State of the Art on Auxiliary Lanes Between Freeway Interchanges: Part-time Shoulder Use Review

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RESEARCH &
DEVELOPMENT

State of the Art on Auxiliary Lanes Between Freeway Interchanges: Part-time Shoulder Use Review

FINAL REPORT

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Submitted by

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16. Abstract
This Technical Assistance Request (TAR) study reviewed national and international practices related to Part-Time Shoulder Use (PTSU) and Hard Shoulder Running (HSR) to guide potential implementation along North Carolina freeways, particularly the I-77 corridor in Charlotte. The study evaluated the safety, operational efficiency, maintenance, and enforcement implications of repurposing shoulders for peak-period travel and identified key design and management considerations for North Carolina conditions. The review combined an extensive literature synthesis with survey and targeted interviews involving agencies in Washington (SR-14), Ohio (I-670 SmartLane), Michigan (US-23 Flex Route), and Massachusetts (Route 3). Findings indicate that dynamic shoulder operations with active lane control can improve corridor performance by 7–25 % in capacity and reduce travel-time variability by 15–20 %, provided that operations are supported by robust incident management, CCTV monitoring, and coordinated enforcement. Safety outcomes remain mixed but manageable: overall crash frequencies may increase slightly during open periods, yet crash severity generally decreases, yielding fewer fatal and serious-injury crashes. No U.S. agency has discontinued a PTSU facility for safety reasons. Left-shoulder configurations tend to offer higher operational efficiency where geometry permits, while right-shoulder designs, as proposed for I-77, are most effective on segments with limited ramp activity. The findings recommend a phased implementation approach emphasizing early manual activation and pre-opening inspection; integration of lane-use control and variable speed systems; close coordination with maintenance and law enforcement; and longitudinal monitoring to evaluate safety, efficiency, and public response over time.

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EXECUTIVE SUMMARY

This report provides an evidence-based assessment of the operational, safety, and implementation considerations for auxiliary lane and Part-Time Shoulder Use (PTSU) applications, with emphasis on their feasibility along the I-77 corridor in the Charlotte metropolitan area. The study synthesizes lessons from domestic and international implementations to guide NCDOT Division 10 and the Mobility and Safety Division in evaluating when and how shoulder use can effectively relieve congestion and enhance freeway reliability. The review was completed over a three-month period and included (1) a systematic examination of published and unpublished literature (2010–2024) and (2) direct consultation through surveys and interviews with transportation professionals who have implemented PTSU systems across the United States.

Evidence from international and domestic programs shows that auxiliary lanes can deliver measurable safety and congestion-reduction benefits when coupled with strong operational control and enforcement strategies.

- **Safety Performance**: Safety performance findings from both international and U.S. studies show that PTSU can improve traffic flow but presents mixed safety outcomes depending on design, operating hours, and supporting technology. U.S. evidence from NCHRP Project 17-89 indicates that while fatal-and-injury and property-damage-only crashes can rise during active PTSU periods, severity tends to shift toward less-severe outcomes, with fewer K/A crashes reported. Hour-level analysis showed that crash rates during active shoulder-use periods were roughly 138% higher than during hours when the shoulder was closed, while crash levels in closed-shoulder periods were like those observed on comparable non-PTSU corridors. Sites with frequent turnouts (≈0.5-mile spacing) experienced ~5–10% lower crash rates and, when operated only during the most congested hours, could even produce net crash-cost reductions. Transitioning from static to dynamic PTSU was associated with ~7% fewer crashes, highlighting the value of adaptive operations and active traffic management. The clearest risk-mitigation levers are: limiting operation to true peak periods, providing ~0.5-mile turnouts, avoiding lane narrowing below 11 ft (or excluding trucks when lanes are narrower), and integrating PTSU with VSL and queue-warning systems, alongside real-time monitoring, rapid incident response, and driver education to support safe operations. Recent agency-level studies, such as those from the Wisconsin Department of Transportation, have reported safety improvements, suggesting that more detailed longitudinal evaluations are needed for corridors with unique shoulder-use designs.
- **Operational Efficiency**: Capacity improvements of 7–25 percent was documented during peak hours at bottleneck locations. On corridors such as California's I-580 and Minnesota's I-35W, travel time reductions ranged from 10 to 17 minutes per peak period, with consistent throughput maintained in general-purpose lanes. Systems that activate lanes dynamically in response to congestion thresholds tend to outperform those operating on fixed schedules.
- **Design and Geometric Constraints**: Performance is highly dependent on available shoulder width, structure limitations, and the presence of emergency pull-outs. Projects with constrained geometry, such as trestle bridges or reduced-width cross-sections, required additional refuge areas or modified operating rules to maintain acceptable safety margins.

Practitioner feedback highlighted a consistent set of lessons:

- Gradual automation: Agencies such as WSDOT and WisDOT advise starting with manual activation supported by CCTV checks before transitioning to full automation.
- End-of-lane visibility: MDOT emphasized designing clear lane-drop warnings to prevent late merges.
- ITS reliability: MassDOT and Ohio DOT recommended additional sensors, cameras, and message boards to improve situational awareness and automate VSL controls.

- Maintenance access: WisDOT recommended locating cameras and detectors on the outside shoulder for easier maintenance without closing travel lanes.
- Training and enforcement: Mr. Pete Jenior (Kittelson & Associates) and WSDOT emphasized early-phase driver education about new signs and enforcement to stabilize compliance during the first month of operation.

Common operational challenges include maintaining consistent TMC operator coordination, managing public expectations about limited operating hours, and ensuring rapid clearance of debris and incidents. Agencies noted that once systems mature, enforcement demand decreases and compliance stabilizes above 95%. Agencies also emphasized that successful PTSU deployment depends on proactive, adaptable, and well-coordinated implementation strategies. For example, New Hampshire DOT advised opening the shoulder slightly earlier as congestion begins to build, rather than waiting for strict threshold triggers, to maintain driver trust and smooth flow. Several agencies noted the importance of “right-sizing” each installation to corridor-specific conditions: geometry, traffic patterns, and technology readiness should dictate the final design and level of automation. Strong partnerships with law enforcement and public information offices were considered essential to ensure consistent enforcement and clear communication with the traveling public. Likewise, agencies stressed the need for clear, predictable activation windows and the capacity for rapid incident clearance to maintain public confidence. Finally, operations should remain flexible, allowing agencies to adjust hours of activation as traffic patterns evolve post-deployment.

Considering the costs, literature recommends that dynamic PTSU corridors typically cost $2–6 million per mile, driven largely by ITS gantries, dynamic message signs, sensors, and control software integration. Static systems cost 40–60 % less but lack flexibility. Annual operations and maintenance costs range from $100 000–$300 000 per mile, covering staffing, inspections, CCTV monitoring, and ITS maintenance. Agencies such as MDOT and WSDOT reported that cost-effectiveness improves when ITS investments are extended corridor-wide for future ATM readiness.

Overall, when implemented under defined geometric and operational conditions and following the informational sheets and design guidance provided in this report, part-time shoulder use can deliver measurable congestion relief and travel-time reliability improvements at a fraction of the cost of traditional widening. Experience from peer agencies demonstrates that, with robust ITS control, rapid incident clearance capability, well-trained personnel, and proactive public communication, PTSU can enhance freeway performance and reliability without compromising safety.

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Federal, State, and National Agencies / Programs

AASHTO – American Association of State Highway and Transportation Officials
Caltrans – California Department of Transportation
FHWA – Federal Highway Administration
MassDOT – Massachusetts Department of Transportation
MDOT – Michigan Department of Transportation
MnDOT – Minnesota Department of Transportation
NCDOT – North Carolina Department of Transportation
NCHRP – National Cooperative Highway Research Program
NHDOT – New Hampshire Department of Transportation
NJDOT – New Jersey Department of Transportation
ODOT – Ohio Department of Transportation
UDOT – Utah Department of Transportation
USDOT – United States Department of Transportation
WisDOT – Wisconsin Department of Transportation

Corridor and Facility Technical Terms

ADT – Average Daily Traffic
ATM – Active Traffic Management
BBS – Bus Bypass Shoulder
BOS – Bus-on-Shoulder
DMS – Dynamic Message Sign
DSU – Dynamic Shoulder Use
EB – Empirical Bayes (safety analysis method)
ETL – Express Toll Lane
GP – General-Purpose (lane)
HOT – High-Occupancy Toll (lane)
HOV – High-Occupancy Vehicle (lane)
HSR – Hard Shoulder Running
ITS – Intelligent Transportation Systems
LCS – Lane Control Signal
LOS – Level of Service
PTSU – Part-Time Shoulder Use
PPSU/PPLU – Peak Period Shoulder Lane Use
PUSL – Peak-use Shoulder Lane
TMC – Traffic Management Center
TOC – Transportation Operations Center
TOD – Time of Day (operation schedule)
VMT – Vehicle Miles Traveled
VSL – Variable Speed Limit

Regional or Project-Specific Acronyms

FIRST – Freeway Incident Response Safety Team (Minnesota)
Flex Route – MDOT's US-23 Dynamic Shoulder Use Corridor
PDSL – Priced Dynamic Shoulder Lane (MnPASS program, Minnesota)
RSR Bridge – Richmond–San Rafael Bridge (California)
SmartLane – ODOT's I-670 Dynamic Shoulder Lane Program

Chapter 1. Introduction

1.1 Background

Auxiliary lanes are segments of roadway adjoining the mainline travel lanes that support entering, exiting, and weaving movements. They are designed to reduce turbulence caused by merging and diverging traffic and to maintain a more balanced distribution of vehicles along a corridor (Neudorff et al., 2003). These lanes typically match the width of the through lanes, generally between 10 and 12 ft, with adjacent shoulders of 2–6 ft in areas with frequent heavy-vehicle activity (AASHTO, 2018).

Auxiliary lanes can be installed on both conventional roadways and freeways to manage merging, diverging, or weaving traffic movements. This study focuses on auxiliary lanes located on freeways between interchanges, where they serve as short connecting segments designed to balance traffic flow and reduce turbulence at ramp junctions. These lanes are typically introduced to accommodate local traffic exchanges and improve corridor-level operating conditions without requiring full mainline widening. When interchanges are closely spaced, auxiliary lanes may be extended between them to improve operational efficiency and provide a continuous merge–diverge area, whereas for widely spaced interchanges, a shorter auxiliary lane may be introduced upstream or downstream of the ramp terminals to facilitate smoother transitions (Neudorff et al., 2003).

Building on this principle, several transportation agencies have explored **part-time shoulder use (PTSU)** — also referred to as hard shoulder running (HSR), peak-period shoulder lane use (PPSU or PPLU), peak-use shoulder lane (PUSL), or dynamic shoulder use (DSU) — as an operational adaptation of the auxiliary-lane concept for freeway congestion management. Instead of constructing a permanent lane, PTSU temporarily repurposes the existing shoulder as a travel lane during periods of peak demand or recurring congestion. According to the AASHTO Transportation Operations Handbook (AASHTO, 2023), part-time shoulder use may apply to all vehicles or be limited to transit operations, activated either on a fixed schedule or dynamically through Traffic Management Center (TMC) control systems. As shown in Figure 1.1, different terminologies are used across agencies to describe these applications within broader active traffic management (ATM) frameworks (NASEM, 2024).

Figure 1.2 further illustrates the current distribution of PTSU/HSR, and Bus-on-Shoulder (BOS) facilities across the United States. As of July 2025, there are approximately 30 operational PTSU or HSR facilities and over 20 bus-on-shoulder corridors nationwide, spanning more than a dozen states. These include notable examples in Washington (SR-14, I-405), Minnesota (I-35W), Ohio (I-670), Massachusetts (I-93, Route 3), Michigan (US-23), and California (I-580). Collectively, these facilities represent a growing adoption of shoulder lane strategies to improve peak-period performance, safety, and reliability. The operational frameworks vary, from static peak-hour activations to fully dynamic, sensor-controlled systems, reflecting differences in corridor geometry, agency capability, and traffic management philosophy. For further details on design features, operational outcomes, and evaluation metrics of these facilities, see Jenior et al. (2016), Jenior et al. (2019), and the updated national synthesis in Jenior et al. (2024).

Building off this growing nationwide interest in PTSU, NCDOT's Division 10 is evaluating the potential for such treatments on select segments of I-77 in the Charlotte metropolitan area. This corridor experiences recurring congestion and bottlenecks, particularly in the northbound direction between Gilead Road and Catawba Avenue, and in the southbound direction between Gilead Road and I-485 as well as Sam Furr Road. Persistent spillback from interchange ramps and limited merge capacity have resulted in travel speeds dropping below 10 mph during peak hours (RS&H, 2025). Previous simulation analyses, including those based on VISSIM models, produced inconclusive results regarding the operational benefits of partial PTSU implementations. Subsequent 2035 scenario evaluations showed that while the Full Build alternative (implementation of PPSU along all feasible segments between Exits 19 and 35 on I-77) yielded an increase in average corridor speeds by approximately 6–10% and an increase in completed trips by about 10–15% during peak periods, the Partial Build scenario provided limited or inconsistent benefits compared to the No-Build case (RS&H, 2025).

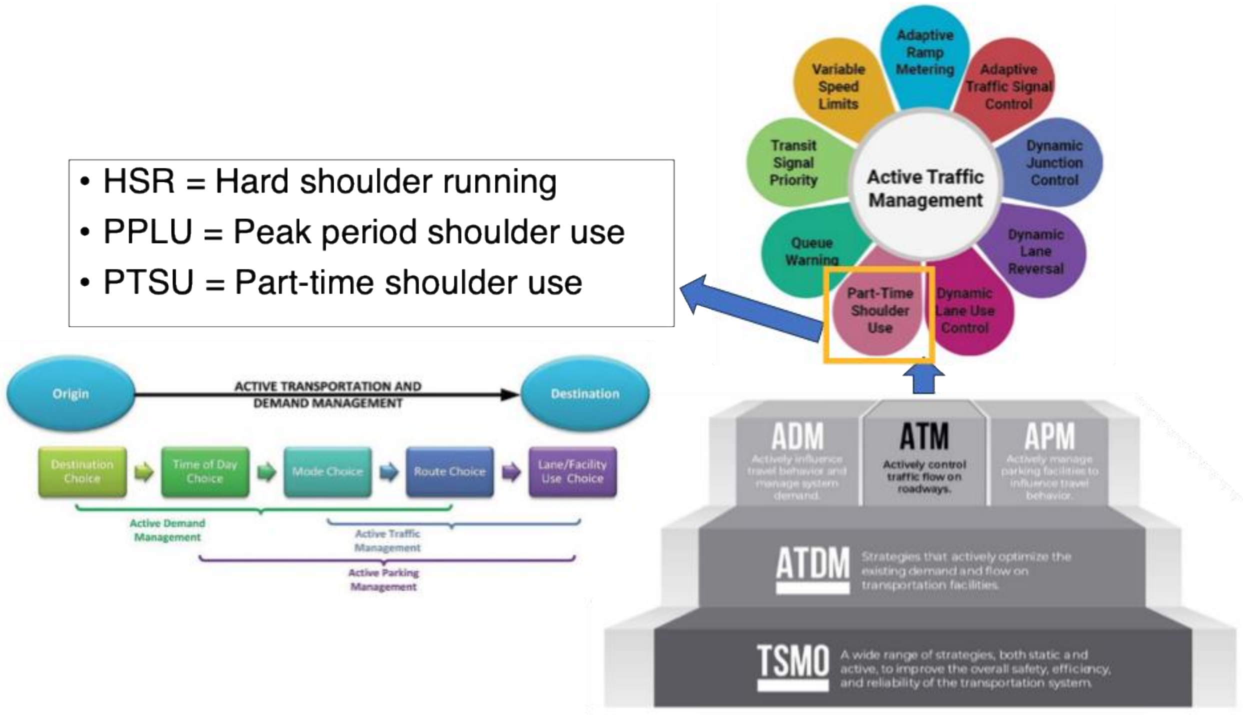


Figure 1.1 Terminologies used for part-time shoulder use in the context of active traffic management strategies (Image sources: NASEM, 2024 and Jenior et al., 2016)

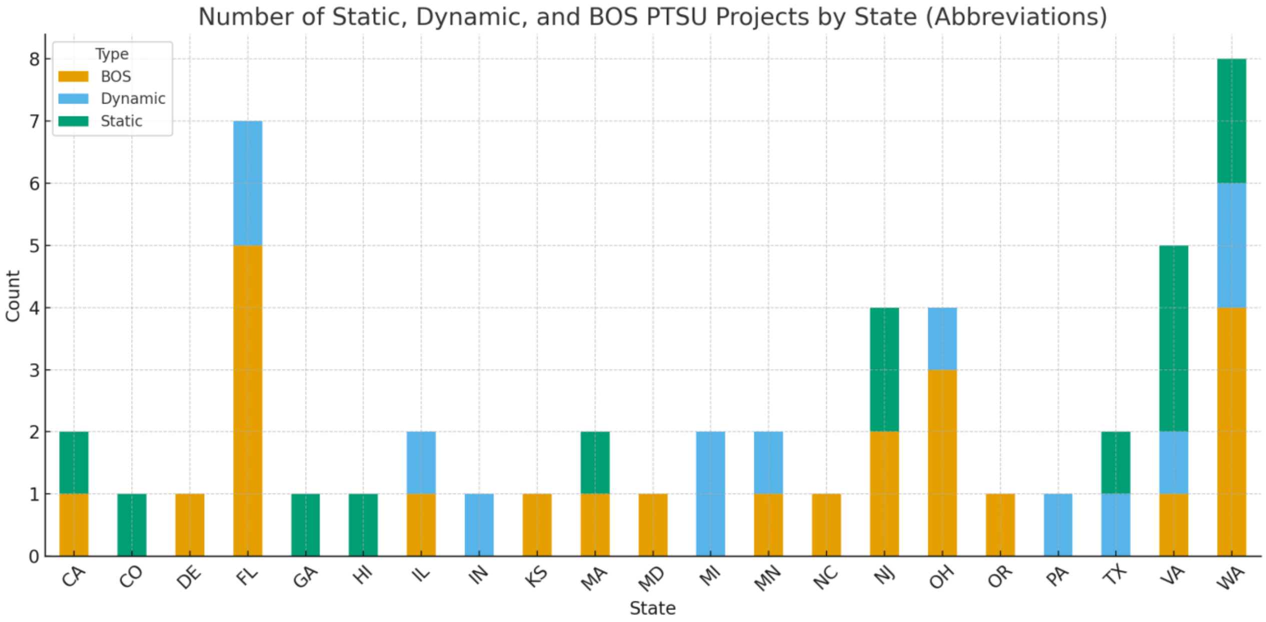


Figure 1.2 Number of static, dynamic, and bus-on-shoulder PTSU facilities across the United States (current as of Jul 2025) (Information Sources: Jenior et al., 2016; Jenior et al., 2024; and Manual Verification)

Given these conditions, division 10 seeks a clearer understanding of the safety and operational outcomes that can reasonably be expected from converting shoulders into peak-period travel lanes. The emphasis of this study is therefore on the shoulder lane use concept and the evidence available from existing implementations in the United States and abroad.

1.2 Research Objective and Scope

The primary objective of this study is to consolidate the best available information on the operational and safety effects of peak-hour shoulder use auxiliary lanes to guide decision-making for I-77 and similar corridors. Given Division 10's interest in understanding the practical outcomes of peak-hour shoulder use, the following questions were developed to capture lessons from agencies that have implemented similar facilities elsewhere:

1. How were lanes operated and how was lane clearing managed operationally?
2. How effective was the approach in terms of safety and maintenance goals? Were there any clear or visible safety or efficiency benefits observed—either through anecdotal reports from TMC operators or crash history analysis?
3. What was the level of driver compliance, and how was it managed (e.g., static vs. dynamic signage)? How much additional enforcement is needed to operationalize hard shoulder lanes?
4. What types of issues emerged during implementation, and how were they addressed?

Building on these questions, the specific objectives of this study were to:

- Evaluate operational and safety performance - review documented effects of PTSU and auxiliary lanes on congestion, travel time, throughput, crash rates, and emergency response.
- Assess design and implementation feasibility - examine geometric, structural, maintenance, and operational control considerations, including signage, incident management, and driver compliance.
- Synthesize best practices and recommendations - summarize lessons from U.S. and international applications to inform NCDOT's evaluation of potential pilot locations on I-77.

This project was limited to literature and case study review. It did not include new traffic modeling, field data collection, or on-site performance measurement.

1.3 Research Approach

This research approach combined a structured literature review with targeted outreach to practitioners. The process involved three main steps:

- Document Review: Compilation and analysis of published and unpublished research on auxiliary lanes, PTSU, and HSR programs from U.S. and international sources.
- Professional Consultation: Interviews and correspondence with state DOT staff experienced in implementing peak-hour shoulder use systems, including California, Minnesota, and Washington.
- Synthesis and Analysis: Integration of the findings to identify consistent trends, performance outcomes, and implementation challenges relevant to NCDOT's context.

The approach prioritized reliability of evidence and direct applicability to North Carolina's operational and geometric conditions.

1.4 Report Organization

The remainder of this report is organized as follows:

- Chapter 2 – Methodology: Describes the process used to collect, review, and synthesize published research and agency input.

- Chapter 3 – Literature Review: Summarizes the documented safety and operational impacts of auxiliary lanes and PTSU systems.
- Chapter 4 – Case Studies: Presents selected examples from state DOTs and international programs, focusing on implementation details and outcomes.
- Chapter 5 – Implications for NCDOT Division 10: Interprets key findings in the context of the I-77 corridor and outlines practical considerations for Division 10. Provides final observations and guidance for potential future studies or pilot implementations.

Chapter 2. Methodology

This study applied a structured approach to compile the up-to-date information on auxiliary lane and shoulder-use operations. The process involved two main components: (1) a comprehensive literature review with case studies and (2) practitioner outreach and survey analysis.

2.1 Literature Review and Case Studies

The study began with an extensive review of both published and unpublished materials related to HSR, PPSU, and PTSU. A combination of targeted keywords and controlled vocabulary terms was used to identify relevant studies and technical references. The review covered sources from 2010 through 2024, with particular attention to studies published after 2016, following the release of the Federal Highway Administration's (FHWA) Use of Freeway Shoulders for Travel report (Jenior et al., 2016).

Sources included peer-reviewed journal articles, FHWA and state DOT technical reports, and documented evaluations of operational projects. The focus was primarily on U.S.-based research to maintain consistency with domestic highway design standards, safety regulations, and operational conditions. International programs were reviewed selectively for comparison where relevant.

Following the literature review, the research team developed detailed case studies to examine how state DOTs have implemented, operated, and evaluated HSR or PPSU systems. Data were collected from agency reports, FHWA databases, and publicly available evaluations of existing corridors.

Each case study documented design features (lane configuration, shoulder width, structural modifications), operational strategies (activation times, signage, lane control, inspection routines), enforcement and incident management procedures, and the documented effects on safety, congestion, and travel time reliability.

2.2 Practitioner Outreach and Survey

To complement the document-based analysis, the research team contacted transportation professionals from several U.S. state DOTs with experience in operating or planning HSR and PTSU projects. This included structured email correspondence and a detailed online survey distributed nationally.

The survey sought information on:

- Project characteristics (corridor type, shoulder side used, width, and restrictions).
- Operational practices (inspection procedures, activation triggers, speed management).
- Infrastructure features (signing, pavement markings, emergency refuge areas).
- Safety and enforcement outcomes (observed crash trends, compliance issues, and enforcement methods).
- Implementation experiences (cost, public response, institutional coordination, and lessons learned).
- Survey responses were synthesized using an evaluation framework centered on safety, efficiency, compliance, and enforcement. This framework allowed for cross-comparison of agency experiences and helped identify patterns in performance outcomes.

A copy of the full survey instrument is provided in Appendix A for reference. The survey was administered between September 12, 2025, and October 3, 2025, and received 10 responses from representative agencies. Two incomplete responses were also reviewed for their feedback on earlier questions. In addition, three follow-up interviews were conducted to contextualize the survey findings. Finally, Google Maps imagery was reviewed for each of the selected facilities to obtain additional information related to the questions outlined in Section 1.2.

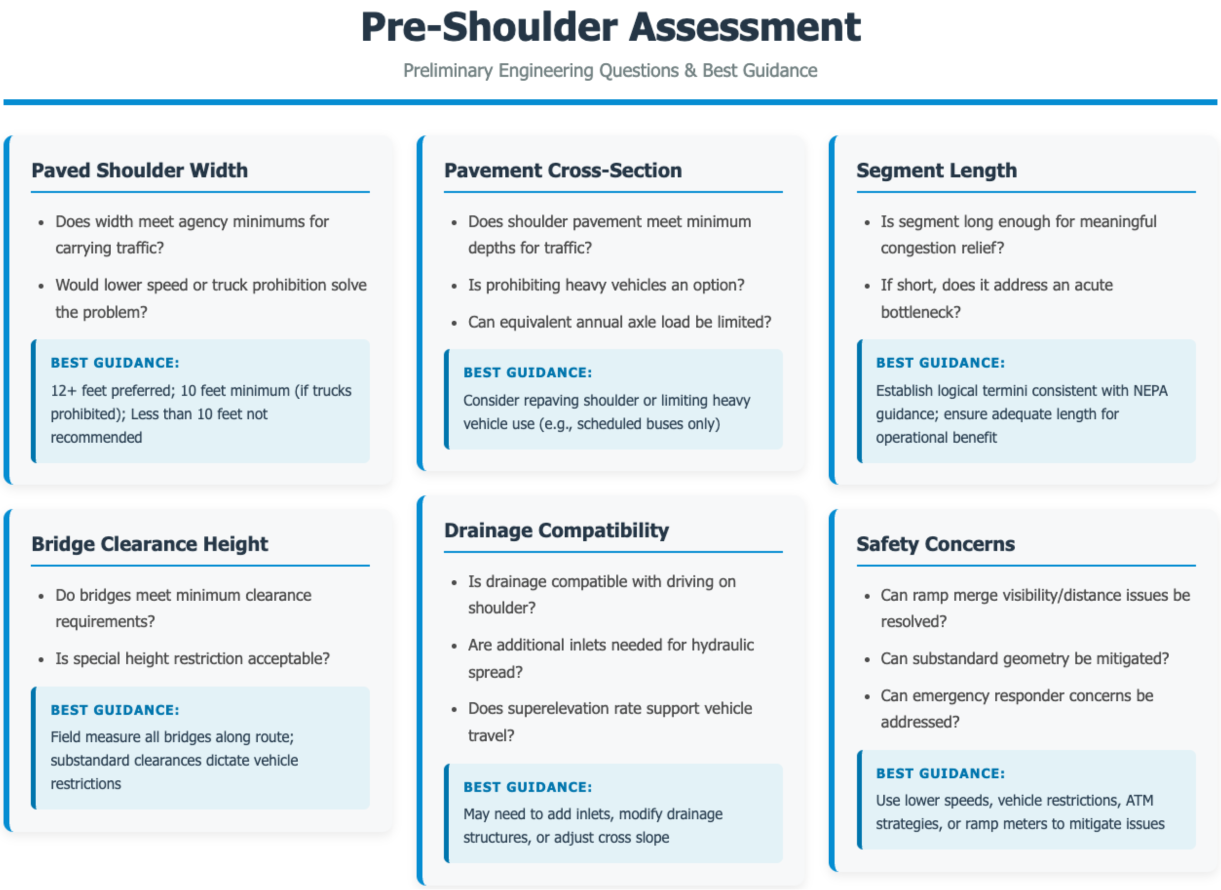
Chapter 3. Literature Review: Evidence from Research Studies

This chapter summarizes the current body of research and guidance on the planning, design, and operation of PTSU facilities. It reviews both domestic and international studies to classify implementation types, identify best practices, and evaluate performance outcomes. The chapter begins with a taxonomy of shoulder-use applications and design considerations, followed by a synthesis of operational guidance on lane activation and closure strategies. Subsequent sections examine documented benefits, safety and operational effects, driver compliance and enforcement approaches, maintenance and incident management practices, and cost components associated with implementation.

3.1 Taxonomy of Shoulder Implementations and Best Guidance

3.1.1 Preliminary assessment

Before implementing part-time shoulder use, agencies must conduct a comprehensive preliminary engineering assessment to evaluate whether existing infrastructure can support shoulder operations. Figure 3.1 shows an overview of these preliminary assessment questions synthesized from the literature with best practice guidance for each consideration.



Pre-Shoulder Assessment

Preliminary Engineering Questions & Best Guidance

Paved Shoulder Width

- Does width meet agency minimums for carrying traffic?
- Would lower speed or truck prohibition solve the problem?

BEST GUIDANCE:
12+ feet preferred; 10 feet minimum (if trucks prohibited); Less than 10 feet not recommended

Pavement Cross-Section

- Does shoulder pavement meet minimum depths for traffic?
- Is prohibiting heavy vehicles an option?
- Can equivalent annual axle load be limited?

BEST GUIDANCE:
Consider repaving shoulder or limiting heavy vehicle use (e.g., scheduled buses only)

Segment Length

- Is segment long enough for meaningful congestion relief?
- If short, does it address an acute bottleneck?

BEST GUIDANCE:
Establish logical termini consistent with NEPA guidance; ensure adequate length for operational benefit

Bridge Clearance Height

- Do bridges meet minimum clearance requirements?
- Is special height restriction acceptable?

BEST GUIDANCE:
Field measure all bridges along route; substandard clearances dictate vehicle restrictions

Drainage Compatibility

- Is drainage compatible with driving on shoulder?
- Are additional inlets needed for hydraulic spread?
- Does superelevation rate support vehicle travel?

BEST GUIDANCE:
May need to add inlets, modify drainage structures, or adjust cross slope

Safety Concerns

- Can ramp merge visibility/distance issues be resolved?
- Can substandard geometry be mitigated?
- Can emergency responder concerns be addressed?

BEST GUIDANCE:
Use lower speeds, vehicle restrictions, ATM strategies, or ramp meters to mitigate issues

Figure 3.1 Pre-Shoulder Lane Installation Assessment (Information sources: Jenior et al., 2016; AASHTO Operations Manual, 2023; and Jenior et al., 2021)

This assessment addresses six critical categories: paved shoulder width (evaluating whether the existing width meets agency minimums or if speed reductions or truck prohibitions could compensate for narrower shoulders), bridge clearance height (determining if special vehicle restrictions are needed for substandard vertical clearances), pavement cross-section depth (assessing whether the shoulder structure can handle traffic loads or if heavy vehicle restrictions are required), drainage compatibility (identifying needs for additional inlets or cross-slope modifications), segment length (confirming adequate distance for meaningful congestion relief or bottleneck mitigation), and safety concerns (resolving ramp merge visibility issues, substandard geometry, and emergency responder needs through lower speeds, vehicle restrictions, or active traffic management strategies).

3.1.2 Selection options for shoulder use

Once preliminary assessment confirms PTSU feasibility, agencies must make four critical operational decisions that fundamentally shape the project's design, cost, and performance characteristics. Figure 3.2 shows an overview of these selection options synthesized from literature, presenting each decision with associated advantages, disadvantages, and implementation impacts. First, the shoulder design type selection between left-side and right-side operation involves significant trade-offs; while left-side PTSU provides more tangible capacity improvements (Coffey and Park, 2018) and experiences less emergency vehicle conflicts, it presents sight distance challenges with median treatments and typically offers narrower shoulders, whereas right-side PTSU is easier to implement with wider existing shoulders but suffers from conflicts at ramp merge and diverge areas (Jenior et al., 2016). Second, speed limit control determines whether the shoulder operates at posted speeds or requires reduced speeds, with lower speeds significantly improving safety on geometrically constrained or narrow segments. Third, the shoulder user type ranges from bus-only operations (requiring minimal ITS infrastructure) to HOV-only, HOT (high-occupancy toll), all vehicles except trucks (the most common configuration for dynamic and static PTSU), or all vehicles including trucks. Fourth, hours of operation distinguish between static PTSU with fixed time-of-day schedules and dynamic PTSU with congestion-based activation, noting that while dynamic operation provides a 7.3% crash reduction compared to static operation, it requires extensive ITS infrastructure and traffic management center operations (Jenior et al., 2021).

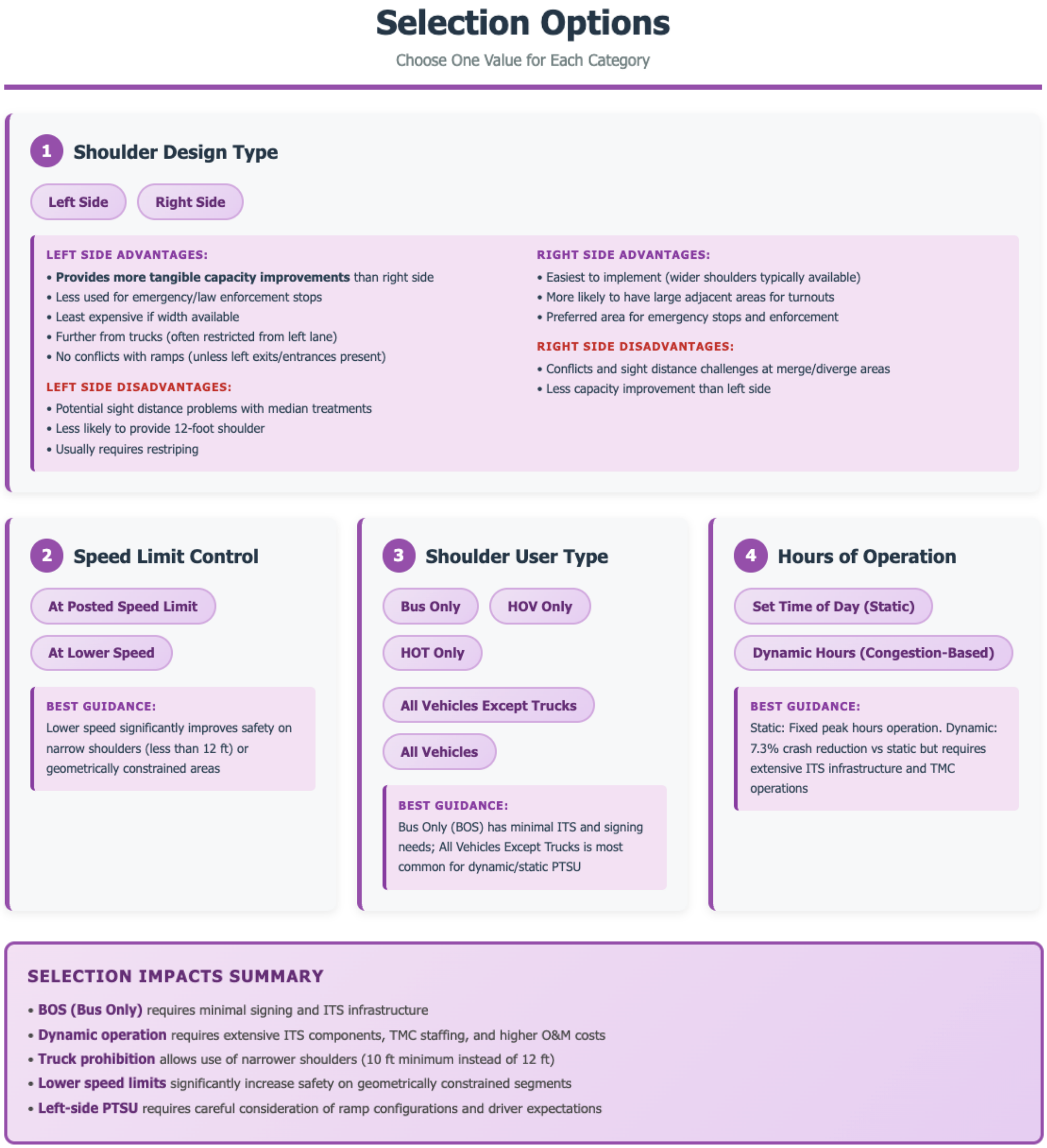
3.1.3 Design considerations

After establishing the operational framework through the selection process, agencies must address thirteen detailed design considerations to ensure safe and effective PTSU implementation. These design levers span geometric, operational, and safety requirements. Figure 3.3 shows an overview of these design levers synthesized from literature, organized into three columns with specific guidance values and requirements for each consideration.

The key considerations and guidance include the following (Jenior et al., 2016; AASHTO, 2018):

- Beginning and end segments must be located at logical termini with high visibility to approaching drivers, avoiding horizontal curves, crest vertical curves, and high driver workload areas.
- lane width should be 12 feet or greater, with a minimum of 10 feet acceptable only when trucks is prohibited and adequate lateral offset exists.
- shoulder width must leave several feet beyond the PTSU lane for vehicle departures and maintenance needs.
- lateral offset to obstructions requires a minimum of 1.5 feet from the lane edge to barriers, guardrails, or bridge rails; bridge width must provide at least 11.5 feet total (10-foot lane plus 1.5-foot offset).
- stopping sight distance on horizontal curves may fall below AASHTO minimums, requiring barrier relocation, speed restrictions, or design exceptions; cross slope may need adjustment through grade break rounding or pavement overlays.
- vertical clearance must be field measured for all bridges with substandard clearances dictating vehicle restrictions.
- ramp-freeway junctions can accommodate PTSU with either taper or parallel-style ramps, with ramp meters highly effective at mitigating conflicts.

- turnout placement should provide emergency refuge spaces at 0.5-mile intervals that are 16 feet or wider (though not needed for BOS).
- signs must use black-on-white regulatory markings placed at segment termini, ramps, and recurring intervals.
- pavement markings require a solid edge line plus a second solid line at the pavement edge in matching colors (white for right, yellow for left) with no diamond symbols for BOS; and
- colored pavement should not be used unless approved as an experiment by the MUTCD team.



Selection Options

Choose One Value for Each Category

1 Shoulder Design Type

Left Side | Right Side

LEFT SIDE ADVANTAGES:
- **Provides more tangible capacity improvements** than right side
- Less used for emergency/law enforcement stops
- Least expensive if width available
- Further from trucks (often restricted from left lane)
- No conflicts with ramps (unless left exits/entrances present)

LEFT SIDE DISADVANTAGES:
- Potential sight distance problems with median treatments
- Less likely to provide 12-foot shoulder
- Usually requires restriping

RIGHT SIDE ADVANTAGES:
- Easiest to implement (wider shoulders typically available)
- More likely to have large adjacent areas for turnouts
- Preferred area for emergency stops and enforcement

RIGHT SIDE DISADVANTAGES:
- Conflicts and sight distance challenges at merge/diverge areas
- Less capacity improvement than left side

2 Speed Limit Control

At Posted Speed Limit

At Lower Speed

BEST GUIDANCE:
Lower speed significantly improves safety on narrow shoulders (less than 12 ft) or geometrically constrained areas

3 Shoulder User Type

Bus Only | HOV Only

HOT Only

All Vehicles Except Trucks

All Vehicles

BEST GUIDANCE:
Bus Only (BOS) has minimal ITS and signing needs; All Vehicles Except Trucks is most common for dynamic/static PTSU

4 Hours of Operation

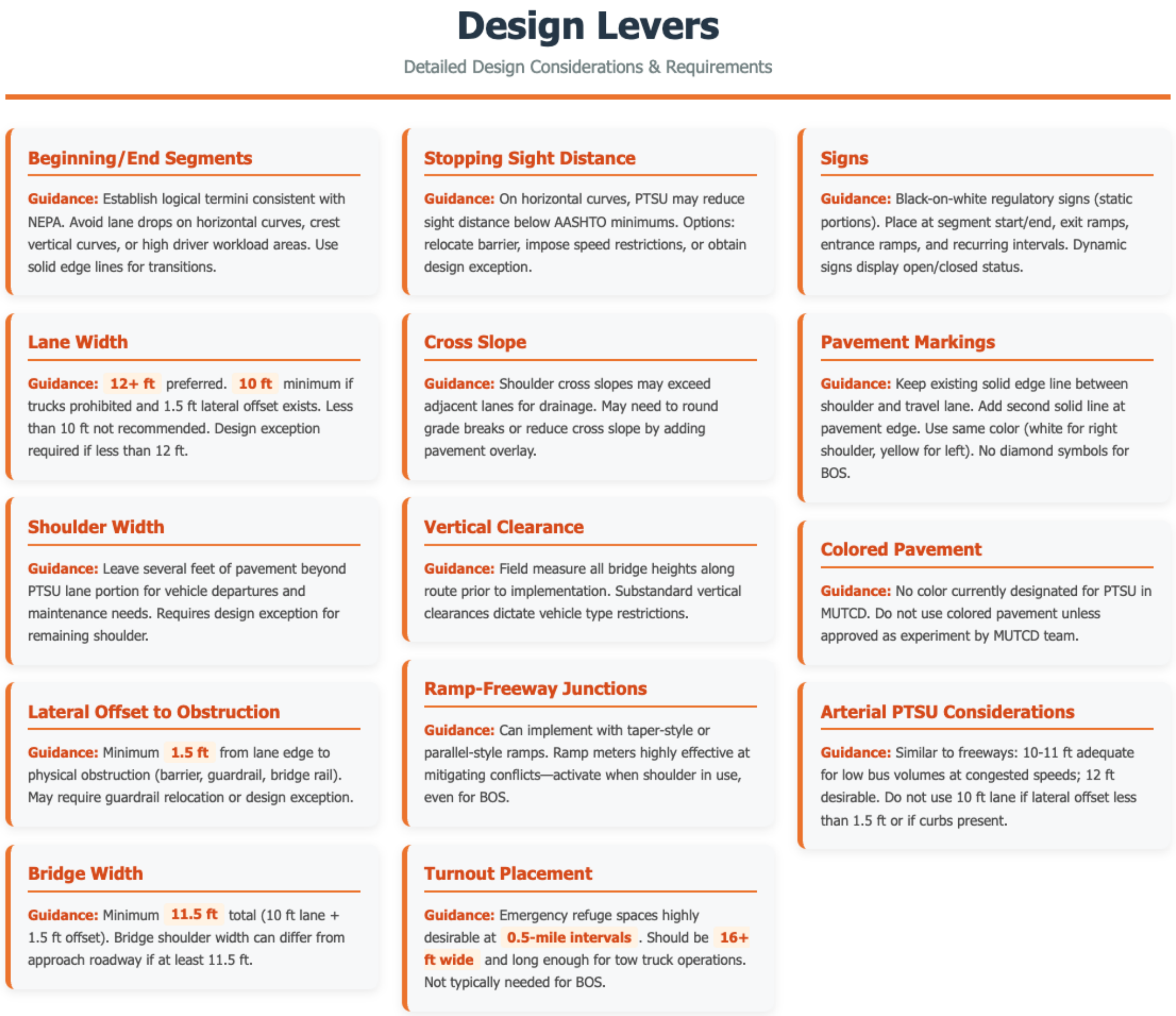
Set Time of Day (Static)

Dynamic Hours (Congestion-Based)

BEST GUIDANCE:
Static: Fixed peak hours operation. Dynamic: 7.3% crash reduction vs static but requires extensive ITS infrastructure and TMC operations

SELECTION IMPACTS SUMMARY
- **BOS (Bus Only)** requires minimal signing and ITS infrastructure
- **Dynamic operation** requires extensive ITS components, TMC staffing, and higher O&M costs
- **Truck prohibition** allows use of narrower shoulders (10 ft minimum instead of 12 ft)
- **Lower speed limits** significantly increase safety on geometrically constrained segments
- **Left-side PTSU** requires careful consideration of ramp configurations and driver expectations

Figure 3.2 Shoulder Lane selection options summary (Jenior et al., 2016)



Design Levers

Detailed Design Considerations & Requirements

Beginning/End Segments

Guidance: Establish logical termini consistent with NEPA. Avoid lane drops on horizontal curves, crest vertical curves, or high driver workload areas. Use solid edge lines for transitions.

Lane Width

Guidance: **12+ ft** preferred. **10 ft** minimum if trucks prohibited and 1.5 ft lateral offset exists. Less than 10 ft not recommended. Design exception required if less than 12 ft.

Shoulder Width

Guidance: Leave several feet of pavement beyond PTSU lane portion for vehicle departures and maintenance needs. Requires design exception for remaining shoulder.

Lateral Offset to Obstruction

Guidance: Minimum **1.5 ft** from lane edge to physical obstruction (barrier, guardrail, bridge rail). May require guardrail relocation or design exception.

Bridge Width

Guidance: Minimum **11.5 ft** total (10 ft lane + 1.5 ft offset). Bridge shoulder width can differ from approach roadway if at least 11.5 ft.

Stopping Sight Distance

Guidance: On horizontal curves, PTSU may reduce sight distance below AASHTO minimums. Options: relocate barrier, impose speed restrictions, or obtain design exception.

Cross Slope

Guidance: Shoulder cross slopes may exceed adjacent lanes for drainage. May need to round grade breaks or reduce cross slope by adding pavement overlay.

Vertical Clearance

Guidance: Field measure all bridge heights along route prior to implementation. Substandard vertical clearances dictate vehicle type restrictions.

Ramp-Freeway Junctions

Guidance: Can implement with taper-style or parallel-style ramps. Ramp meters highly effective at mitigating conflicts—activate when shoulder in use, even for BOS.

Turnout Placement

Guidance: Emergency refuge spaces highly desirable at **0.5-mile intervals**. Should be **16+ ft wide** and long enough for tow truck operations. Not typically needed for BOS.

Signs

Guidance: Black-on-white regulatory signs (static portions). Place at segment start/end, exit ramps, entrance ramps, and recurring intervals. Dynamic signs display open/closed status.

Pavement Markings

Guidance: Keep existing solid edge line between shoulder and travel lane. Add second solid line at pavement edge. Use same color (white for right shoulder, yellow for left). No diamond symbols for BOS.

Colored Pavement

Guidance: No color currently designated for PTSU in MUTCD. Do not use colored pavement unless approved as experiment by MUTCD team.

Arterial PTSU Considerations

Guidance: Similar to freeways: 10-11 ft adequate for low bus volumes at congested speeds; 12 ft desirable. Do not use 10 ft lane if lateral offset less than 1.5 ft or if curbs present.

Figure 3.3 Overview of design guidance for PTSU installations (Information sources: Jenior et al., 2016 and AASHTO Green Book, 2018)

3.1.4 Ramp-freeway junction design for right and left shoulders

When the right shoulder is designated for part-time travel, its layout should ensure driver comprehension, operational consistency, and safety at transitions. The guidance suggests that logical termini must be established early in project scoping, typically in locations that are highly visible, tangent, and free of visual obstructions such as horizontal or crest vertical curves (Jenior et al., 2019). Beginnings of right-side shoulder use should use pavement markings and signage that clearly guide vehicles from the adjacent general-purpose lane into the shoulder (see Figure 3.4 for sample design illustrations). A diagonal solid edge line and dotted continuity line are typically applied to create a smooth lateral shift while maintaining the through-lane alignment. The shoulder may also begin as an add-lane extension from an on-ramp, allowing ramp traffic to merge directly into the shoulder when open, a desirable configuration at high-volume ramps or bottlenecks. However, this approach should be avoided if the shoulder serves a restricted use (e.g., HOV or bus-only) or where truck percentages are high.

At the end of the PTSU section, taper markings and a solid edge line should guide traffic back into the main line. Shoulders should not terminate directly onto exit ramps, as this can surprise drivers, except where ramp volumes are large, and the operational intent is clear (e.g., major system interchanges). If a general-purpose lane is added upstream of an interchange, the shoulder can logically terminate where that lane begins, minimizing operational disruption. In some complex systems, the shoulder may continue through a fork to provide additional lane balance, as seen on US 2 (WA) and SR 29 (NJ). For corridors with closely spaced interchanges, states such as Georgia and Hawaii employ static or limited part-time shoulder use between interchanges only, effectively serving as temporary auxiliary lanes that relieve merge–diverge turbulence without functioning as continuous through lanes (though capacity improvements occur more when continuous lane movement is allowed) (Jenior et al., 2016). Expert interviews recommended focusing on corridors with high ramp activity and performing entry–exit analyses to determine whether a continuous shoulder-use lane or a limited ramp-to-ramp configuration would provide greater operational benefit.

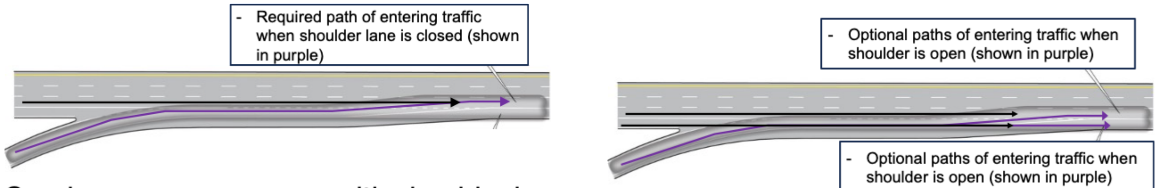
Figure 3.4 shows sample design for how one-lane on and off ramps can be arranged for shoulder use. For one-lane ramps, PTSU is generally compatible, but the treatment depends on ramp type. Parallel-style ramps, which include a short speed-change lane adjacent to the freeway, are easiest to integrate when the shoulder opens, the speed-change lane becomes part of the shoulder, effectively creating a temporary taper-style ramp. This design can slightly reduce ramp capacity if the gore angle is large (short merge distance), but performs well when geometry allows long, gentle tapers. Taper-style ramps, by contrast, directly cross the shoulder and can create conflicts between ramp and shoulder traffic. To avoid this, agencies should convert taper ramps to parallel configurations with a marked speed-change lane before implementing shoulder use—usually achievable with pavement marking changes if the shoulder is structurally adequate (Jenior et al., 2016).

For two-lane ramps, integration becomes more complex. In parallel two-lane on-ramps, the inner speed-change lane typically merges into the shoulder lane when open, forming an inside merge that may surprise drivers and should only be used where visibility and driver awareness are high. For taper two-lane ramps, conflicts are even more pronounced; these usually require adding a second speed-change lane, terminating the PTSU section upstream, or reducing the ramp to one lane. Where geometric or operational constraints make modification impractical, agencies may also apply junction control strategies, such as variable merge control or dynamic lane assignment, to safely manage interactions between ramp and shoulder users.

Recent studies have highlighted that converting the left shoulder into a part-time travel lane can be an effective congestion-management strategy when traditional widening is infeasible due to cost or environmental constraints. Compared with right-shoulder use, the left-shoulder configuration can improve operations by providing an additional lane where bottlenecks occur near the media and provide more continuous flow of traffic relative to right-shoulder use which is interrupted due to on and off ramps (Coffey & Park, 2018). Moreover, simulation and field evaluations have shown that such dynamic shoulder lanes can raise freeway capacity by up to 20–25 percent and lower rear-end crashes through reduced queuing and smoother traffic flow (Deng et al., 2023). Use of both left and right shoulders at the same time is not recommended for safety reasons (Jenior et al., 2016).

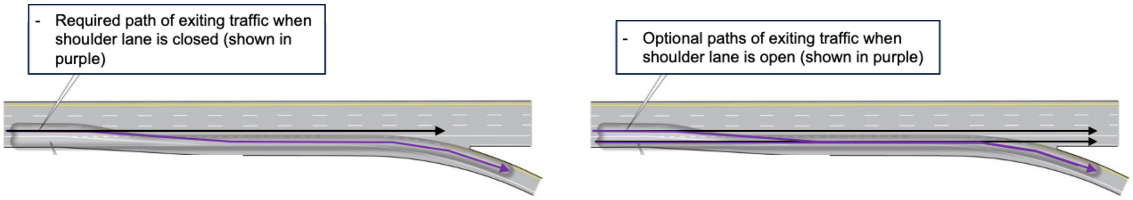
Typical start of part-time shoulder use

Typical end of part-time shoulder use



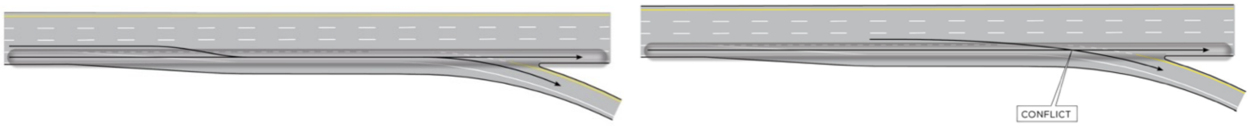
One-lane on-ramp merge with shoulder lanes closed (parallel-style merge)

One-lane on-ramp merge with shoulder lanes open (taper-style merge)

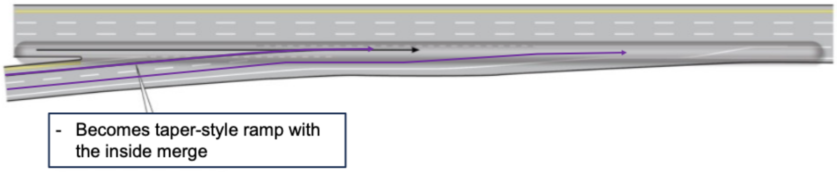


One-lane off-ramp diverge with shoulder lanes closed (parallel-style diverge)

One-lane off-ramp diverge with shoulder lanes closed (taper-style diverge)



One-lane off-ramp diverge with shoulder lanes open (parallel-style ramps are preferred over taper-style ramps due to conflict)



Two-lane on-ramp merge with shoulder lanes open (taper-style merge for the inner on-ramp and parallel merge for the outer on-ramp). Some two-lane ramps are not compatible with shoulder use without major modifications.

Figure 3.4 Various design illustrations for right-shoulder operations (Source: Kittleson and Associates; Jenior et al., 2016)

Ramp Signage and ITS Treatments:

While extensive guidance exists for corridor-level ITS devices supporting part-time shoulder use (e.g., overhead lane-control signals, CCTV coverage, and dynamic message signs), the literature provides very limited detail on ramp-specific signage or ITS treatments for PTSU corridors. Few agencies document how on-ramp drivers are informed about shoulder-lane status or how merge expectations are communicated when the shoulder functions as a travel lane. Given the operational importance of these locations, where drivers must make quick decisions about lane selection and merging, this represents a notable gap in available guidance. Preliminary interviews suggest that static or dynamic "shoulder open/closed" indicators at on ramps could help reinforce driver expectations and reduce confusion.

Additional research and agency coordination will be needed to identify best practices, develop standard treatments, and refine design guidance for ramps in PTSU environments.

3.2 Guidance on Operations of Dynamic PTSU: When to Open and When to Close?

Determining when to open a PTSU lane is one of the most critical operational design decisions. Three primary strategies are commonly used: fixed time-of-day, volume-based, and speed-based activation. Each approach balances operational simplicity, reliability, and responsiveness differently. Fixed schedules are suited to corridors with highly predictable peak congestion, requiring minimal infrastructure investment but offering limited adaptability to incidents or atypical conditions. Volume-based parameters are proactive, using real-time flow thresholds (typically 70–80% of breakdown flow rate) to anticipate congestion and initiate opening in time to prevent flow collapse. This approach works best where demand growth and bottleneck capacity are well characterized but requires accurate detectors and advance sweep time. Speed-based parameters, on the other hand, are reactive, triggering opening when observed speeds fall below a threshold (often 45 mph), indicating active congestion. While easier to implement using field sensors, this approach risks "late" activation, as breakdown may already have occurred. The response from NHDOT also encouraged DOTs to not be "afraid to open their shoulder a little earlier than the numbers suggest," to prevent driver frustration when the traffic is building up but the signs are still off.

An emerging alternative is occupancy-based decision logic (Yao et al., 2024), which measures detector occupancy (the proportion of time a sensor is covered by vehicles) to infer approaching breakdown. While not yet widely used in U.S. deployments, occupancy can serve as a hybrid indicator, bridging speed and volume by providing early warning of density build-up, and could enhance predictive reliability when combined with other data streams.

The most effective and resilient practice is to **combine both volume and speed thresholds**, allowing proactive congestion prevention and reactive response to unexpected slowdowns. Operators should retain discretionary control during adverse weather or downstream incidents (Jenior et al., 2019).

The decision to close a dynamic part-time shoulder use (D-PTSU) lane must balance operational efficiency with safety and incident readiness. In general, shoulders should be closed as soon as traffic volumes drop sufficiently to maintain free-flow conditions on the remaining lanes, but not so early that closure reintroduces congestion. Because speed typically recovers quickly after breakdown, speed-based thresholds alone are unreliable for closure decisions. Instead, a volume-based parameter, set so that per-lane volumes on the general-purpose lanes remain below the agency's reopening threshold, is most effective. This ensures that once the shoulder closes, total demand can still be served without renewed queueing. Agencies are encouraged to adjust closure thresholds based on observed field performance and operator experience over time.

Beyond traffic flow, non-traffic conditions, such as incidents, stalled vehicles, debris, maintenance, or adverse weather, may necessitate early closure regardless of demand. D-PTSU systems enable operators to close the shoulder almost immediately in such situations, offering greater flexibility and safety than static part-time configurations. Finally, **safety remains central**: shoulders should remain open only as long as congestion relief benefits outweigh the temporary loss of emergency refuge space. Regular monitoring and coordination with maintenance crews, law enforcement, and emergency responders are essential to ensure safe and timely closure decisions.

3.3 Benefits of PTSU

As shown in Figure 3.5, the primary benefits of PTSU include travel time reliability improvements, reduced congestion and vehicle-hours traveled, and enhanced level of service (LOS) through increased lane-level capacity during peak periods (NASEM, 2024). Secondary benefits may include reductions in crash rates and severity, improved responder safety, and greater compliance with dynamic signage when integrated with ATM systems. These safety and compliance gains, while less consistently documented, complement the primary operational improvements of PTSU. These are explored further in next few sections.

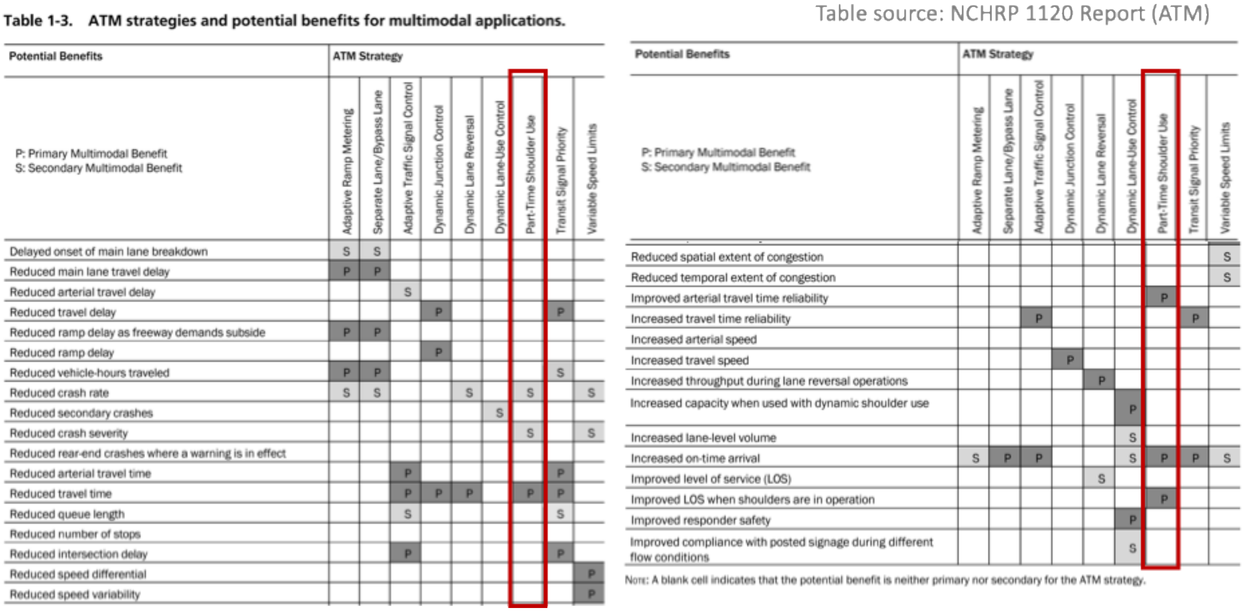


Table 1-3. ATM strategies and potential benefits for multimodal applications.

Table source: NCHRP 1120 Report (ATM)

Potential Benefits P: Primary Multimodal Benefit S: Secondary Multimodal Benefit	Adaptive Ramp Metering	Separate Lane/Bypass Lane	Adaptive Traffic Signal Control	Dynamic Junction Control	Dynamic Lane Reversal	Dynamic Lane-Use Control	Part-Time Shoulder Use	Transit Signal Priority	Variable Speed Limits
Delayed onset of main lane breakdown	S	S							
Reduced main lane travel delay	P	P							
Reduced arterial travel delay			S						
Reduced travel delay				P				P	
Reduced ramp delay as freeway demands subside	P	P							
Reduced ramp delay				P					
Reduced vehicle-hours traveled	P	P						S	
Reduced crash rate	S	S			S		S		S
Reduced secondary crashes						S			
Reduced crash severity							S		S
Reduced rear-end crashes where a warning is in effect									
Reduced arterial travel time			P					P	
Reduced travel time			P	P	P		P	P	
Reduced queue length			S					S	
Reduced number of stops									
Reduced intersection delay			P					P	
Reduced speed differential									P
Reduced speed variability									P

Potential Benefits P: Primary Multimodal Benefit S: Secondary Multimodal Benefit	Adaptive Ramp Metering	Separate Lane/Bypass Lane	Adaptive Traffic Signal Control	Dynamic Junction Control	Dynamic Lane Reversal	Dynamic Lane-Use Control	Part-Time Shoulder Use	Transit Signal Priority	Variable Speed Limits
Reduced spatial extent of congestion									S
Reduced temporal extent of congestion									S
Improved arterial travel time reliability							P		
Increased travel time reliability			P					P	
Increased arterial speed									
Increased travel speed				P					
Increased throughput during lane reversal operations					P				
Increased capacity when used with dynamic shoulder use						P			
Increased lane-level volume						S			
Increased on-time arrival	S	P	P			S	P	P	S
Improved level of service (LOS)					S				
Improved LOS when shoulders are in operation							P		
Improved responder safety						P			
Improved compliance with posted signage during different flow conditions						S			

NOTE: A blank cell indicates that the potential benefit is neither primary nor secondary for the ATM strategy.

Figure 3.5 Potential benefits of part-time shoulder use include travel time benefits and improve LOS (primary benefits) and reduced crash rate and severity (as secondary benefits). (Image source: NASEM, 2024)

3.4 Safety Effects of PTSU

Broadly, analyzing the safety effects of PTSU requires detailed longitudinal studies. The best guidance in terms of safety effects comes from NCHRP 17-89 Vol 1 and 2 (Jenior et al., 2021). The safety analysis in this report was conducted using a rigorous predictive-modeling framework consistent with the Highway Safety Manual (AASHTO, 2010). The safety models were developed using crash and roadway data from 10 representative freeway corridors across the United States, including GA 400 (GA), I-264 (VA), I-495 (VA), I-H1 (HI), I-35W (MN), I-66 (VA), and I-85 (GA) for PTSU sites, and I-35W/I-94/US 169 (MN), I-670/I-70 (OH), and I-71 (OH) for BOS sites, covering over 100 miles of one-way facilities with comparable control segments for before-after and cross-sectional analysis. Researchers developed Crash Prediction Models (CPMs) for freeway segments and ramp junctions based on negative binomial regression, relating crash frequency to geometric and operational variables such as lane width, shoulder width, and PTSU operating duration. Separate models were estimated for fatal-and-injury (FI) and property-damage-only (PDO) crashes to reflect their distinct causal mechanisms. The core modeling used the Safety Performance Function (SPF) with calibration and adjustment factors (AFs) derived from statistically significant site features, following HSM Part C procedures. Three model forms were used (fixed-parameter, random-parameter, and latent-class models) and were compared to capture both observed and unobserved heterogeneity across study corridors. While the advanced model types provided additional insights, the fixed-parameter negative binomial CPMs were recommended for future HSM inclusion due to their stability and transferability. The models were supplemented by Severity Distribution Functions (SDFs) that apportioned predicted FI crashes into K, A, B, and C levels, enabling a full assessment of PTSU's crash frequency and severity impacts across diverse sites.

3.4.1 Key Findings

#1 Overall crash frequency vs. severity mix: Urban freeway segments with PTSU generally see higher FI and PDO crash frequencies than comparable non-PTSU segments, but the severity mix shifts away from the most severe (K/A) crashes toward B/C levels. In model terms, typical FI crash AFs are greater than 1 (e.g., ≈1.4 at 11–12 ft lanes and ~20% operating time), while the SDF shows lower K/A proportions as operating time and barrier adjacency increase. This pattern largely stems from increased lane-change activity near merge and diverge points during PTSU operation. Broadly, crash outcomes represent a complex interplay of design and operational factors, including: (a) proportion of time that PTSU operates, (b) PTSU lane width, (c) extent of transition zone coverage, (d) number of through lanes, and the (e) presence and spacing of turnouts, as discussed next:

- **"Open vs. closed" matters most**: There is higher safety risk when the shoulder is open: hourly analyses show ~138% increase in total crashes with the shoulder open vs. closed, while PTSU closed is equivalent to safety under no PTSU (no practical difference).
- **Operating time is a strong driver**: More hours of PTSU operation led to more crashes (AF increases with the proportion of time open). Conversely, limited use plus good design can mitigate or reverse cost impacts.
- **Turnouts reduce risk**: Regular turnouts (≈0.5-mile spacing) lower FI AFs by about 5–10% relative to no turnouts, and when operation is limited (≈≤0.06 of the day), crash cost can be lower than the base (net safety benefit). FHWA recommends ~0.5-mile spacing. (Jenior et al., 2016.)
- **Narrow lanes/shoulders increase crashes**: <11-ft lanes and narrow shoulders are associated with higher crash frequency; widening shoulders matters even more when lanes are narrow. (Bonneson et al., 2012a; AASHTO HSM Supplement 2014; Dixon et al., 2016; Curren, 1995; Bauer et al., 2004; Islam et al., 2014.) Typical guidance holds that if lane width is narrow, trucks should not be allowed to use the shoulder facilities.
- **Density effects and bottleneck relocation**: Crash risk shows a U-shaped relationship with density; PTSU often lowers density through bottlenecks (reducing upstream rear-ends), but can shift the bottleneck downstream, raising crashes there. (Kononov et al., 2012; Harwood et al., 2013; Aron et al., 2013; Geistefeldt, 2012; Jones et al., 2011.) However, if the shoulder use with ramp exit was better planned, then operational improvements in safety can be observed (as discussed later for US-specific evidence of improved safety.)

#2 Static vs. dynamic operations: No practical safety difference exists between dynamic lane-control signs and static schedule signs in the datasets analyzed. However, converting S-PTSU to D-PTSU is associated with about a 7.3% decrease in total crashes (all types/severities) (NCHRP 17-89 Vol. 1–2).

#3 Left vs. right shoulder: NCHRP 17-89 Vol. 1–2 dataset (which had fewer left-side sites) shows no statistically significant difference between left- and right-side PTSU (with right-side ramps). European work suggests context matters where left-side PTSU can be more crash-prone at low volumes (higher speeds), approximately safe at medium/high volumes, and sometimes safer than right-side due to fewer left exits. (Drolenga et al., 2015; Rijkswaterstaat, 2007.)

#4 International evidence on safety is mixed: Many EU cases show travel time reductions and capacity gains (e.g., Germany +20–25% capacity), with upstream rear-end reductions but mixed segment-level crash changes (some increases on the PTSU segment itself). (Geistefeldt, 2012; Veld, 2009; Rijkswaterstaat, 2007; Andersen, 2016.) The UK M42 pilot demonstrated a 71% reduction in crash frequency (5.2 to 1.5 crashes per month), while German 13-year longitudinal studies of seven freeway sections reported "high safety level" performance, with crash occurrence primarily dependent on traffic conditions rather than PTSU implementation itself (Geistefeldt, 2012; CEDR, 2022).

#5 U.S. site-specific outcomes vary: Examples include US-2 WA (+15% expected crashes), I-35W MN (+28% expected; attributed to volume/pattern changes), and I-66 VA (one study showed 8% reduction during open hours, while another showed 38% increase during open hours). Context/design/operations clearly mediate effects (Margiotta et al., 2014; Davis et al., 2017; Suliman et al., 2017; Lee et al., 2007; Kuhn et al., 2013.) Broadly, VSL deployments can reduce total crashes (e.g., −29% on I-5 WA) but have shown rear-end increases or mixed results where compliance is low. **Queue-warning at work zones**

showed large benefits (reduction in 44% crashes). The implication is that coordinated ATM with PTSU likely matters. (Pu et al., 2016; Chambers et al., 2016; Downey & Bertini, 2016; Ullman et al., 2016.) Implementing PTSU on freeways can enhance safety when designed and operated correctly. For instance, the SR 14 part-time shoulder lane in the Portland-Vancouver area integrated ramp meters and a temporary traffic backup warning system during the auxiliary lanes project, which led to a decrease in collisions within the work zone during the construction of the project. Specifically, there were 8 collisions and 1 disabled vehicle after the warning system and ramp meter were in place, compared to 18 collisions and 7 disabled vehicles before; however, due to lack of weather and volume-related controls, this finding is likely less reliable (Washington State Department of Transportation [WSDOT], 2023).

Similarly, the US-23 Flex Route near Ann Arbor, Michigan, employs part-time shoulder use by converting the left shoulder into a temporary travel lane during peak traffic periods and special events. The system employs advanced traffic management technologies, including variable speed advisories and queue warning systems, to reduce stop-and-go driving conditions and enhance overall roadway safety. According to a study conducted by the Michigan Department of Transportation (MDOT), the Flex Route contributed to a 17% overall reduction in traffic crashes, with a more pronounced 34% decrease observed in the southbound direction (Palmer 2025; Kassens-Noor et al., 2021; MDOT, 2021). Similar crash reduction effects were reported in the evaluation of multiple candidate routes across Michigan for potential PTSU installations (Savolainen et al., 2025).

In Columbus, Ohio, I-670 eastbound features a dynamic PTSU system that opened in 2019. This "smart lane" converts the left shoulder into a travel lane during peak congestion, guided by overhead lane control signals (LCS) and variable speed limits (VSL). When traffic conditions improve, the lane closes automatically. Safety outcomes were highly positive: monthly crash frequency dropped from approximately six incidents to one incident per month, providing strong empirical evidence that well-managed PTSU systems can maintain or improve safety performance (NASEM, 2024; Appendix C).

#11 BOS safety record is strong: BOS programs report few/no early safety issues, continued expansions, and no statistically significant crash differences vs. non-BOS in large datasets; safety practices include low speed differentials, shoulder-width minima, training, conspicuity, and driver discretion. (Martin & Levinson, 2012; FDOT, 2017; Pessaro, 2013; Gitelman et al., 2016; NCHRP 17-89 Vol. 2.)

Overall, the evidence on the safety performance of PTSU remains mixed. Cross-sectional studies, including NCHRP 17-89, indicate that while crash frequencies may rise slightly when shoulders are opened, crash severity generally decreases, with fewer fatal and serious-injury crashes. European corridors such as Germany’s A3 and A5 show neutral or positive safety outcomes when operational controls are strong. Expert interviews emphasize that operational discipline, clear control systems, rapid incident detection, and timely closures, determines whether outcomes are positive or negative. Overall, more longitudinal before-after evaluations are needed to strengthen the evidence base. **Current recommended safety practices include**:

- limit operating hours to truly congested periods,
- provide frequent turnouts (every 0.5 mi),
- avoid narrowing below 12 ft where feasible (or bolster shoulder width if 11-ft lanes are necessary and not allow trucks on narrower lanes), and
- pair PTSU with other effective ATM strategies (such as VSL and queue warning).

3.5 Operational and Performance Effects

Operational evaluations of auxiliary and part-time shoulder use systems consistently show measurable improvements in corridor capacity, travel time, and overall network reliability. Evidence from both international deployments and U.S. field implementations indicates that properly managed PTSU can provide 7–25% increases in effective capacity and notable reductions in delay during peak periods.

3.5.1 International Evidence

European experience has strongly influenced the development of U.S. shoulder-use strategies. Early programs in the Netherlands, Germany, and the United Kingdom established the foundational standards for lane control, variable speed limits, and active traffic management that are now standard in modern PTSU systems.

The Netherlands introduced nationwide HSR operations in 2003 as part of a broader active traffic management initiative. Across multiple corridors, traffic capacity increased between 7% and 22%, with consistent reductions in delay and queue formation. All deployments in the Netherlands pair shoulder use with speed harmonization, typically operating at reduced speeds (50–60 mph) under congestion conditions. (Guerrieri and Mauro, 2016)

In Germany, temporary HSR programs on the A3 and A5 motorways achieved 20–25% capacity increases during peak hours while maintaining stable safety levels. Operational success depended on comprehensive CCTV monitoring spaced every 200–300 meters, integration of dynamic lane control signs (red X / green arrow displays), and dedicated emergency refuge areas. The German programs also established cost-benefit evaluation frameworks that later informed FHWA guidance on U.S. applications. (Geistefeldt, 2012)

The United Kingdom's M42 Active Traffic Management pilot demonstrated similar efficiency gains, including a 26% reduction in journey times and 27% reduction in journey time variability, confirming that part-time shoulder running can substantially improve corridor reliability when combined with active management technologies (Sultan et al., 2008).

3.5.2 U.S. Case Studies and Field Evidence

Field evidence from U.S. projects confirms that well-planned PTSU and auxiliary lane conversions can reduce delay and improve throughput at constrained freeway segments (Jenior et al., 2019, NASEM, 2024; and AASHTO, 2023).

- Minnesota (I-35W Minneapolis): Peak-hour HSR operation increased corridor capacity by approximately 20%, alleviating bottlenecks near the downtown core and improving travel time reliability without major safety degradation.
- Washington (US-2 and I-405 Corridors): WSDOT's PUSL projects have reported positive results in early performance monitoring. On I-405, average general-purpose lane travel times reduced by 50%, and express toll lane (ETL) users experienced 6–8 minutes of average time savings. Post-implementation data showed smoother traffic flow, consistent travel speeds, and improved express bus reliability, with transit ridership increasing by about 5%.
- Vancouver, WA (SR-14 Corridor): After shoulder conversion, peak-period speeds stabilized at approximately 54 mph, compared to pre-project speeds frequently below 50 mph, improving corridor reliability and reducing queuing.
- Boston, MA (I-93 PTSU Lane): Operated as part of the Central Artery/Tunnel ("Big Dig") program, the static shoulder lane for authorized buses reduced peak-hour congestion and improved flow consistency, according to operations center feedback.
- Ann Arbor, MI (US-23 Flex Route): Michigan's first dynamic PTSU corridor (9 miles) demonstrated meaningful travel time savings and reduced delay following activation in 2017. While some congestion migrated to downstream segments, overall operational performance improved. Continuous monitoring via ITS components—dynamic lane control, variable speed limits, and CCTV—enabled adaptive management to sustain performance over time.

Collectively, these examples confirm that PTSU can deliver corridor-wide efficiency improvements when implemented with appropriate control systems and real-time traffic management infrastructure.

3.5.3 Modeled and Simulated Performance

Simulation studies further support the observed benefits of full-scale shoulder-use implementation. The detailed VISSIM analysis of I-77 between I-485 and Brawley School Road evaluated three scenarios—No-Build, Partial Build, and Full Build—representing progressive levels of PPSU deployment (RS&H, 2025).

- Southbound direction: The Full Build scenario increased average AM peak speeds from 15.6 mph to 34.9 mph and PM peak speeds from 14.3 mph to 32.4 mph, processing up to 15% more vehicles than the No-Build case.
- Northbound direction: Improvements were modest (28.2 mph to 30.2 mph) due to residual bottlenecks near Sam Furr Road, illustrating the importance of comprehensive corridor treatment rather than isolated segments.
- Partial Build scenario: Limited implementation (three segments) provided little operational benefit, emphasizing that fragmented deployment may not relieve congestion effectively.

These findings align with other modeling efforts, including TxDOT's work zone studies, which reported 35–42% capacity increases and significant reductions in travel delay and queue length when shoulders were opened for temporary use (Ullman et al., 2016).

3.5.4 Observed Trends and Operational Considerations

Across all documented studies, HSR and PTSU applications consistently yield measurable reductions in congestion and travel time variability. Reported capacity gains generally fall within the 7–25% range (Guerrieri & Mauro, 2016), though results depend heavily on geometric design and the extent of implementation.

Interviews with practitioners emphasized that while shoulder use can mimic the effect of adding a lane, potentially increasing capacity by 45–50% under ideal conditions, the benefits of auxiliary lanes are more localized, improving weaving and merging rather than corridor-wide throughput. In some cases, congestion displacement to downstream segments was observed, particularly where on- and off-ramps are closely spaced or have high entering and exiting volumes.

Additionally, several agencies noted that left-side shoulder lanes tend to provide a more continuous flow of traffic than right-side configurations, resulting in fewer interruptions and reduced causes of delay. Because left shoulders are generally less affected by merging, exiting, or ramp activity, their use can enhance flow stability and sustain higher speeds under peak conditions.

The Netherlands' long-term monitoring further illustrates that while average trip times can drop by several minutes and peak-hour capacity can rise by 20%, maintaining these gains requires continuous oversight through ITS-based lane control and active incident management systems to ensure consistent performance and user compliance.

3.6 Driver Compliance and Enforcement

3.6.1 Compliance Patterns and Signage Approaches

Driver compliance with PTSU systems depends primarily on the clarity of lane control messages, activation timing, and speed harmonization. Studies consistently show that compliance improves markedly under dynamic signage and active monitoring. The 2024 FHWA Synthesis Report—based on interviews with eight agencies—found that dynamic message systems achieved higher compliance rates than static signage, with five of the eight agencies adopting dynamic lane control signals to improve operational flexibility and driver understanding (Jenior et al., 2024).

Dynamic displays such as red X/green arrow indications were reported as the most effective means of communicating lane status. When combined with VSLs, typically reduced to 45–55 mph during shoulder activation, these systems improved lane discipline and reduced unsafe merges. ITS elements such as CCTV monitoring and automated dynamic message signs also reduced the need for manual enforcement, allowing agencies to manage compliance in real time from traffic management centers.

Research on speed differential compliance indicates that drivers generally travel 5–10 mph slower in shoulder lanes than in adjacent general-purpose lanes, and that clear dynamic signage minimizes hesitation or abrupt lane changes. Early European trials near Lausanne–Geneva found that while 75 % of surveyed drivers viewed crossing the white line as convenient, the presence of real-time lane control mitigated potential confusion (Jenior et al., 2016).

3.6.2 Agency Experience and Field Observations

Field implementations confirm that consistent communication and automation are central to maintaining compliance (Jenior et al., 2024; NASEM, 2024).

- Richmond, CA (I-580 Eastbound): Observational studies of the Richmond–San Rafael Bridge corridor reported 99.6 % compliance with opening and closing schedules. Non-compliance was limited to brief periods within 20 minutes before opening and 30 minutes after closure, averaging less than 1 % of total traffic (After Study for the Richmond–San Rafael Bridge, 2024).
- Vancouver, WA (SR-14): Compliance was governed by dynamic overhead signs with caution-phase yellow arrows that manage transitions smoothly. The system relies on automated controls and TMC monitoring without resolute enforcement teams, and misuse has been negligible.
- Boston, MA (I-93): Dynamic lane-control signs managed by the Operations Control Center have maintained high compliance since implementation. Early issues with weekend misuse were resolved after sign updates clarified weekday operations, underscoring the importance of precise communication.
- Interview Insight – Pete Jenior (Kittelson & Associates): Mr. Jenior emphasized that the primary enforcement challenge involves preventing shoulder use when closed rather than controlling speed. Most violations occur during the early implementation phase; compliance stabilizes once drivers were accustomed to the system. He also noted that right-side shoulders present fewer speeding concerns than left-side shoulders, though the latter require closer monitoring due to higher flow speeds. **Targeted enforcement during the first month and clear public outreach** were cited as the most effective strategies for sustaining compliance.

3.6.3 Observed Issues and Enforcement Requirements

Instances of non-compliance or driver confusion are relatively rare but can lead to temporary increases in rear-end or property-damage collisions, particularly during the early stages of deployment when drivers are still adjusting to new operations. Agencies have observed that such issues are often linked to unclear lane-control messages, inconsistent signal visibility, or unfamiliar activation schedules. Over time, these effects diminish as driver familiarity increases and operational protocols stabilize.

Enforcement resource demands are generally modest once PTSU systems reach steady operation. Most agencies rely on existing patrol coverage, supported by automated monitoring, dynamic signage, and coordinated incident response through traffic management centers. Early enforcement emphasis, combined with visible lane-status indicators and targeted public education campaigns, has proven effective in improving compliance and reducing misuse. (Jenior et al., 2016)

Across documented programs, compliance rates improve markedly when operations are supported by dynamic lane-control systems, clear VSL enforcement, and consistent messaging. Static sign configurations, in contrast, tend to require greater manual oversight and yield slower driver adaptation. Well-defined activation windows and real-time feedback mechanisms are critical for maintaining compliance and minimizing enforcement intervention once systems mature.

3.7 Maintenance and Incident Management

3.7.1 Standardized Lane Clearing Protocols

Recent implementations of PTSU have converged on a common set of operational procedures for lane inspection and clearing prior to activation. According to Jenior et al. (2024), nearly all agencies now follow standardized pre-opening protocols that include:

- Visual inspection by TMC operators through CCTV approximately 30 minutes before activation.
- Physical drive-through inspection by maintenance staff or law enforcement to identify debris, stalled vehicles, or pavement hazards.
- Debris removal coordination involving maintenance or contracted tow services.
- Operator confirmation of clear conditions before automated lane-opening commands were executed.

Between 2016 and 2024, agencies have increasingly emphasized human oversight even within automated systems. The FHWA synthesis reported that operators often assume greater manual control than originally expected, particularly during incidents or when weather conditions affect detection systems.

3.7.2 Agency Practices and Field Operations

Seattle, WA – I-405 Northbound: WSDOT's TMC conducts daily CCTV sweeps before activation to verify a clear shoulder. Maintenance and operations teams respond to any issues identified. During deactivation, lane-control signs transition from "Open – Exit Only" to a yellow merge arrow, followed by "Do Not Drive on Shoulder," ensuring an orderly closure. Debris removal and cleaning occur during off-peak hours to minimize disruptions. Four paved emergency pullouts within the corridor provide refuge for incident response and vehicle recovery (Rouse, 2025).

Columbus, OH – I-670 SmartLane: The SmartLane incorporates left-shoulder operation with variable speed limits (55 mph active, 65 mph standard). Before each morning activation, TMC operators confirm the shoulder's status via 39 CCTV cameras and safety patrol reports. Any irregularities trigger the dispatch of maintenance or incident-response units. Once active, the corridor is continuously monitored through an integrated ATM system. When an incident is detected, lane-control signs immediately display a red "X" to close the shoulder for exclusive use by responders, maintaining a clear path for emergency and maintenance access.

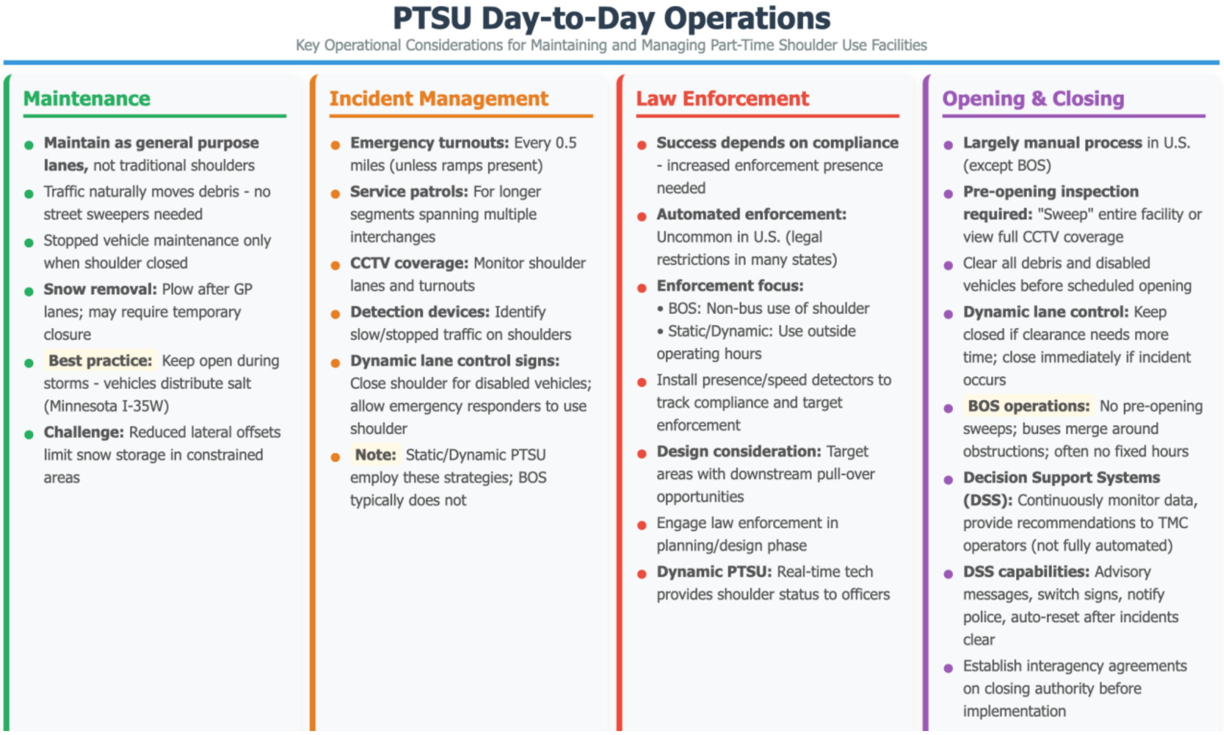
Ann Arbor, MI – US-23 Flex Route: The Michigan DOT Transportation Operations Centers (TOCs) manage the corridor daily in coordination with Michigan State Police. Overhead lane-control gantries display real-time lane status, switching between green arrows and red X symbols. Before activation, TOC operators verify shoulder conditions via CCTV; the lane remains closed if any obstruction is detected. Dedicated crash-investigation sites and continuously operating Safety Service Patrols support rapid clearance and maintain corridor reliability.

California – I-580 Richmond–San Rafael Bridge: Operating daily from 2 p.m. to 7 p.m., this static HSR facility undergoes pre-opening inspection 30 minutes before activation and continuous CCTV monitoring throughout operation. The system's $50 million investment included bridge-specific surveillance integration, illustrating the cost and complexity of maintaining HSR in constrained environments.

Illinois – I-90 Tollway: Covering 32 directional miles, this large-scale dynamic HSR corridor applies lane control over all lanes, with left-shoulder use prioritized for traffic operations and right-shoulder segments reserved for incident response. Field experience showed that, as with other states, human operator intervention remained essential to manage unplanned events effectively.

3.7.3 Guidance for day-to-day maintenance and incident response

Overall guidance, summarized in Figure 3.6 suggests that routine maintenance on PTSU corridors should be performed during non-operational hours, with shoulders maintained to the same standards as general-purpose lanes. Before each activation, TMC operators must conduct CCTV or drive-through inspections to clear debris or disabled vehicles. Staged tow trucks or service patrols should be positioned at key locations, and dynamic lane-control signs must allow immediate closure during incidents. Interagency coordination—particularly close partnerships with law enforcement agencies operating on those corridors—was strongly recommended in interviews to ensure rapid incident clearance, minimize response times, and maintain reliable activation schedules.



PTSU Day-to-Day Operations

Key Operational Considerations for Maintaining and Managing Part-Time Shoulder Use Facilities

Maintenance

- **Maintain as general purpose lanes,** not traditional shoulders
- Traffic naturally moves debris - no street sweepers needed
- Stopped vehicle maintenance only when shoulder closed
- **Snow removal:** Plow after GP lanes; may require temporary closure
- **Best practice:** Keep open during storms - vehicles distribute salt (Minnesota I-35W)
- **Challenge:** Reduced lateral offsets limit snow storage in constrained areas

Incident Management

- **Emergency turnouts:** Every 0.5 miles (unless ramps present)
- **Service patrols:** For longer segments spanning multiple interchanges
- **CCTV coverage:** Monitor shoulder lanes and turnouts
- **Detection devices:** Identify slow/stopped traffic on shoulders
- **Dynamic lane control signs:** Close shoulder for disabled vehicles; allow emergency responders to use shoulder
- **Note:** Static/Dynamic PTSU employ these strategies; BOS typically does not

Law Enforcement

- **Success depends on compliance** - increased enforcement presence needed
- **Automated enforcement:** Uncommon in U.S. (legal restrictions in many states)
- **Enforcement focus:**
  - BOS: Non-bus use of shoulder
  - Static/Dynamic: Use outside operating hours
- Install presence/speed detectors to track compliance and target enforcement
- **Design consideration:** Target areas with downstream pull-over opportunities
- Engage law enforcement in planning/design phase
- **Dynamic PTSU:** Real-time tech provides shoulder status to officers

Opening & Closing

- **Largely manual process** in U.S. (except BOS)
- **Pre-opening inspection required:** "Sweep" entire facility or view full CCTV coverage
- Clear all debris and disabled vehicles before scheduled opening
- **Dynamic lane control:** Keep closed if clearance needs more time; close immediately if incident occurs
- **BOS operations:** No pre-opening sweeps; buses merge around obstructions; often no fixed hours
- **Decision Support Systems (DSS):** Continuously monitor data, provide recommendations to TMC operators (not fully automated)
- **DSS capabilities:** Advisory messages, switch signs, notify police, auto-reset after incidents clear
- Establish interagency agreements on closing authority before implementation

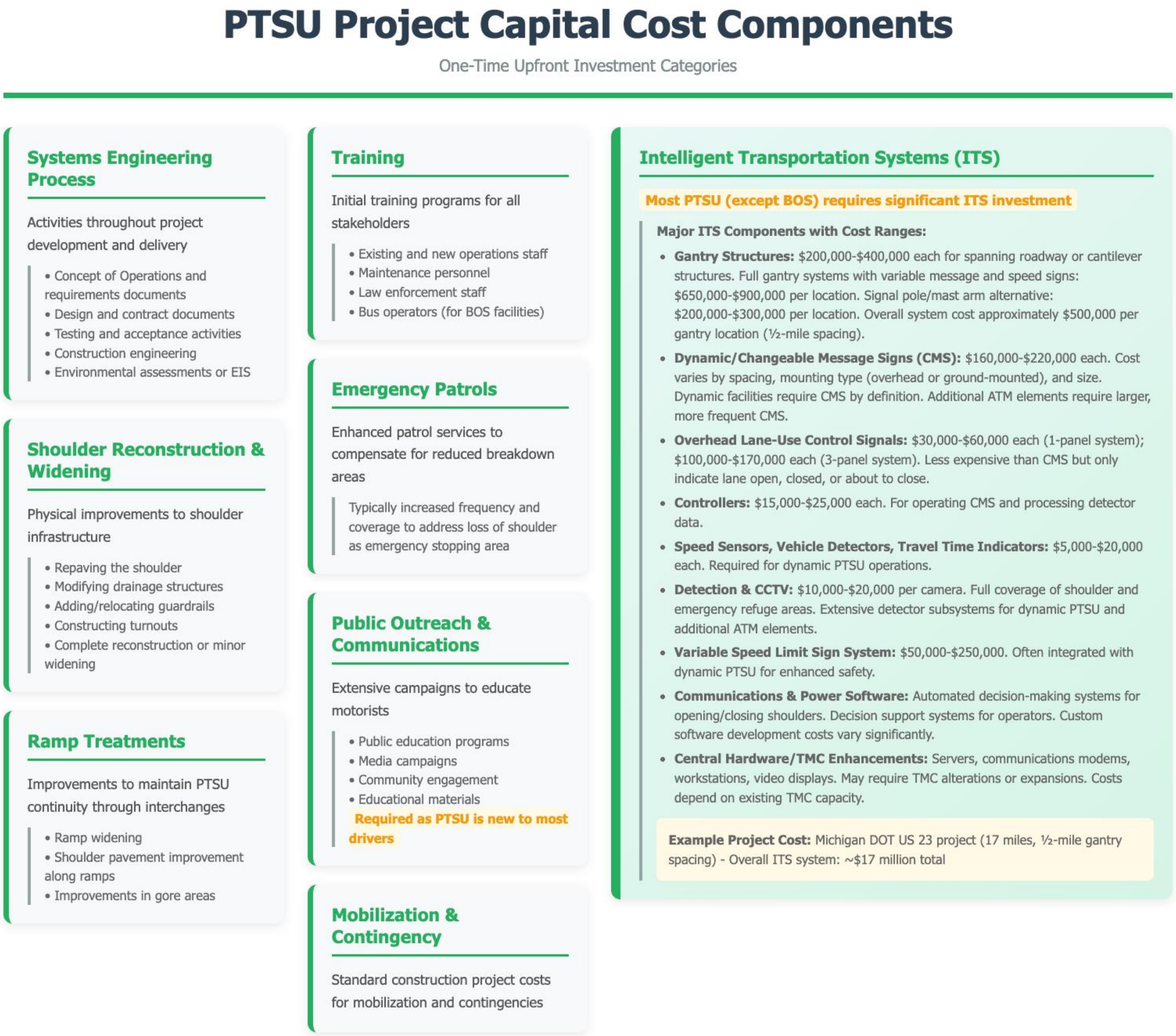
Figure 3.6 Summary of best guidance for day-to-day operations considering PTSU

3.8 Costs Associated with PTSU

Jenior et al. (2016) summarized the key factors affecting the capital and operational and maintenance (O&M) costs associated with shoulder use. The implementation of D-PTSU involves both capital investments and ongoing O&M expenses, with total project costs highly dependent on corridor length, gantry spacing, and the level of ITS integration.

3.8.1 Capital Cost Components

Figure 3.7 summarizes the capital cost components and estimates for various elements (Jenior et al., 2016; Jenior et al., 2019).



PTSU Project Capital Cost Components

One-Time Upfront Investment Categories

Systems Engineering Process

Activities throughout project development and delivery

- Concept of Operations and requirements documents
- Design and contract documents
- Testing and acceptance activities
- Construction engineering
- Environmental assessments or EIS

Shoulder Reconstruction & Widening

Physical improvements to shoulder infrastructure

- Repaving the shoulder
- Modifying drainage structures
- Adding/relocating guardrails
- Constructing turnouts
- Complete reconstruction or minor widening

Ramp Treatments

Improvements to maintain PTSU continuity through interchanges

- Ramp widening
- Shoulder pavement improvement along ramps
- Improvements in gore areas

Training

Initial training programs for all stakeholders

- Existing and new operations staff
- Maintenance personnel
- Law enforcement staff
- Bus operators (for BOS facilities)

Emergency Patrols

Enhanced patrol services to compensate for reduced breakdown areas

Typically increased frequency and coverage to address loss of shoulder as emergency stopping area

Public Outreach & Communications

Extensive campaigns to educate motorists

- Public education programs
- Media campaigns
- Community engagement
- Educational materials

Required as PTSU is new to most drivers

Mobilization & Contingency

Standard construction project costs for mobilization and contingencies

Intelligent Transportation Systems (ITS)

Most PTSU (except BOS) requires significant ITS investment

Major ITS Components with Cost Ranges:

- **Gantry Structures:** $200,000-$400,000 each for spanning roadway or cantilever structures. Full gantry systems with variable message and speed signs: $650,000-$900,000 per location. Signal pole/mast arm alternative: $200,000-$300,000 per location. Overall system cost approximately $500,000 per gantry location (½-mile spacing).
- **Dynamic/Changeable Message Signs (CMS):** $160,000-$220,000 each. Cost varies by spacing, mounting type (overhead or ground-mounted), and size. Dynamic facilities require CMS by definition. Additional ATM elements require larger, more frequent CMS.
- **Overhead Lane-Use Control Signals:** $30,000-$60,000 each (1-panel system); $100,000-$170,000 each (3-panel system). Less expensive than CMS but only indicate lane open, closed, or about to close.
- **Controllers:** $15,000-$25,000 each. For operating CMS and processing detector data.
- **Speed Sensors, Vehicle Detectors, Travel Time Indicators:** $5,000-$20,000 each. Required for dynamic PTSU operations.
- **Detection & CCTV:** $10,000-$20,000 per camera. Full coverage of shoulder and emergency refuge areas. Extensive detector subsystems for dynamic PTSU and additional ATM elements.
- **Variable Speed Limit Sign System:** $50,000-$250,000. Often integrated with dynamic PTSU for enhanced safety.
- **Communications & Power Software:** Automated decision-making systems for opening/closing shoulders. Decision support systems for operators. Custom software development costs vary significantly.
- **Central Hardware/TMC Enhancements:** Servers, communications modems, workstations, video displays. May require TMC alterations or expansions. Costs depend on existing TMC capacity.

Example Project Cost: Michigan DOT US 23 project (17 miles, ½-mile gantry spacing) - Overall ITS system: ~$17 million total

Figure 3.7 PTSU Capital Cost Estimates with ITS costs being the primary cost component (Information Source: Jenior et al., 2016; Interviews and Sources with DOTs)

Major capital cost components include:

- systems engineering activities (concept of operations, design, testing, and environmental review),
- shoulder reconstruction or widening ($1–3 million per mile when full-depth pavement or drainage improvements are needed),
- emergency turnouts (~$250,000–$400,000 each),
- public outreach and communications,
- ramp or gore modifications.

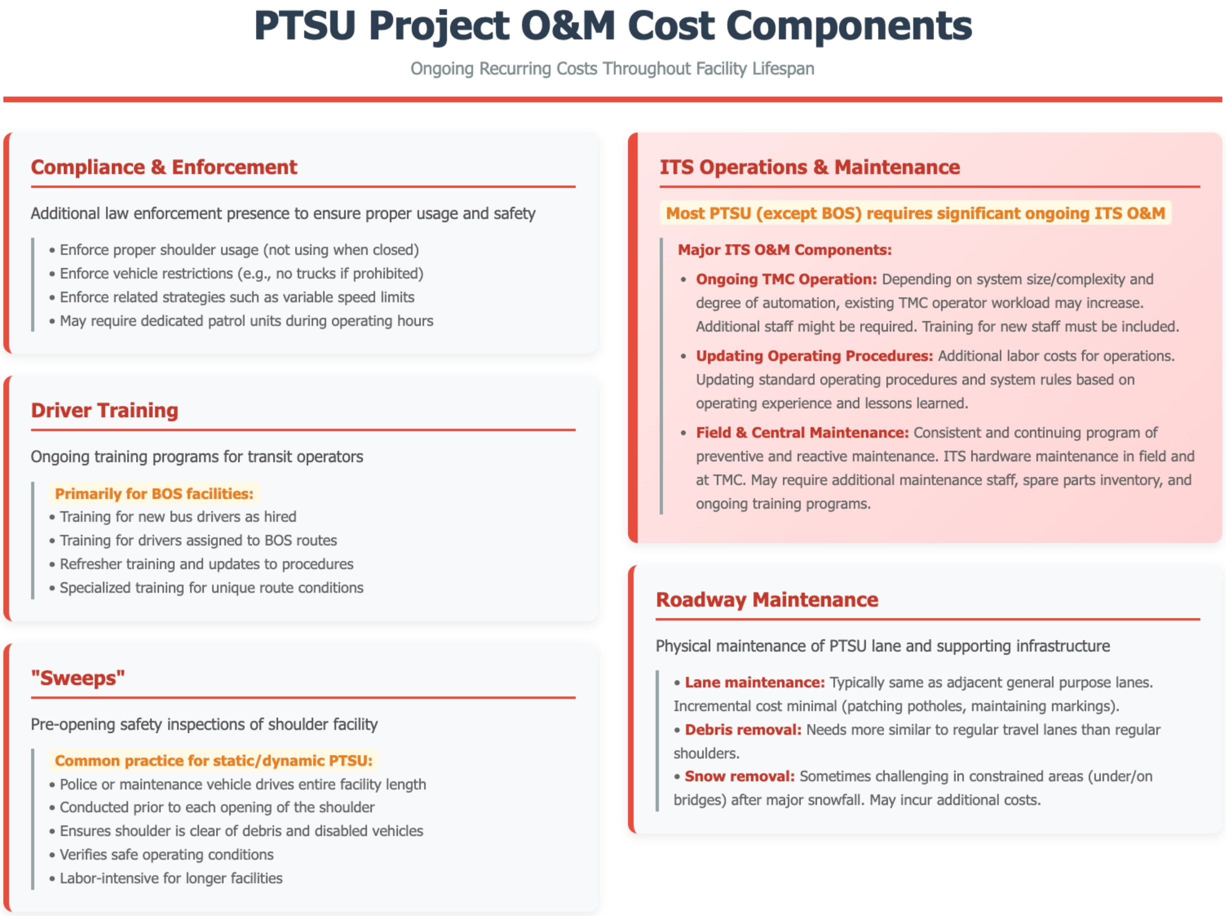
ITS elements, which are typically the cost drivers for dynamic operation, that includes:

- gantries ($200,000–$400,000 each, or $500,000–$900,000 for “smart” overhead assemblies),
- dynamic message and lane-use control signs ($160,000–$220,000 per unit),
- speed sensors and vehicle detectors ($5,000–$20,000 each),
- camera/surveillance systems ($10,000–$20,000 each),
- variable speed limit signs ($50,000–$250,000 per unit), and

- TMC communication and software integration ($1–2 million corridor-wide).

3.8.2 Operations and Maintenance Cost Components

Ongoing operations and maintenance costs (summarized in Figure 3.8) include traffic management center (TMC) staffing, CCTV monitoring, pre-opening sweeps, enhanced patrols and enforcement, and ITS hardware upkeep, typically adding $100,000–$300,000 per mile annually for well-instrumented facilities. Based on experience from Michigan DOT's US-23 project and WSDOT installations, the overall corridor-level cost for D-PTSU ranges from $2–6 million per mile, including ITS deployment, training, and public outreach. Static PTSU installations, by contrast, generally cost 40–60% less, primarily due to reduced ITS and control system needs.


PTSU Project O&M Cost Components

Ongoing Recurring Costs Throughout Facility Lifespan

Compliance & Enforcement

Additional law enforcement presence to ensure proper usage and safety

- Enforce proper shoulder usage (not using when closed)
- Enforce vehicle restrictions (e.g., no trucks if prohibited)
- Enforce related strategies such as variable speed limits
- May require dedicated patrol units during operating hours

Driver Training

Ongoing training programs for transit operators

Primarily for BOS facilities:
- Training for new bus drivers as hired
- Training for drivers assigned to BOS routes
- Refresher training and updates to procedures
- Specialized training for unique route conditions

"Sweeps"

Pre-opening safety inspections of shoulder facility

Common practice for static/dynamic PTSU:
- Police or maintenance vehicle drives entire facility length
- Conducted prior to each opening of the shoulder
- Ensures shoulder is clear of debris and disabled vehicles
- Verifies safe operating conditions
- Labor-intensive for longer facilities

ITS Operations & Maintenance

Most PTSU (except BOS) requires significant ongoing ITS O&M

Major ITS O&M Components:
- **Ongoing TMC Operation:** Depending on system size/complexity and degree of automation, existing TMC operator workload may increase. Additional staff might be required. Training for new staff must be included.
- **Updating Operating Procedures:** Additional labor costs for operations. Updating standard operating procedures and system rules based on operating experience and lessons learned.
- **Field & Central Maintenance:** Consistent and continuing program of preventive and reactive maintenance. ITS hardware maintenance in field and at TMC. May require additional maintenance staff, spare parts inventory, and ongoing training programs.

Roadway Maintenance

Physical maintenance of PTSU lane and supporting infrastructure

- **Lane maintenance:** Typically same as adjacent general purpose lanes. Incremental cost minimal (patching potholes, maintaining markings).
- **Debris removal:** Needs more similar to regular travel lanes than regular shoulders.
- **Snow removal:** Sometimes challenging in constrained areas (under/on bridges) after major snowfall. May incur additional costs.

Figure 3.8 PTSU Operations and Maintenance Cost Components (Information source: Jenior et al., 2016 and Jenior et al., 2019)

These estimates, drawn from Jenior et al. (2016) and Jenior et al. (2019), provide a planning-level benchmark for agencies evaluating the financial feasibility of D-PTSU projects. The exact values can vary from one region to the other.

3.8.3 Insights from Expert Interviews

During stakeholder consultations, Pete Jenior (Kittleson and Associates) noted that modern PTSU systems now rely on lane-control signals (green arrows and red Xs) rather than static time-based signs. He explained that TMCs typically require software modifications costing several hundred thousand dollars, and many agencies choose to upgrade for future ATM readiness—extending dynamic signage and lane-control systems corridor-wide. Jenior also emphasized that longer D-PTSU corridors often necessitate dedicated TMC staffing during peak hours to monitor dynamic operations effectively.

At WSDOT, Rob Brusseau explained that the agency developed its control software in-house rather than purchasing a proprietary system, resulting in lower ongoing costs since their TMC already operates 24/7. He characterized D-PTSU as cost-effective, with initial investments driven by corridor length and local contracting, and maintenance costs comparable to regular roadway upkeep plus ITS component servicing.

Other agencies provided a nuanced range of responses. NHDOT cited an initial capital cost of roughly $10 million for its PTSU deployment, with signage and ITS identified as primary cost drivers. The Ohio DOT estimated $61 million total, noting that major expenses stemmed from ITS sensors, dynamic signage, and interchange ramp reconstruction, but reported travel time reductions of 15 minutes as a direct benefit. MassDOT and MDOT highlighted the importance of emergency pullouts, consistent hours of operation, and operator training as recurring expenditures influencing long-term system performance.

A recurring theme across agencies is that software procurement, integration, and operator-interface development may become the pacing factor for PTSU deployment. To mitigate schedule risk, several states recommend a staged implementation, beginning with static or semi-automated signage while backend software is developed and tested. Agencies also emphasized the value of virtual TMC testing prior to field deployment, which helps refine operator procedures, identify software issues early, and smooth the transition to full dynamic operations.

Overall, practitioner feedback aligns with FHWA cost guidance: ITS and software integration dominate up-front costs, while routine maintenance and staffing represent manageable, predictable expenditures. The combination of congestion reduction, improved reliability, and readiness for future ATM applications continues to justify these investments for most agencies.

Chapter 4. Case Studies: State DOT Experiences

This chapter presents case studies based on the survey responses from the participating DOTs. Tables 4.1 to 4.4 summarize the key lessons on the open-ended responses on lessons learned. The detailed findings are discussed next for the selected PTSU implementations. We also recommend the reader review the ATM case studies discussed in Appendix C of NASEM (2024) and Appendix A of Jenior et al. (2016).

Table 4.1 Open-ended responses to "What would you do differently if implementing shoulder use installation again?"

Responses
NHDOT: Would prefer to use the left shoulder. We did a design-build. I would prefer a design-bid-build.
Ohio DOT: more sensors to be able to fully automate the variable speed limit and reevaluate the huge DMS signs that extend over every lane.
MassDOT: Implement more ITS (cameras, message boards), adjust hours of operations.
Michigan DOT: Ending the shoulder lane is critical. More warning needed for lane drop.
Wisconsin DOT: Reconsider camera and detector installations to be placed on the outside shoulder rather than the median. There would be easier access to devices during maintenance/replacements. Median mounted device repairs require closing the left shoulder which is the Flex Lane.
WSDOT: Ensure consistent operational procedures and integrate automation gradually manual activation with clear visual checks works best initially before moving to full automation.
Pete Jenior (Kittelson): Early-phase enforcement and driver education should precede full rollout; gradual familiarization avoids compliance dips during the first month.

Table 4.2 Open-ended responses to "Biggest Operational Challenge"

Responses
NHDOT: Getting the TMC Operators on the same page in both New Hampshire and Maine.
Ohio DOT: None since it's been running for so long, there is a decent amount of TMC operator effort to open this one and the smarter lanes Ohio adds, the more responsibility added to the TMC Operators.
Mass DOT: Public wants full-time use or extended lengths.
Wisconsin DOT: Enforcement.
WSDOT: Ensuring quick incident clearance and staff readiness during dynamic activation periods.

Table 4.3 Open-ended responses to "What advice would you give to agencies (such as NCDOT) considering part-time shoulder use (PTSU) during peak periods?"

Responses
NHDOT: Don't be afraid to open it a little earlier than the numbers suggest. It is frustrating for drivers to see all the signs and the option to use the shoulder while in heavy traffic, but the signs being off.
Ohio DOT: Right-size your smart lane... look at all the options available out there and pick one that is right for that corridor, each corridor is different.
MassDOT: Ensure you have partnership with public safety.
Michigan DOT: Consistent opening times. Be willing to open earlier as needed.

Responses
Wisconsin DOT: Clear, defined peaks where PTSU would fit the needs as higher midday volumes may muddy the timing of when to close the PTSU have more negative public feedback. Most common question asked by the public is “why isn’t the Lane open all day long?” Ensure quick clearance for incidents, disabled vehicles and debris. Strong media partnerships and agency Public Information Office are helpful. Corridor traffic patterns changed after DPTSU was implemented in WI so ability to adjust operations was important.
WSDOT: Start simple—manual control works well before adding automation. Keep clear communication with public and coordinate early with enforcement and maintenance crews.
Pete Jenior: When upgrading ITS, consider upgrading for other lanes to balance costs.

Table 4.4 Open-ended responses to What key factors most influenced the success?

Responses
NHDOT: Staffing.
Ohio DOT: technology in conjunction with fixing braided interchange ramps at the downstream termini to unclog that bottleneck.
Mass DOT: messaging of operational hours.
Wisconsin DOT: Contracted freeway service team, County highway maintenance, quick response for equipment repair, driver awareness/education.
WSDOT: Strong TMC coordination, reliable ITS, and dedicated maintenance partnerships.
Pete Jenior: Dynamic signage, early enforcement, and cross-agency coordination between TMC and law enforcement.

4.1 California (I-580)

California implemented its first hard shoulder running (HSR) facility on I-580 eastbound in Richmond in 2018, covering 5.5 miles between Marin and Contra Costa Counties. The system operates on a static schedule—open to all vehicles from 2:00 p.m. to 7:00 p.m. daily—and reverts to emergency use outside those hours. The project required special authorization because shoulder travel is generally prohibited under California law.

Q1: How did the case work operationally?

Since opening on April 20, 2018, the eastbound I-580 shoulder lane has reduced PM congestion approaching the Richmond–San Rafael Bridge, saving drivers an estimated 15 minutes per trip during peak hours. This translates to roughly 700,000 weekday and 91,000 weekend vehicle-hours of annual delay reduction (NOCoe, 2020). The project also decreased local street congestion near the bridge and improved signal coordination across corridors in partnership with Caltrans, the City of Richmond, and the Bay Area Toll Authority (BATA).

Q2: Lane clearing process

Caltrans operators at the Traffic Management Center (TMC) conduct CCTV inspections approximately 30 minutes before opening and coordinate with field maintenance and towing services. The lane remains closed if any obstruction is detected.

Q3: Safety and maintenance outcomes

No adverse safety or maintenance effects have been reported. The shoulder continues to serve its original purpose for emergency use during non-operational hours, preserving access for maintenance and enforcement personnel.

Q4: Driver compliance and signage strategy

Lane control is managed via overhead lane-use signs across all three bridge lanes, connected by a redundant fiber-optic network. Changeable message signs display open and closed periods, ensuring clear driver communication. BATA's Phase II Final Report (NOCoe, 2020) found high compliance with the posted operating hours, with minimal unauthorized use before or after activation.

Q5: Observed safety and efficiency benefits

The PTSU lane has eliminated afternoon eastbound congestion on both freeway and adjacent arterials, providing 14–17 minutes of travel time savings during PM peaks. No adverse impacts were observed on incident response times or bridge maintenance (BATA, 2024). TMC staff reported smooth daily operations and improved coordination among maintenance and construction teams.

Q6: Implementation issues and resolutions

Key challenges included the bridge's limited shoulder width, need for emergency access, and environmental clearance. Caltrans resolved these through enhanced incident response protocols, tow-truck staging, and additional design verification to ensure structural adequacy.

Q7: Enforcement needs

Enforcement demand remains low. The California Highway Patrol monitors compliance but has not required additional staffing or enforcement campaigns. Predictable scheduling and clear signage have kept misuse below 1%.

Lessons for NCDOT

The I-580 experience demonstrates that static-schedule shoulder use can substantially reduce recurring congestion even on constrained facilities, provided that lane status is communicated clearly and lane clearing is verified before each activation. It also highlights that bridge and structure retrofits require early coordination with maintenance staff and emergency responders to ensure operational safety.

4.2 Massachusetts – Route 3 Weymouth-Pembroke (MassDOT)

The Massachusetts Department of Transportation (MassDOT) operates a DSU corridor on State Route 3, extending approximately 11 miles from Weymouth to Pembroke, MA. The project began in 1985, making it one of the earliest recurring shoulder-use implementations in the U.S. The right shoulder functions as an additional travel lane during designated peak periods under fixed schedules, primarily serving all vehicles except trucks.

Q1: How does the system operate?

The Route 3 facility follows a fixed operating schedule, with activation controlled through preset hours corresponding to peak congestion. The system is manually managed from the TMC, which monitors real-time conditions and adjusts operating hours as needed.

Q2: What is the pre-activation inspection process?

Prior to each activation, TMC staff verify conditions via CCTV. When operational, dynamic and static message signs display "Shoulder Open" indications. Outside of activation periods, the lane reverts to a conventional right shoulder reserved for emergency use.

Q3: What type of signage, markings, and speed controls are used?

The corridor employs static and DMS positioned throughout the 11-mile stretch. Variable speed limits are not used; the shoulder operates at the same posted speed as adjacent lanes. Pavement markings comply with MUTCD standards, and no rumble strips are present to maintain drivability. End-of-lane merge arrows and clear lane control indicators guide drivers during transitions.

Q4: What were the safety and maintenance observations?

Operational data indicate overall improvement in safety performance following the DSU implementation. The primary safety concern involves drivers failing to yield during ramp mergers, particularly at on ramps. Maintenance access is preserved by limiting shoulder operation hours, ensuring the shoulder remains available for emergency and repair activities when closed.

Q5: How is enforcement handled?

The most common violations are unauthorized use of the shoulder when closed and speeding during active periods. Enforcement is reactive, provided by the Massachusetts State Police on an as-needed basis. Initial heightened enforcement occurred during rollout, followed by periodic monitoring as the public adapted to the system.

Q6: What benefits and operational outcomes were reported?

The DSU corridor has delivered approximately 25 percent effective capacity gains and measurable congestion relief during peak periods. The lane is particularly valuable for maintaining throughput during incidents or maintenance operations. MassDOT reports sustained public support, with community feedback favoring longer operating windows or full-time shoulder conversion.

Q7: Implementation challenges and considerations

As one of the earliest DSU systems, Route 3 lacked the extensive ITS infrastructure available today. Signage upgrades, including DMS and lane control signs installed in 2008–2009, improved visibility and compliance. The corridor's age also requires continued maintenance of pavement and sign structures to meet modern performance and safety standards.

Lessons or advice for NCDOT

MassDOT emphasized the importance of public messaging around operational hours and maintaining close coordination with public safety agencies. Agencies should plan for progressive ITS modernization to replace legacy signage and improve monitoring. The respondent also noted that public acceptance can grow over time, particularly when users experience consistent travel-time reliability.

4.3 Michigan – US-23 Flex Route (MDOT)

The Michigan Department of Transportation (MDOT) operates a dynamic PTSU system known as the US-23 Flex Route, located north of Ann Arbor between M-14 (Exit 41) and M-36 (Exit 54). The project covers approximately 14 miles, utilizing the left shoulder for general-purpose traffic during congestion. The system opened in 2017 and currently serves all vehicles except trucks. The corridor operates under an integrated ATM framework combining Dynamic Lane Control Signs (DLCS), VSL, and continuous CCTV monitoring.

Q1: How does the system operate?

Activation is managed manually and semi-automatically through MDOT's Transportation Operations Center (TOC), supported by field personnel. The lane opens according to a fixed schedule during recurrent congestion and may also be activated dynamically in response to incidents. TOC operators monitor corridor performance and lane status continuously, coordinating with law enforcement and emergency responders in real time.

Q2: What is the pre-activation inspection process?

Before activation, TOC operators perform CCTV-based inspections to ensure the shoulder is clear of obstructions or disabled vehicles. If debris or a stopped vehicle is detected, the lane remains closed until the condition is resolved. Activation follows confirmation by both operations and maintenance staff.

Q3: What type of signage, markings, and speed controls are used?

The Flex Route features overhead lane control gantries equipped with dynamic arrows and red X indicators over each lane, accompanied by variable speed limit displays. Posted speeds on the open shoulder match mainline limits but are dynamically reduced, typically from 70 mph to 60 mph, during activation. Pavement markings follow MUTCD standards, and the shoulder includes crash-worthy delineation and pavement strengthening to support full-time vehicular load during operation.

Q4: What were the safety and maintenance observations?

Post-implementation monitoring indicated significant improvements in both travel-time reliability and crash reduction. Some congestion initially shifted to the terminus of the northbound segment, but this was addressed through signal timing and merge-lane adjustments. Maintenance operations occur during non-activation periods, and the shoulder remains closed until responders arrive at incidents, preserving safe access.

Q5: How is enforcement handled?

An initial education period lasting about a month accompanied deployment, during which targeted enforcement ensured compliance with new lane rules. Subsequent enforcement returned to standard patrol levels. When an incident occurs, the shoulder is immediately closed to traffic until emergency responders are on scene.

Q6: What benefits and operational outcomes were reported?

MDOT's evaluation reported travel-time reductions of up to 30–50 percent and measurable increases in reliability. Crash rates decreased compared to pre-project levels, and corridor throughput improved without adverse effects on adjacent lanes. Operational data show sustained performance stability after several years of use.

Q7: Implementation challenges and considerations

The primary challenge involved calibrating the automated control logic for variable speed limits and lane-use transitions. MDOT addressed this through iterative adjustments and coordination with law enforcement and maintenance crews. Lessons from the initial phase informed future Flex Route designs, such as extended warning signage before lane drop points.

Lessons or advice for NCDOT

MDOT recommended maintaining consistent opening times to build driver expectancy and flexibility to open earlier when congestion builds unexpectedly. The agency stressed the importance of ending transitions clearly, providing early merger cues and sufficient taper distance. Integration of the ITS infrastructure and real-time data analytics was considered critical to operational success.

4.4 Minnesota (I-35W Minneapolis)

The Minnesota Department of Transportation (MnDOT) operated a 3-mile dynamic priced shoulder lane on I-35W northbound, between 42nd Street and downtown Minneapolis, until 2018. The left shoulder was dynamically opened to traffic based on congestion levels and linked to the MnPASS express toll system. The facility represented one of the earliest large-scale dynamic PTSU corridors in the United States.

Q1: How did the case work operationally?

The shoulder was typically opened on weekdays around 6 a.m., coinciding with the start of MnPASS tolling operations, and on weekends as congestion warranted. MnDOT coordinated with the Freeway

Service Patrol to confirm the shoulder was clear before activation. The dynamic lane allowed operators to open or close it in real time based on traffic volumes approaching downtown.

Q2: Lane clearing process

- Before activation, the corridor was inspected using two methods:
- Physical sweep: a patrol vehicle drove the entire segment.
- Camera sweep: operators visually verified conditions via CCTV.
- If debris or disabled vehicles were observed, the lane remained closed until cleared.

Q3: Safety and maintenance outcomes

An FHWA empirical-Bayes before/after study found a 28.4 % increase in total crashes after PDSL implementation. MnDOT attributed this partly to the simultaneous removal of an upstream bottleneck, which increased traffic flow into the segment. Maintenance activities follow standard lane protocols and are conducted when the shoulder is closed. MnDOT's Regional Traffic Management Center (RTMC) coordinates incident management and maintenance scheduling through its integrated ITS system.

Q4: Driver compliance and signage strategy

Compliance was managed through dynamic overhead lane-use signs combined with static regulatory markers and restricted double-white lines. Early non-compliance issues were corrected through longer operating periods, refined signage, and targeted enforcement. Dynamic messaging and traveler information improved user understanding over time.

Q5: Observed safety or efficiency results

The dynamic shoulder lane processed up to 1,100 vehicles per hour at average speeds near 55 mph, with no measurable speed reductions in adjacent general-purpose lanes (Jenior et al., 2016). This indicates that the facility added throughput rather than redistributing existing demand, achieving tangible congestion relief.

Q6: Implementation issues and resolutions

Because dynamic shoulder operation removes the continuous refuge area, MnDOT relies on the Freeway Incident Response Safety Team (FIRST) for rapid intervention. Additional pull-out bays were added for emergencies, and the RTMC maintains real-time communication with State Patrol and towing services. Overhead dynamic lane-control signs allow operators to close the shoulder within seconds of detecting an incident, immediately updating upstream message boards to warn drivers.

Q7: Enforcement needs

Enforcement employs mobile transponder verification systems (Raytheon), allowing officers to identify violators in MnPASS lanes. The self-funded toll system offsets operational costs. While some initial enforcement was required, violation rates remained low as drivers adapted to the dynamic system.

Lessons for NCDOT

The I-35W experience demonstrates both the capacity benefits and the operational complexities of dynamic shoulder use. Although crash frequency increased following implementation, this was attributed to broader traffic pattern changes rather than the PTSU itself. The case highlights the importance of real-time lane-closure capability, coordinated incident management, and clear communication with users. For NCDOT, Minnesota's lessons underscore that dynamic systems require advanced operator training and interagency integration to balance throughput gains with operational safety.

4.5 New Hampshire – I-95 Portsmouth (NHDOT)

The New Hampshire Department of Transportation (NHDOT) operates a dynamic shoulder use (DSU) system on I-95 in Portsmouth, covering approximately 3.2 miles of right shoulder. The project opened in 2024, allowing all vehicle types to use the shoulder continuously along the corridor during activation periods. The shoulder is 12 feet wide, functioning as an additional general-purpose lane when opened.

Q1: How did the system operate?

Activation is manual, managed directly from the Traffic Management Center (TMC). Coordination between New Hampshire and Maine TMC operators was identified as an early operational challenge due to the cross-jurisdictional nature of the corridor.

Q2: What is the pre-activation inspection process?

Before each activation, TMC operators perform visual inspections via CCTV and coordinate with field crews. Lane opening typically occurs after a 30-minute pre-check window, ensuring the shoulder is clear of debris or disabled vehicles.

Q3: What type of signage, markings, and speeds are used?

The corridor uses DMS and lane control signals mounted overhead. When active, travel speeds match those of the mainline lanes. The outside edge line was modified to include two solid white stripes, one at the traveled way and another at the edge of pavement. The respondent noted that this configuration can confuse unfamiliar drivers when the shoulder is closed, as it visually resembles a travel lane (however, DMS indications help).

Q4: What were the safety and maintenance observations?

Preliminary outcomes suggest operational and safety performance have possibly improved, though no formal before-after study has been completed. The most significant concern is unauthorized shoulder use during off-hours, which poses a hazard to maintenance personnel performing inspections or repairs on the closed shoulder. To date, no incidents involving maintenance crews have been reported.

Q5: How is enforcement handled?

The primary enforcement challenge is driver use of the shoulder when closed. NHDOT relies on routine patrols by State Police rather than dedicated enforcement. No major violations or sustained enforcement campaigns have been necessary since deployment.

Q6: What operational benefits and capacity improvements were reported?

The agency estimated a 25 percent increase in effective corridor capacity during activation, with noticeable reductions in recurring congestion and smoother incident management operations.

Q7: What were the costs and delivery structure?

The project's initial capital cost was approximately $10 million, driven largely by ITS and signage infrastructure. The project was delivered via design-build, though the respondent indicated a preference for design-bid-build in hindsight for greater design control.

Lessons for NCDOT

The respondent advised opening the shoulder slightly earlier than model thresholds suggest reducing driver frustration during visible congestion. Early coordination between staffing teams across TMCs and proactive operational planning were also cited as critical for consistent performance.

4.6 New Jersey – US-1 South Brunswick (NJDOT)

The New Jersey Department of Transportation (NJDOT) operates a DSU system along US-1 in South Brunswick, covering approximately 7 miles. The corridor began operation in 2017 and allows all vehicles except trucks to use the right shoulder as a travel lane during active periods. The facility is continuous along both directions and was designed for bidirectional operation, activated according to congestion and traffic demand.

Q1: How does the system operate?

Activation is controlled manually from the TMC, with support from law enforcement. The system can also operate on a fixed schedule when recurring peak conditions are expected. Dynamic opening and closing decisions are made based on congestion thresholds observed through CCTV monitoring.

Q2: What is the pre-activation inspection process?

Before each activation, CCTV verification is performed by TMC staff to ensure the shoulder is clear of obstructions, debris, or disabled vehicles. If any issues are identified, the lane remains closed until resolved.

Q3: What type of signage, markings, and speed controls are used?

The corridor uses a mix of static signs, DMS, and lane control signals positioned at regular intervals. Speeds in the shoulder lane are the same as adjacent mainline lanes, maintaining operational uniformity. Shoulders were repaved and re-striped to support continuous operation, with dotted lane lines across ramps to guide merging and exiting traffic.

Q4: What were the safety and maintenance observations?

Formal crash analyses have not been reported, but operational feedback indicates no major safety incidents. The system requires ongoing monitoring to prevent unauthorized shoulder use during inactive periods. Routine maintenance occurs during off-peak hours, and the lane can be closed at any time if debris or obstructions are detected.

Q5: How is enforcement handled?

The main enforcement challenge has been unauthorized use of the shoulder when closed. NJDOT relies on regular patrols and reactive enforcement when incidents occur. Dedicated patrol units were not added, but initial coverage was increased during the rollout period to reinforce compliance.

Q6: What benefits and operational outcomes were reported?

The facility was primarily designed to improve traffic flow through congested suburban segments of US-1 and enhance reliability during incidents. Preliminary observations show that lane utilization is balanced and that throughput during activation periods has improved without increasing crash exposure.

Q7: Implementation challenges and considerations

Due to the large number of side streets, driveways, and local business access points, maintaining driver awareness of shoulder status was a key issue. Continuous signage reinforcement and TMC monitoring have been essential for consistent operation. The system’s design accommodates frequent ingress and egress along the arterial corridor, which distinguishes it from freeway-based shoulder use programs.

Q8: Lessons or advice for NCDOT

The NJDOT respondent emphasized that driver communication and consistent signage are critical when managing PTSU on corridors with numerous access points. Agencies should anticipate the need for real-time operational oversight and be prepared for higher visual demands on TMC operators compared with freeway applications.

4.7 Ohio – I-670 "SmartLane" ODOT

The Ohio Department of Transportation (ODOT) operates a dynamic shoulder use (DSU) facility known as the I-670 SmartLane in Franklin County (Columbus area). The project covers approximately 4 miles of left shoulder and was opened in 2019. The SmartLane serves all vehicles and is continuously configured as an additional travel lane during activation. The system also incorporated major interchange and ramp reconstruction as part of a broader corridor modernization effort.

Q1: How does the system operate?

Activation is managed manually from the Traffic Management Center (TMC), with assistance from field personnel. Operators monitor corridor conditions and open or close the shoulder lane as needed based on congestion and incident status. The respondent noted that the SmartLane requires significant TMC operator effort, especially as additional managed lanes are added statewide.

Q2: What is the pre-activation inspection process?

Before opening, TMC staff and field crews verify shoulder conditions through CCTV inspection and direct communication. This ensures no obstructions, maintenance vehicles, or debris are present. Once confirmed, lane control signs display a green arrow to indicate the lane is active.

Q3: What type of signage, speeds, and infrastructure are used?

The corridor employs overhead dynamic message signs (DMS) and lane control signals (LCS) over each lane. When the SmartLane is active, variable speed limits (VSLs) are applied, typically reducing the corridor speed limit from 65 mph to approximately 55 mph for all lanes. The respondent noted that large overhead sign structures proved effective but visually dominant, and future deployments might reconsider sign size and spacing.

Q4: What were the safety and maintenance observations?

No major safety issues were reported. Maintenance access is managed through off-peak closures or by temporarily deactivating the SmartLane. The system allows lane-by-lane closure, enabling crews or responders to isolate affected segments without shutting down the full corridor. Overall, maintenance and operations staff report smooth coordination between field and control center teams.

Q5: How is enforcement handled?

Enforcement is conducted through regular State Highway Patrol patrols rather than dedicated units. No recurring violations were reported. The TMC's real-time monitoring capability supports quick detection of improper use or breakdowns, reducing reliance on manual enforcement.

Q6: What benefits and performance outcomes were reported?

The SmartLane has produced measurable operational improvements, including an average travel-time reduction of approximately 15 minutes during peak periods. The corridor also experiences reduced congestion and improved incident management, attributed to dynamic control and coordinated signal timing at interchanges.

Q7: What were the costs and delivery details?

The total project cost was approximately $61 million, which included significant system interchange ramp reconstruction in addition to ITS infrastructure. Signage and lane control systems represented a substantial portion of the ITS investment.

Q8: What lessons or advice were offered for NCDOT?

ODOT emphasized the importance of "right-sizing" SmartLane designs to match corridor context. Each segment should balance technology investment with expected operational benefit. The respondent advised ensuring that downstream bottlenecks or braided interchanges are addressed simultaneously to preserve the effectiveness of the added shoulder lane.

4.8 Utah – SR-224 Bus-on-Shoulder (UDOT)

The Utah Department of Transportation (UDOT) operates a bus-on-shoulder (BOS) facility on SR-224, an arterial corridor near Park City in Summit County. The corridor is approximately 2.5 miles long, utilizing the right shoulder (12 ft) exclusively for transit buses. The facility operates on a fixed schedule and is not part of a freeway segment; it includes signalized intersections, distinguishing it from freeway-based PTSU systems.

Q1: How does the system operate?

The BOS lane functions during defined time periods that correspond to scheduled transit service peaks. It allows buses to bypass congestion while operating under the same general-purpose lane speed limits. All general traffic remains restricted from using the shoulder.

Q2: What is the pre-activation inspection process?

No formalized pre-activation inspection process is required. Operations rely on standard maintenance observation rather than active verification. Because SR-224 is an arterial, shoulder readiness is maintained through routine corridor inspections rather than TMC-driven activation.

Q3: What type of signage, markings, and speed controls are used?

The facility uses static regulatory signs indicating "Bus Use Only" during operational hours. Speeds on the shoulder are the same as adjacent lanes. No dynamic message signs or variable speed limits are used. Pavement markings comply with UDOT's arterial standards.

Q4: What were the safety and maintenance observations?

Safety performance data were not available, but no major operational incidents have been reported. Winter maintenance poses an occasional challenge: snow plowing from the main lanes can temporarily block the shoulder, forcing buses to merge back into general traffic until a subsequent snow-removal pass clears the shoulder.

Q5: How is enforcement handled?

Because the lane is limited to transit use, enforcement is minimal and largely self-regulated through bus operations. No dedicated enforcement units are assigned.

Q6: What benefits have been observed?

The primary benefit is improved transit reliability, enabling buses to maintain consistent travel times during congestion. This has enhanced schedule adherence for the regional transit provider.

Q7: Costs and implementation details

Project cost information was not reported, but the implementation did not require ITS infrastructure or lane-control systems, keeping expenditures relatively low compared with freeway-based BOS programs.

Q8: What lessons or advice were offered for NCDOT?

The respondent emphasized that maintenance sequencing is critical in winter climates. Snow clearance schedules must be coordinated to prevent operational interruptions. For arterial BOS designs, integration with signal operations and transit agency dispatch should be established early in planning.

4.9 Washington – US-2 Trestle and SR-14 Peak Use Shoulder Lane (WSDOT)

The Washington State Department of Transportation (WSDOT) has implemented multiple PTSU applications across the state, including static and dynamic systems. On US-2, a static peak-period shoulder lane operates on the eastbound Hewitt Avenue Trestle, approximately 1.5 miles long, serving as a third lane between 2:00 p.m. and 7:00 p.m. on weekdays. On SR-14 near Vancouver, a 1.8-mile dynamic Peak Use Shoulder Lane (PUSL) operates during congestion periods, activated manually from the Traffic Management Center (TMC).

Q1: How do the systems operate?

On US-2, fixed roadside signs indicate static weekday operating hours for the eastbound shoulder lane. During activation, the shoulder functions as a third general-purpose lane to relieve afternoon congestion across the trestle.

On SR-14, operations are dynamic and congestion-responsive. The TMC activates the shoulder when detectors and CCTV feeds confirm sustained congestion. Operators can open the entire corridor or individual segments using an in-house software platform. Activation typically occurs after a pre-opening inspection by incident response teams.

Q2: What are the lane clearing and activation procedures?

For US-2, the shoulder is inspected via camera surveillance and field review before the posted opening time. If obstructions are present, the shoulder remains closed until cleared.

For SR-14, the process involves multiple safety checks: incident response teams sweep the shoulder before 6 a.m., operators verify via cameras that it is clear, and then manually activate the system. A two-minute caution period is used during closure to allow vehicles to safely exit before the "Do Not Drive on Shoulder" message appears.

Q3: What signage, infrastructure, and speed management systems are used?

US-2: Static regulatory signs and pavement markings communicate scheduled availability. The system relies on posted hours and clear lane-use markings, without dynamic speed adjustments.

SR-14: Overhead gantries with electronic lane-control signs display green arrows when open and red Xs when closed. Emergency pull-outs are provided to maintain safety and allow quick clearance of disabled vehicles. Both systems are monitored by WSDOT's TMC and supported by CCTV coverage.

Q4: What safety and maintenance outcomes were observed?

For US-2, an empirical Bayes evaluation found a 15 percent increase in expected crash frequency, attributed to the corridor's unique geometry and static operations (Jenior et al., 2021). The trestle's narrow width and structural constraints limit refuge areas and reduce sight distance, making its safety context atypical. Despite these factors, congestion-related delays dropped from 8–10 minutes to 1–2 minutes.

For SR-14, early observations show no serious injuries or fatalities since opening, and overall crash frequency has declined after an initial adjustment period. Drivers quickly adapted to dynamic operations, and incident management response has improved due to TMC coordination and rapid closure protocols.

Q5: How is driver compliance and enforcement managed?

On US-2, compliance is maintained through fixed signage, routine patrols, and public education campaigns that inform users about scheduled shoulder operations via the state's 511 traveler information system. On SR-14, compliance is high. The corridor is designated a mandatory tow-away zone, and the Washington State Patrol assists in removing abandoned or disabled vehicles. Enforcement focuses on preventing shoulder use when closed, rather than active policing during operations.

Q6: What efficiency benefits were reported?

Both corridors show clear congestion mitigation benefits. US-2: Peak travel delays were reduced by up to 75 percent, demonstrating that even a static system on a constrained structure can deliver substantial short-term relief. SR-14: The dynamic PUSL significantly improved flow through the 1.8-mile segment, smoothing congestion with minimal additional staffing and no major operational issues. Operators report faster travel speeds and fewer bottlenecks during peak hours.

Q7: What were the main implementation challenges and resolutions?

For US-2, the main challenges were structural limitations of the trestle, environmental constraints due to adjacent wetlands, and the inflexibility of static operations. WSDOT incorporated mitigation measures within its Planning and Environmental Linkages (PEL) study, including maintenance protocols, ITS equipment maintenance plans, and documented incident response procedures. For SR-14, the challenges were primarily operational: integrating the system into the TMC workflow and developing reliable in-house activation software. The system's low-cost ITS expansion and internal software development minimized procurement delays and kept ongoing resource needs modest.

Q8: What lessons or advice were offered for NCDOT?

WSDOT's experience highlights several transferable lessons:

- Static systems like US-2 can deliver short-term relief in geometrically constrained corridors but require rigid adherence to schedule and clear signage.
- Cross-disciplinary coordination between maintenance, operations, and enforcement is essential.
- Pre-activation sweeps and strong TMC oversight are needed for reliable and safe operations.

4.10 Wisconsin – US 12/18 Madison Beltline (WisDOT)

The Wisconsin Department of Transportation (WisDOT) implemented a DSU system on the US-12/18 Madison Beltline in Dane County, covering approximately 10 miles. The corridor opened in 2022 and allows all vehicles except trucks to use the left shoulder as a travel lane during congestion. The facility operates continuously under dynamic control, with activation managed from the regional TMC.

Q1: How does the system operate?

The Beltline DSU operates as a TMC-controlled dynamic system. Operators activate the shoulder based on real-time traffic conditions and congestion thresholds, often during peak commuting hours. Coordination between TMC staff and law enforcement supports safe activation and deactivation.

Q2: What is the pre-activation inspection process?

Prior to opening, CCTV inspections are conducted along the corridor to verify the shoulder is clear of debris, disabled vehicles, or obstructions. Once verified, lane control signs display green arrows authorizing travel. Upon deactivation, yellow merge arrows and red "X" indicators are used to transition drivers safely back into general-purpose lanes.

Q3: What type of signage, markings, and speed controls are used?

The corridor employs static and DMS, as well as lane control signals (LCS) above each lane. Speeds in the shoulder lane are identical to the mainline lanes, promoting uniform flow. Additional lane-end arrow markings were installed to reinforce proper merging when the shoulder closes.

Q4: What were the safety and maintenance observations?

WisDOT conducted a formal before-and-after crash analysis, which found that overall safety definitely improved after implementation. The most common crash type remained rear-end collisions, often linked to localized speed variation during transition phases. Maintenance operations are scheduled during off-peak hours, and the left shoulder remains closed whenever possible to maintain emergency access.

Q5: How is enforcement handled?

Enforcement responsibilities are shared between regular patrol units and short-term targeted campaigns conducted immediately after rollout. The primary violations observed were unauthorized use when closed and speeding within the open shoulder. Heightened enforcement lasted several weeks post-launch, followed by intermittent campaigns as needed.

Q6: What benefits and operational outcomes were reported?

WisDOT reported that corridor operations definitely improved following activation, with reduced travel time variability and smoother mainline flow during congested periods. Operators noted improved incident clearance times due to continuous monitoring and faster lane control response.

Q7: Implementation challenges and considerations

The key operational challenge was managing driver expectations during opening and closing transitions. Ensuring that messaging, signals, and speed harmonization were synchronized across the corridor required extensive calibration of ITS systems and driver education.

Q8: Lessons or advice for NCDOT

WisDOT emphasized that public communication and early enforcement are critical to driver acceptance. Maintaining clear visual cues, particularly during merge phases post shoulder operations, is essential to reducing confusion and rear-end collisions. The agency also recommended that shoulder lanes remain closed whenever feasible to preserve access for first responders.

4.11 Lessons from International Experiences

Europe pioneered the large-scale deployment of PTSU and Dynamic Hard Shoulder Running (DHSR) systems, particularly in Germany and the Netherlands, both of which integrate shoulder use with speed harmonization and advanced ITS.

- Germany (A3 and A5 Corridors): Dynamic PTSU operates on over 200 km of roadway, including the A5 corridor near Frankfurt (Darmstadt–Eberstadt to the Hessian state border) and A3 segments in the Black Forest region (FHWA, 2010).
- Netherlands (National DHSR Network): Since 2003, DHSR has been deployed on the A1, A2, A4, A15, A27, A28, A50, and other motorways, totaling ≈1,000 km (620 mi) (Jenior et al., 2016). Both systems form the backbone of their respective national Active Traffic Management programs.

Q1: How do the systems operate?

In Germany, the shoulder opens dynamically when traffic demand exceeds threshold volumes, managed through Traffic Center Hessen, which monitors flow and obstructions via ≈80 CCTV cameras. Real-time activation provides up to 20 % capacity gain without degrading safety (Geistefeldt, 2012). In the Netherlands, DHSR is always coupled with speed harmonization. Loop detectors at 500 m spacing feed the Motor Control and Signaling System (MCSS), which automatically adjusts speed limits (50–120 km/h) and displays them on dynamic message signs (DMS). Human operators at Rijkswaterstaat verify system readiness before activation (Anderson, 2016).

Q2: Lane clearing and activation procedures

Both nations follow rigorous clearance protocols before opening shoulders.

Germany: CCTV and patrol inspection precede every activation; any obstruction triggers immediate closure. Netherlands: Automated detection loops and camera feeds assess lane status; the control algorithm recommends activation, but a human operator authorizes final opening.

Q3: Safety and maintenance outcomes

Empirical results demonstrate substantial safety improvements when shoulder use is paired with active speed control. Germany: Corridors with PTSU show accident rates 25 % lower than similar roads without hard shoulders (Ferguson, 2009). Adaptive timing—opening just before breakdown and closing promptly afterward—further reduces secondary crashes (Geistefeldt, 2012). Netherlands: DHSR with speed harmonization cut collisions by ≈16 %, raised throughput by 3–5 %, and lowered congestion-related delay by up to 80 % (Jenior et al., 2019). Broader assessments reported congestion reductions of 25 % and crash reductions ranging 25–85 % (CEDR, 2018).

Q4: Driver compliance and signage strategies

Both countries rely on highly legible, standardized lane-control symbols. Germany: Overhead gantries display a green arrow (lane open), red X (closed), and yellow arrow (merge/closure warning). Speed harmonization typically sets limits between 80–100 km/h (50–60 mph) when active. Netherlands: DMSs spaced ≈1 km (0.6 mi) display variable limits within red circles (mandatory) or without circles (advisory). Automated photo radar enforces compliance, with penalties beginning at 4 km/h (2.5 mph) over the limit. The clarity and consistency of these symbols have produced exceptionally high compliance rates across both networks. (Waller et al., 2009)

Q5: Observed efficiency benefits

Germany: Temporary hard-shoulder running increased capacity 20–25 %, improved travel times, and reduced personal-injury crashes by ≈29 %. Netherlands: DHSR sections achieved 7–22 % capacity increases, 1–3 minute travel-time savings, and throughput gains up to 7 % during peaks. Integrated speed harmonization further cut severe accidents by nearly one-third. (Jenior et al., 2016)

Q6: Implementation challenges and resolutions

Early challenges involved ITS density, signage upgrades, and driver adaptation. Germany resolved these through coordinated investment in CCTV networks, radar/loop sensors, and centralized control strategies to fine-tune speed limits (Fellendorf & Graf, n.d.). The Netherlands supplemented automation with public education campaigns, added emergency refuge areas at regular intervals, and enhanced incident detection via full-matrix signs and CCTV (Jenior et al., 2016).

Both countries now treat shoulder use as a mature, integral component of their motorway management architecture.

Q7: Enforcement

Enforcement is largely automated. Germany: CCTV systems also support violation detection; unauthorized shoulder use can incur fines up to €320 and license suspension. Netherlands: Photo radar enforces dynamic speed limits and shoulder restrictions, ensuring uniform compliance even during adverse weather. Manual police intervention is minimal due to automation and the reliability of detection systems.

Chapter 5. Findings and Recommendations

This study synthesized national and international practices on Part-Time Shoulder Use (PTSU) and auxiliary lanes to inform NCDOT Division 10's evaluation of potential freeway applications—particularly on I-77 in the Charlotte region. The review addressed five key questions: how shoulder lanes are operated and cleared, what safety and efficiency effects have been observed, how compliance and enforcement are maintained, what issues agencies encountered, and what implementation strategies have proven most effective.

5.1 Summary of Findings

5.1.1 Lane operations and clearing procedures

Across nearly all agencies reviewed, operations follow standardized pre-opening protocols involving visual CCTV checks and on-site drive-through inspections 30 minutes before activation. TMCs coordinate directly with maintenance and law enforcement to remove debris, verify shoulder readiness, and stage tow trucks or safety patrols at key locations. During incidents, dynamic lane-control signs display a red "X" within seconds to close the lane, preserving responder access. This approach, confirmed in Ohio, Michigan, and Washington DOTs, was found to shorten clearance times and maintain high reliability of activation schedules.

5.1.2 Safety Implications

Safety findings from both domestic and international implementations indicate that the effects of PTSU on crash outcomes remain mixed but generally manageable under disciplined operations.

Cross-sectional studies, including NCHRP 17-89, show that while total crash frequency may rise slightly during active shoulder operation, the severity mix shifts toward less-severe injury levels, with fewer fatal and serious-injury (K/A) crashes. European evaluations of facilities such as Germany's A3 and A5 report neutral or positive safety outcomes when supported by strong operational controls, active lane management, and reliable incident response. Importantly, no U.S. PTSU facilities have been removed for safety reasons, underscoring that risks can be effectively managed through proper design and oversight.

Dynamic systems employing lane-use control signs (green arrow/red X) tend to outperform static, time-based configurations by reducing uncertainty and improving driver compliance. Right-side PTSU designs, as proposed for the I-77 corridor, generally pose lower speeding concerns than left-side configurations, though they introduce challenges for debris removal and emergency response access that must be addressed through pre-opening inspections, dedicated service patrols, and rapid closure capability.

Overall, safety performance depends more on operational discipline, incident-management readiness, and driver education than on geometry alone. To enhance safety and build confidence in future North Carolina applications, agencies should conduct longitudinal before–after evaluations and adhere to the following best-practice principles:

- Limit operating hours strictly to periods of recurring congestion.
- Provide frequent emergency turnouts (≈ 0.5 mi spacing).
- Maintain lane widths ≥ 12 ft where feasible or prohibit trucks on narrower shoulders.
- Integrate PTSU with complementary ATM tools such as VSL and queue-warning systems to moderate flow and improve driver awareness.

When implemented with these controls, part-time shoulder use can deliver congestion-relief benefits without compromising overall corridor safety.

5.1.3 Emergency Response Considerations

All agencies emphasized that emergency access planning is essential before PTSU activation.

- When shoulders are open to traffic, responders lose their traditional refuge and access path.
- Both MnDOT and WSDOT rely on quick clearance patrols and refuge bays to minimize response time.
- Mr. Jenior noted that responders adapt to the current traffic conditions and find a way to reach the incident site but require operational protocols and training.
- Facilities such as Washington's SR-14 incorporate emergency pull-outs every 0.5–1 mile and real-time incident monitoring from the TMC.

For North Carolina's I-77 corridor, coordination with Highway Patrol and emergency services will be vital to define access routes, backup response paths, and incident-handling procedures during active shoulder operation.

5.1.4 Efficiency Implications

Shoulder use provides measurable travel time and congestion reduction benefits, though the magnitude varies significantly by corridor geometry, side of implementation, and operational strategy.

Across U.S. deployments, capacity increases typically range from 7–25%, with 15–20% reductions in travel time variability reported where continuous or dynamically controlled shoulders are in use.

Left-side shoulder lanes have generally shown greater efficiency benefits than right-side implementations because they provide a more continuous flow of traffic with fewer interruptions from merging, weaving, or ramp activity. Their operation allows smoother speed harmonization and less frequent deceleration, leading to greater overall throughput gains.

By contrast, right-side shoulder lanes, such as those used in Washington (SR-14) and under consideration for North Carolina's I-77 corridor, tend to be most effective where ramp density is low or where shoulders can serve as auxiliary or exit-only lanes that start and stop between interchanges. These configurations help relieve localized bottlenecks but do not provide corridor-wide capacity relief.

In dynamic systems like SR-14 (Washington), real-time activation yields higher reliability and smoother recovery from peak congestion compared to static schedules. However, for I-77's proposed auxiliary-lane concept, benefits are expected to be incremental rather than continuous, primarily improving weaving and merging efficiency rather than overall corridor throughput.

Therefore, while meaningful operational gains can be achieved, efficiency benefits will remain highly site-specific, dependent on ramp spacing, lane continuity, and activation strategy. These should be validated through microsimulation before implementation and post-deployment performance monitoring thereafter.

5.1.5 Operational and Institutional Considerations

Technology and Signage:

Both interviewees and survey responses highlight that static signs are insufficient for reliability and enforcement. Transitioning to dynamic lane-control signals (green arrows/red X) and fiber-connected gantries will be critical for I-77 implementation. TMC software upgrades, costing several hundred thousand dollars, would be required to integrate this functionality and may require dedicated operator oversight during peak periods. ITS costs are the primary contributor to capital and O&M expenses for PTSU projects.

Enforcement:

The key enforcement challenge lies in preventing drivers from using shoulders when closed. Initial phases should include heightened patrol presence and public messaging campaigns. Automated enforcement (e.g., speed cameras) remains illegal in North Carolina, so compliance will depend on sign clarity and early enforcement visibility.

5.2 Summary of Recommendations

Based on literature synthesis, survey feedback, and expert interviews, the following recommendations are provided for NCDOT's consideration. These are organized by implementation phase.

5.2.1 Pre-Opening (Planning and Design Phase)

- Conduct a detailed geometric and operational feasibility review, focusing on ramp spacing, shoulder width, and emergency pull-out locations. A corridor selection strategy can also be proactively applied like the study done in Michigan (Savolainen et al., 2025).
- Engage early with first responders and TMC operators to co-develop incident response and lane closure protocols.
- While expensive, consider a design for ITS integration (e.g., lane-control gantries, CCTV coverage every 0.5 mi, etc.) to allow for long-term ATM benefits.
- Develop and test TMC software interfaces for lane activation, status display, and real-time incident alerts.
- Perform baseline data collection for crash, speed, and reliability metrics to support before–after analysis.
- Finalize an enforcement coordination plan with Highway Patrol prior to activation.

5.2.2 Before Starting Shoulder Use (Commissioning Phase)

- Perform a full field inspection and simulation-based "readiness check."
- Train TMC staff and emergency responders on activation, closure, and communication protocols.
- Launch public information campaigns explaining lane rules, signage meanings (green arrow/red X), and enforcement periods.
- Test CCTV, lane-control, and communications systems under controlled conditions before opening to the public.
- Establish a decision-support tool that sets activation criteria based on congestion thresholds and camera verification (see Jenior et al., 2019 for more guidance on dynamic use operations).

5.2.3 During Shoulder Operation

- Implement mandatory pre-opening clearance inspections via CCTV and on-site patrols.
- Activate dynamic signage simultaneously along the corridor, avoiding staggered openings that may confuse drivers.
- Maintain continuous TMC monitoring for incidents, with immediate lane closure capability.
- Deploy quick-response tow and maintenance units during active hours to minimize clearance time.
- Coordinate with Highway Patrol for targeted enforcement during initial weeks to ensure compliance.

5.2.4 After Shoulder Use (Post-Operation and Monitoring Phase)

- Close the shoulder promptly at scheduled times or upon detection of obstruction.
- Collect operational data on speed, flow, and crash frequency during the first year.
- Conduct quarterly evaluations to identify maintenance issues and software performance.
- Prepare annual safety and performance reports comparing pre- and post-implementation conditions.

5.2.5 Long-Term Evaluation and Continuous Improvement

- Pursue a longitudinal before–after crash study to strengthen the evidence base for North Carolina applications or participate in a pooled study with other DOTs to achieve detailed documentation on long-term safety benefits of PTSU.
- Document lessons learned on TMC coordination, enforcement adaptation, and responder access for future corridors.
- Integrate PTSU readiness into future corridor planning and ATM strategies as part of a holistic congestion management and ITS modernization strategy.

5.3 Implementation and Technology Transfer Plan

This study provides a structured synthesis of national and international practices on part-time shoulder use, with clear guidance on planning, design, operations, and monitoring that can be directly applied by NCDOT and partner agencies. Section 5.2 outlines actionable steps across implementation phases—pre-opening, commissioning, active operation, and post-deployment—covering elements such as geometric feasibility, ITS integration, incident management protocols, and enforcement coordination. These recommendations are based on observed practices across multiple DOTs and are intended to support informed decision-making for corridors such as I-77.

A key implementation resource developed through this effort is the living database of shoulder-use facilities (see Appendix C). The database compiles facility locations, approximate segment limits, left- versus right-shoulder designation when identifiable, and supporting references used in the review. This resource supports peer benchmarking and makes it easier for agencies to compare corridor types, operating strategies, and design choices across existing deployments. The database also highlights an important pattern noted in the study: many earlier U.S. installations used the right shoulder, whereas most more recent dynamic systems use the left shoulder, with right-shoulder applications now more often functioning as short auxiliary treatments between ramps.

Technology transfer from this project occurred through both the final report, presentations, and the accompanying database, which together organize the findings into accessible, usable formats for planners, traffic operations staff, ITS engineers, and decision-makers. Together, these products strengthen NCDOT's ability to evaluate candidate corridors, communicate with peer agencies, and support future planning or pilot efforts involving shoulder-use operations.

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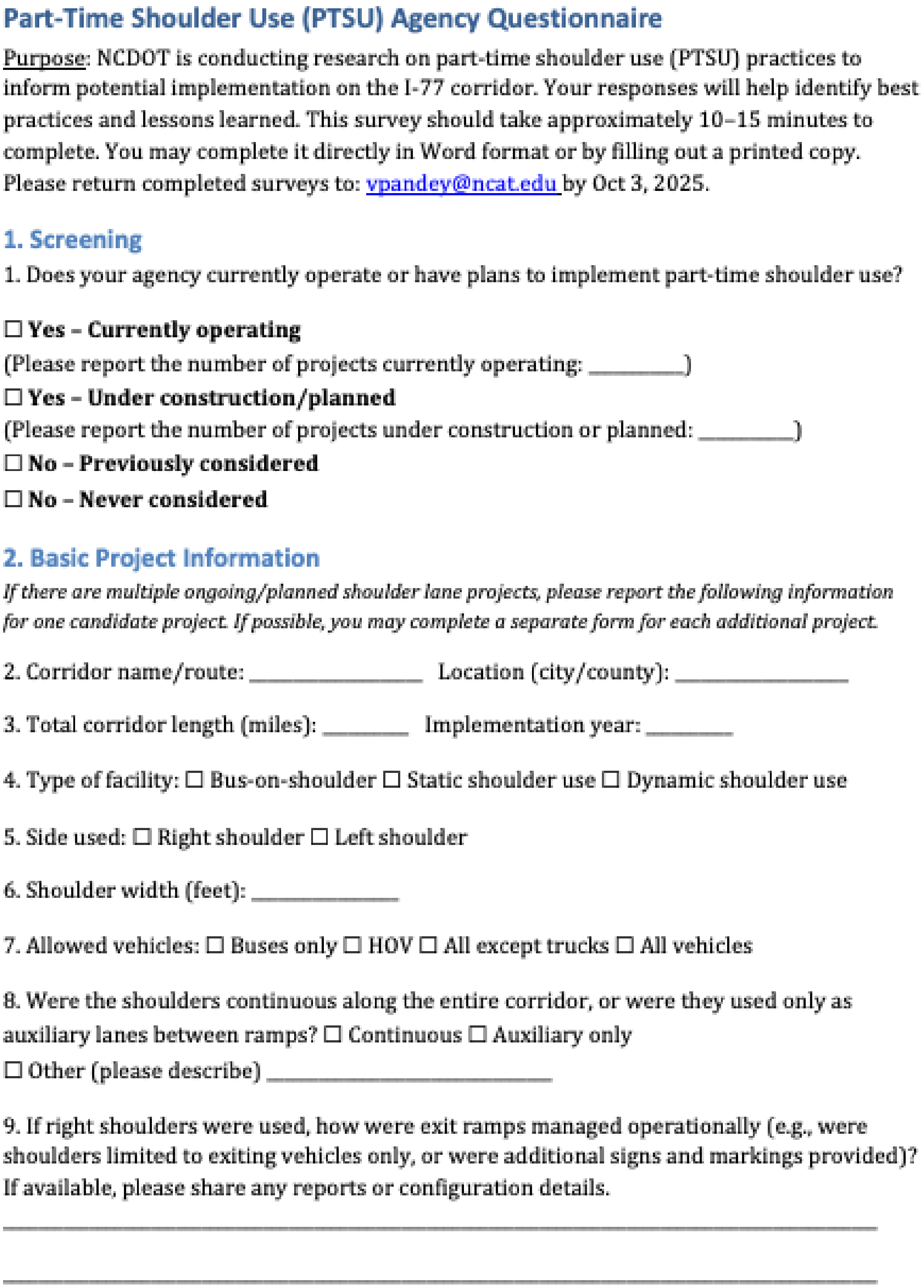
Appendix A. Survey Circulated to Transportation Agencies



Part-Time Shoulder Use (PTSU) Agency Questionnaire

Purpose: NCDOT is conducting research on part-time shoulder use (PTSU) practices to inform potential implementation on the I-77 corridor. Your responses will help identify best practices and lessons learned. This survey should take approximately 10–15 minutes to complete. You may complete it directly in Word format or by filling out a printed copy. Please return completed surveys to: vpandey@ncat.edu by Oct 3, 2025.

1. Screening

1. Does your agency currently operate or have plans to implement part-time shoulder use?

☐ **Yes – Currently operating**
(Please report the number of projects currently operating: _________)
☐ **Yes – Under construction/planned**
(Please report the number of projects under construction or planned: _________)
☐ **No – Previously considered**
☐ **No – Never considered**

2. Basic Project Information

If there are multiple ongoing/planned shoulder lane projects, please report the following information for one candidate project. If possible, you may complete a separate form for each additional project.

2. Corridor name/route: ________________ Location (city/county): ________________

3. Total corridor length (miles): ________ Implementation year: ________

4. Type of facility: ☐ Bus-on-shoulder ☐ Static shoulder use ☐ Dynamic shoulder use

5. Side used: ☐ Right shoulder ☐ Left shoulder

6. Shoulder width (feet): _____________

7. Allowed vehicles: ☐ Buses only ☐ HOV ☐ All except trucks ☐ All vehicles

8. Were the shoulders continuous along the entire corridor, or were they used only as auxiliary lanes between ramps? ☐ Continuous ☐ Auxiliary only
☐ Other (please describe) __________________________

9. If right shoulders were used, how were exit ramps managed operationally (e.g., were shoulders limited to exiting vehicles only, or were additional signs and markings provided)? If available, please share any reports or configuration details.

____

____

3. Operations & Infrastructure

10. Activation method: ☐ Manual from TMC ☐ Automated ☐ Fixed schedule

11. Pre-activation inspection:
☐ Drive-through sweep the entire lane ☐ Camera verification ☐ Both ☐ Neither ☐ Other
If other, please describe: ____

12. Who performs activation? ☐ TMC staff ☐ Field personnel ☐ Law enforcement

13. Emergency pull-outs provided? ☐ Yes ☐ No If yes, typical spacing: ________ miles

14. Signage type: ☐ Static ☐ Dynamic message signs ☐ Lane control signals

15. Speed limits on shoulders: ☐ Same as general purpose lanes ☐ Reduced ☐ Variable

If reduced/variable, what is the differential compared to other lanes? ______________
____

16. Were rumble strips or special pavement markings used? ☐ Yes ☐ No
If yes, please describe: ____

4. Safety & Enforcement

17. Have you conducted before/after crash analysis? ☐ Yes ☐ No ☐ Ongoing

18. Overall safety trend since implementation:
☐ Definitely improved ☐ Possibly improved ☐ No change
☐ Possibly worsened ☐ Definitely worsened ☐ Unknown

19. Most common safety issues observed (if any): ____________________________
____

20. Primary enforcement challenge: ☐ Unauthorized use when closed ☐ Speeding
☐ Lane violations ☐ Minimal issues

21. Enforcement approach: ☐ Regular patrol ☐ Cameras ☐ Initial education period
☐ Reactive only

22. How long was heightened enforcement needed after rollout? ___________________
____

23. How do emergency vehicles or incident teams access incidents if all lanes, including shoulders, are blocked? ____
____

5. Costs & Benefits

24. Approximate initial capital cost for the PTSU project: $ ____________________________
(or ☐ Not available)

25. Primary cost drivers: ☐ Signage/ITS ☐ Shoulder reconstruction ☐ Emergency pull-outs
☐ Other: ________

If signage/ITS were used, can you specify approximate costs for static vs. dynamic signs vs. lane control signals? _________________

26. Estimated capacity increase during operation (%): _____________ (or ☐ Not available)

27. Primary observed benefit: ☐ Congestion relief ☐ Transit improvement
☐ Incident management ☐ Other: _________________________________

28. Have you conducted before/after efficiency improvement analysis? ☐ Yes ☐ No ☐ Ongoing
Please provide supporting evidence if available (travel time, crash analysis, operator feedback): ____________________________

6. Lessons Learned

29. What would you do differently if implementing shoulder use installation again?
____
____

30. Biggest operational challenge: ____
____

31. What advice would you give to agencies (such as NCDOT) considering part-time shoulder use (PTSU) during peak periods? ____
____

32. What key factors most influenced the success (technology, staffing, messaging, geometry, etc.)? ____

7. Contact Information

Name: _______________________ Title: _________________

Agency: ____

Email: ___________________________ Phone: _________________

Would you be willing to participate in a brief follow-up interview by the research team?
☐ Yes ☐ No

Thank you for taking the time to share your agency's experience. Your input will directly support NCDOT in evaluating best practices for part-time shoulder use.

Appendix B. Individuals Interviewed/Surveyed

Name	Title / Role	Agency / Organization	Email	Phone
Charles Blackman	ITS Project Manager	New Hampshire DOT (NHDOT)	charles.e.blackman@dot.nh.gov	(603) 227-0016
Matt Luker	ITS Program Manager	Utah DOT (UDOT)	mluker@utah.gov	(801) 887-3792
Ryan Lowe	TSMO Administrator	Ohio DOT (ODOT)	ryan.lowe@dot.ohio.gov	(614) 275-1306
Neil Boudreau	Assistant Administrator, Traffic & Safety	Massachusetts DOT (MassDOT)	neil.boudreau@dot.state.ma.us	(857) 368-9655
Jason Firman	ITS Operations	Michigan DOT (MDOT)	firmanj@michigan.gov	(517) 388-3378
Liz Schneider	Freeway Operations / DPTSU Engineer	Wisconsin DOT (WisDOT)	elizabeth1.schneider@dot.wi.gov	(414) 750-2918
Rob Brusseau	Corridor Operations Engineering WSDOT SWR Traffic	Washington DOT (WSDOT)	robert.brusseau@wsdot.wa.gov	(360)-989-4142
Pete Jenior	Principal Engineer	Kittelson & Associates, Inc.	pjenior@kittelson.com	—
NJDOT respondent (unnamed)	Traffic Operations Division	New Jersey DOT (NJDOT)	—	—

Appendix C. Database of Part-time Shoulder Use Facilities in the US

The living document is available at the Google Sheets link below:
https://docs.google.com/spreadsheets/d/1zuftjFQ4ucOi7jIXSl2qyZVv-0OQiwct3VTCEEGKK9Q/edit?usp=sharing

Please contact the PI (vpandey@ncat.edu) if you'd have further questions or comments.