.

Figure 56. Photo. Dynamic sign signifying the shoulder is closed to traffic, I-95 breakdown lanes.

(Source: Massachusetts Department of Transportation)

Figure 57. Photo. Dynamic sign signifying the shoulder is open for use, I-95 breakdown lanes.

(Source: Massachusetts Department of Transportation)

New Jersey

SR 29 in New Jersey employs static part-time shoulder use in the westbound direction that operates during the a.m. peak period. Ground-mounted black-on-white regulatory signs with the message “cars only may use shoulder 7 AM – 10 AM Mon-Fri” are placed along the route, as shown in Figure 58. Similar signs state the shoulder is only for access to SR 129, the right-hand side of a major fork at the end of the part-time shoulder use segment. There is one portable variable message sign at the start of the segment that supplements the static signs and informs drivers when the shoulder is open to traffic.

Figure 58. Photo. Regulatory sign, SR 29 mainline.

(Source: Google Maps)

The New Jersey Turnpike Newark Bay Extension currently employs part-time shoulder use to mitigate closure of the Pulaski Skyway, an adjacent facility, for reconstruction. Dynamic signs are used on the facility to open the shoulder during peak periods if traffic conditions warrant it. Some dynamic lane control signs are standalone (see Figure 59), and others are part of gantries with variable speed limit signs and variable message signs (see Figure 60)

Figure 59. Photo. Mast Arm Dynamic Lane Control Sign, New Jersey Turnpike Newark Bay Extension.

(Source: Kittelson & Associates, Inc.)

Figure 60. Photo. Dynamic Lane Control Sign on Gantry, New Jersey Turnpike Newark Bay Extension.

(Source: Kittelson & Associates, Inc.)

Virginia

Virginia's initial static part-time shoulder use facilities—I-66 in suburban Washington and I-264 in Virginia Beach—were both implemented in the early 1990s and uses similar signs. The shoulders on I-66 were converted to dynamic part-time shoulder use in 2015, and signing changed. Both facilities used black on white regulatory signs. Overhead signs had a dynamic section that displayed a red "x" when the shoulder was closed to traffic and green arrow when it was open the traffic. Ground mounted static signs listed the hours of the operation and other regulatory information. The shoulder was opened and closed on a fixed schedule, but operators could override the schedule and change dynamic indications if special conditions warranted opening or closing the lane outside of scheduled hours.

For travelers on the mainline, a combination of overhead and post-mounted signage denoted the start of permitted part-time shoulder uses, shown in Figure 61. Post-mounted signs displaying the hours of permitted shoulder use were spaced approximately every quarter mile throughout the corridor. Subsequent signs provided notice that there was no physical shoulder during the prescribed hours of shoulder use, shown in Figure 62.

Figure 61. Photo. Combination of static and dynamic signage, I-66 mainline.

(Source: Virginia Department of Transportation)

Figure 62. Photo. Notice informing motorists of the lack of right shoulder during shoulder running operations, I-66 mainline.

(Source: Google Maps)

While the shoulder was not in use, drivers were permitted to use the shoulder to exit the freeway a few hundred feet in advance of the gore point; Figure 63 illustrates the post-mounted, static signage used to inform motorist where they were permitted to begin exiting.

Figure 63. Photo. Static signage denoting permitted use of shoulder to exit during non-operational hours of shoulder use, I-66 mainline.

(Source: Virginia Department of Transportation)

Washington

Part-time shoulder use was implemented on US 2 eastbound in Everett, Washington, in 2009 on a trestle crossing wetlands. WSDOT used static signs to reduce the project cost and initially planned to implement dynamic signs at a later date. As of 2015, the static signs are working effectively and WSDOT no longer plans to implement dynamic signs. The US 2 part-time shoulder use segment is a commuter-oriented facility on a bridge with few ramps and minimal curvature, signs, and other elements that would increase driver workload. This makes it a good candidate for having static signs only.(33) Figure 64 shows an overhead regulatory sign on US 2 at the start of the part-time shoulder use segment. Ground mounted regulatory signs are used within the part-time shoulder use segment.

Figure 64. Photo. Overhead regulatory sign, US 2.

(Source: Google Maps)

Washington previously allowed buses and HOVs (with three or more passengers) to travel on the shoulder of westbound SR 520 approaching Lake Washington at all times. It was frequently described as static part-time shoulder use, but it was not in the sense it was never available for emergency refuge and always open to traffic. The lane was signed with static black on white regulatory signs prior to its replacement with a general purpose lane in 2015 as part of a roadway widening project.

Turnouts

Figure 65 shows the turnout sign sequence current in use in Virginia. Massachusetts uses one small black on white sign at the start of the turnout and does not provide any advance signs. For consistency with other types of roadside refuge areas such as slow moving truck turn offs on rural two-lane highways, the term "turnout" is preferred over "pull off".

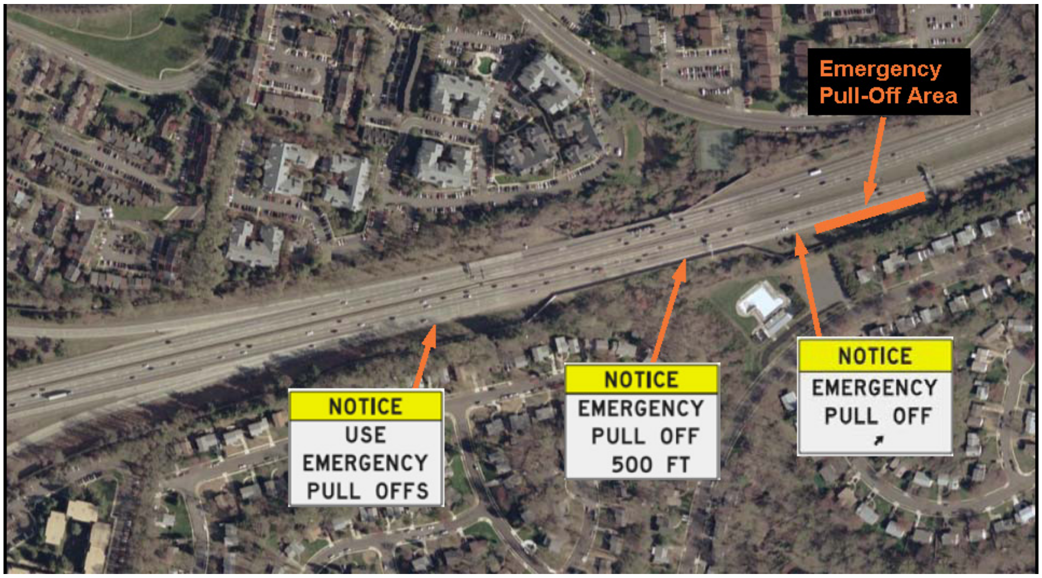


Figure 65. Photo. Turnout sign sequence, I-66.

(Source: Virginia Department of Transportation)

Pavement Marking

Figure 66 shows the use of two edge lines on I-H-1 in Hawaii, with the outside edge line terminating at the start of the bridge. "Shldr lane" word markings are provided (see red arrow).

Figure 66. Photo. Edge lines and "shldr lane" work markings on a part-time shoulder use section of I-H-1.

(Source: Kittelson & Associates, Inc.)

At the start and end of part-time shoulder use segments, the line between the shoulder and the adjacent travel lane typically changes from solid white to dotted white to encourage travel onto/off of the shoulder. Sometimes diagonal solid or dotted lines are used to further guide the transition. Figure 67 shows pavement markings at the start of the part-time shoulder use segment of US 2 in Washington State.

Figure 67. Photo. Edge line markings at the start of part-time shoulder use segment, US 2.

(Source: Google Earth)

Pavement markings at on- and off-ramp are more complex. They vary based on the types of entrance and exit configurations described in the geometric design section of this chapter, and existing state ramp-freeway junction marking practices. In general, pavement markings in the vicinity of a merge or diverge should provide a clear means for drivers on the mainline shoulder to pass through the ramp freeway junction, and they should also provide a means to transfer from the freeway to ramp or vise verse. Striping can create parallel or taper style merges and diverges.

MassDOT uses parallel style entrances and exits on part-time shoulder use facilities. Figure 68 illustrates the typical striping plans for part-time shoulder use at ramps on I-93 in Boston. The painted gore at on-ramps is used to terminate the exclusive use of the shoulder lane, allowing vehicles entering the freeway to drive on the shoulder for several hundred feet and then merge with the general purpose lanes. The acceleration lane for merging traffic is tapered down, and part-time shoulder use is resumed. Figure 69 shows an example of this merge; the solid white lines denote the shoulder, which reaches full-width after the acceleration lane is eliminated via the taper.

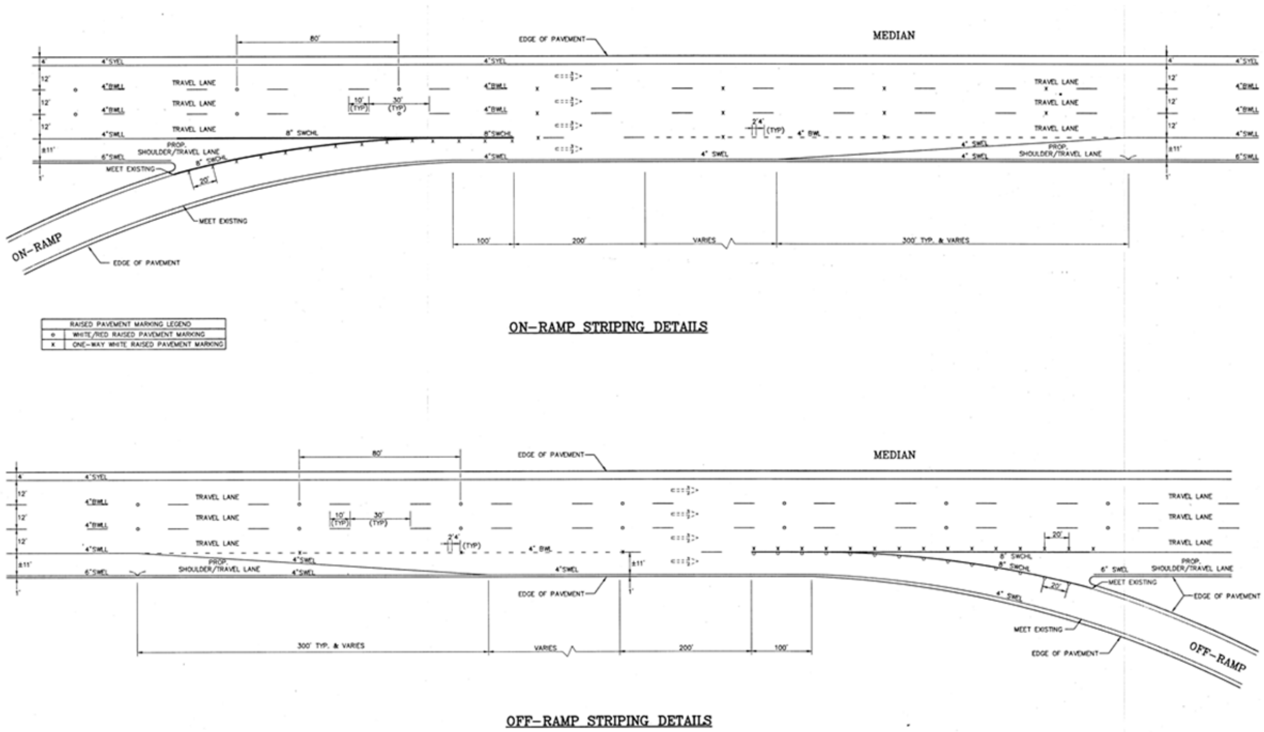


Figure 68. Illustration. On- and off-ramp striping plans, I-93.

(Source: Massachusetts Department of Transportation)

Figure 69. Photo. On-ramp striping, I-93.

(Source: Massachusetts Department of Transportation)

At off-ramps, a single solid line is used to transition traffic from general purpose lanes onto the shoulder, allowing general purpose traffic to exit. Part-time shoulder use resumes beyond the painted gore; Figure 70 illustrates an example of this transition.

Figure 70. Photo. Off-ramp striping, I-93.

(Source: Massachusetts Department of Transportation)

On I-66 in Virginia, the pavement markings for part-time shoulder use are carried through the on- and off-ramps. Vehicles from the general purpose lanes use a short portion of the shoulder to access the off-ramp, which is a taper-style design. Past the painted gore of the off-ramp, the shoulder lane again becomes a part-time lane.

Figure 71. Photo. Off-ramp striping, I-66.

(Source: Google Earth)

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