PART-TIME SHOULDER USE SYNTHESIS OF PRACTICE

FHWA Publication No. FHWA-HOP-23-066 June 2024

U.S. Department of Transportation
Federal Highway Administration

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TECHNICAL REPORT DOCUMENTATION PAGE

<table>
<tr><td colspan="2">1. Report No.
FHWA-HOP-23-066</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="3" rowspan="2">4. Title and Subtitle
Part-Time Shoulder Use Synthesis of Practice</td><td colspan="2">5. Report Date
June 2024</td></tr>
<tr><td colspan="2">6. Performing Organization Code:</td></tr>
<tr><td colspan="3">7. Author(s)
Pete Jenior, Anusha Musunuru, Rick Dowling, Sonu Matthew, David Hale</td><td colspan="2">8. Performing Organization Report No.</td></tr>
<tr><td colspan="3" rowspan="2">9. Performing Organization Name and Address
Leidos Inc.
1750 Presidents Street
Reston, VA 20190

Kittelson & Associates, Inc.
20 S Charles St., Suite 406
Baltimore, MD 21201</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.</td></tr>
<tr><td colspan="3" rowspan="2">12. Sponsoring Agency Name and Address
Federal Highway Administration
1200 New Jersey Ave., SE
Washington, DC 20590</td><td colspan="2">13. Type of Report and Period Covered
Final Report; July 2022 – January 2024</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code
HOP</td></tr>
<tr><td colspan="5">15. Supplementary Notes
Greg Jones served as the Government Task Manager.</td></tr>
<tr><td colspan="5">16. Abstract
Part-time shoulder use (PTSU) has recently become an accepted active transportation and demand management strategy for periods of capacity-related congestion. When FHWA published Use of Freeway Shoulders for Travel—Guide for Planning, Evaluating, and Designing Part-Time Shoulder Use as a Traffic Management Strategy in 2016, there was a void in information on the planning, design, and operations of PTSU. This project looks at recent facility developments to see if the information in Use of Freeway Shoulders is sufficient or if there are gaps in the information that need to be addressed. This report describes a synthesis review of recently deployed PTSU projects to see what, if any, factors were not sufficiently addressed in Use of Freeway Shoulders and presents findings from interviews with agencies that recently implemented PTSU.</td></tr>
<tr><td colspan="2">17. Key Words
Part-time shoulder use, hard shoulder running, shoulder lanes, active traffic management, transportation systems management and operations, freeway</td><td colspan="3">18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.
http://www.ntis.gov</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td colspan="2">20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
47</td><td>22. Price
N/A</td></tr>
</table>

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

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ATDM	active transportation and demand management
ATM	active transportation management
BOS	bus-on-shoulder
Caltrans	California Department of Transportation
CCTV	closed-circuit television
C-TRAN	Clark County Public Transportation Benefit Area
DMS	dynamic message sign
DOT	department of transportation
FHWA	Federal Highway Administration
HSM	*Highway Safety Manual*
I–	Interstate
ITS	intelligent transportation system
MnDOT	Minnesota Department of Transportation
MUTCD	*Manual on Uniform Traffic Control Devices for Streets and Highways*
N/A	not applicable
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
ODOT	Oregon Department of Transportation
PTSU	part-time shoulder use
SEPA	State Environmental Policy Act
SH	State highway
SR	State route
TBD	to be determined
TMC	transportation management center
USDOT	U.S. Department of Transportation
VSL	variable speed limit
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

The 2016 Federal Highway Administration (FHWA) document *Use of Freeway Shoulders for Travel—Guide for Planning, Evaluating, and Designing Part-Time Shoulder Use as a Traffic Management Strategy* (Jenior 2016), hereafter referred to as *Use of Freeway Shoulders,* was the first attempt to provide information on part-time shoulder use (PTSU) at the national level. Agencies are now using the 2016 guide for planning, designing, and implementing PTSU projects. Generally, many agencies consider PTSU applications as a cost effective active transportation and demand management (ATDM) strategy for periods of capacity-related congestion. The agencies perceive the planning, designing, and operating of shoulders as travel lanes during capacity-related congestion as viable, less expensive, and rapidly implementable solutions for congestion mitigation. Moreover, PTSU can defer expensive capacity-adding construction for many years.

Several PTSU projects have opened since *Use of Freeway Shoulders* was published in 2016, and other projects are in the planning and design stages. The body of knowledge on PTSU in the United States has increased as the new deployers have learned from one another. It may now be helpful to update the 2016 guide with more recent experience to provide information on newer applications of PTSU, which are becoming more technologically advanced than the older facilities.

PURPOSE OF THE REPORT

The purpose of this synthesis report is to provide a review of the recently deployed PTSU facilities in the United States and to identify successful practices and lessons learned from the following perspectives:

- Planning and evaluation
- Mobility, safety, and environmental analysis techniques and outcomes
- Design and implementation
- Operations, maintenance, and standard operating procedures

METHODOLOGY

The research team conducted a literature review and agency interviews to gather information on the degree to which agencies used the 2016 *Use of Freeway Shoulders* and whether they found the report helpful during PTSU project planning and design. The team's literature review included updating the current inventory of PTSU projects and documentation from departments of transportation (DOT) and public-facing outreach materials, such as websites. The team identified eight agencies to interview, established a list of interview questions, and conducted the interviews through virtual meeting platforms.

KEY RESULTS

Key findings include:

- Some projects that opened shortly after 2016 made minimal use of *Use of Freeway Shoulders* because planning and design had largely been completed by the time the guide was published.

- States that had already implemented PTSU (even in another DOT district or geometric region of the State) tended to use guidance and lessons learned from their first PTSU implementation more than *Use of Freeway Shoulders*.

- *Use of Freeway Shoulders* could become more helpful to agencies by providing additional information on the following:
  - Concept of operations activities
  - Traffic management center (TMC) software for PTSU operation
  - Agency standard operating procedures for day-to-day operation of PTSU

- Although informational guides such as the National Cooperative Highway Research Program's (NCHRP) *Project 17-89*, *Safety Performance of Part-time Shoulder Use on Freeways* are available, safety still remains a key question about PTSU during the planning and design phase.

CHAPTER 1. INTRODUCTION

BACKGROUND

The 2016 Federal Highway Administration (FHWA) document *Use of Freeway Shoulders for Travel—Guide for Planning, Evaluating, and Designing Part-Time Shoulder Use as a Traffic Management Strategy* (Jenior 2016) was the first attempt to provide information on part-time shoulder use (PTSU) at the national level. Agencies are now using this guide for planning, designing, and implementing PTSU projects. Several PTSU projects have opened following publication of the guide, and others are in the planning and design stages. The body of knowledge on PTSU in the United States has increased, and there is an emerging PTSU practice in the United States as agencies have learned from one another. Newer facilities are more technologically advanced than older facilities, with features such as gantries with lane control signals over all lanes, variable speed limits (VSL), and increased incident management capabilities.

Generally, many agencies in the United States have come to accept PTSU applications as a cost effective ATDM strategy for periods of capacity-related congestion. These agencies perceive the planning, designing, and operating of shoulders as travel lanes during capacity-related congestion as viable, less expensive, less impactful to right-of-way and environmental resources, and rapidly implementable solutions for congestion mitigation. PTSU can be a short-term or long-term solution for a corridor.

Prior to the 2016 publication of *Use of Freeway Shoulders*, little information existed at the national level on the planning, design, operation, and implementation of PTSU. At that time, 32 known PTSU installations in the United States existed, of which 18 were bus-on-shoulder (BOS) installations. The remaining installations were static or dynamic PTSU facilities (i.e., the shoulder was open to all passenger vehicles), with 12 static facilities and 2 dynamic facilities. Since 2016, there have been 13 new PTSU installations in the United States, which are characterized as follows:

- 6 BOS facilities
- 1 static PTSU facility
- 5 dynamic PTSU facilities

Additionally, there are five known dynamic PTSU facilities in design and construction. Chapter 2 provides a list of these facilities.

It may be helpful for agencies to have more information on newer applications of PTSU, which tend to be more technologically advanced than older facilities.

OBJECTIVE

The purpose of this synthesis report is to provide a review of recently deployed PTSU facilities, particularly in the United States, following the 2016 publication of *Use of Freeway Shoulders*. The objective is to communicate the effectiveness of the guide in supporting the planning and design of PTSU installations, identify successful practices, and understand lessons learned from the following perspectives:

- Planning and evaluation
- Mobility, safety, and environmental analysis techniques and outcomes
- Design and implementation
- Operations, maintenance, and standard operating procedures

CHAPTER 2. SITE SELECTION

The *Use of Freeway Shoulders* (Jenior 2016) inventoried 30 PTSU projects in 16 States from 2015 to 2016, a few of which were in the planning stage and had not been implemented yet at the time of publication of the guide. FHWA partially updated that inventory in *Decision Support Framework and Parameters for Dynamic Part-Time Shoulder Use—Considerations for Opening Freeway Shoulders for Travel as a Traffic Management Strategy* (Jenior 2019). As part of this project, the research team updated the inventory in fall 2022.

Table 1 summarizes the planned or implemented PTSU facilities in the United States following publication of the 2016 guide. For each PTSU facility, the team collected information about locations, route numbers, facility types, side of shoulder used, PTSU types, eligible vehicle usage, hours of operation, speed limits, and cross sections. Lengths in table 1 reflect directionality. For example, a facility with PTSU in both directions for 1 mile has a reported length of 2 miles. This list helped identify eight PTSU projects for more indepth evaluation of the following:

- How did agencies use (or not use) the material in the *Use of Freeway Shoulders*?
- How did the *Use of Freeway Shoulders* help in the planning and design of the PTSU project?
- How did gaps in the 2016 guide hinder the planning and design of the PTSU project?

SELECTION CRITERIA AND TOP 10 SITES

The team initially identified 16 PTSU projects. One of these projects is a BOS facility implemented in 2011 that uses the left-side (median) shoulder, which is uncommon for BOS. Beyond that facility, agencies implemented or planned the other 15 facilities following publication of the 2016 guide.

Of the identified 16 PTSU projects, the team selected 10 projects that represented a cross section of agencies, PTSU project types, geographic locations, and context (right side versus left side, urban versus rural, all passenger vehicles versus bus only). Of the 10 projects, 8 facilities focused on PTSU open to all passenger vehicles, and 2 facilities included BOS usage. The team searched for information available in the public domain with respect to these 10 facilities, including safety and operational performance data.

The team submitted an initial list of 10 projects to FHWA for review and acceptance. Once the review was complete, the team contacted the associated agencies to assess their willingness, ability, and availability to participate in an interview. Based on the agency responses, the team selected eight agencies for indepth interviews.

Table 1. Part-time shoulder use facility implementations after publication of the 2016 guide.

No.	Location	Corridor	Length (Lane-Miles)	Opened	PTSU Type	Notes
1	Richmond, CA (Contra Costa County, Marin County)*	I–580 eastbound	5.5	2018	Static	None
2	Seattle, WA (King County, Snohomish County)*	I–405 northbound	3	2017	Dynamic	None
3	Columbus, OH*	I–670 eastbound	5	2019	Dynamic	Lane control signals over all lanes, VSL
4	Suburban Chicago, IL*	I–90 Illinois Tollway	32	2018	Dynamic	Lane control signals over all lanes
5	Gary, IN*	I–80	28	TBD	TBD	Currently under design
6	Vancouver, WA*	SR 14 westbound	1.5	2024 planned	Dynamic	Currently under construction
7	Suburban Philadelphia, PA	I–76	5	2027 planned	Dynamic	Will begin construction summer 2024
8	Fort Worth, TX	SH 121	3	2020	Dynamic	Dynamic message signs (DMS)
9	Vancouver, WA*	I–5	3.5	2018	BOS	Southbound only
10	Orlando, FL	SR 429	26	2024 planned	Dynamic	Lane control signals over all lanes, VSL
11	Orlando, FL	SR 417	46	2024 planned	Dynamic	Lane control signals over all lanes, VSL
12	Ann Arbor, MI (Washtenaw County)	US 23	18	2017	Dynamic	Lane control signals over all lanes, VSL
13	Oakland County, MI	I–96	11	2024 planned	TBD	None
14	Pinellas County, FL	I–275	10	2021	BOS	N/A
15	Boston, MA	I–93	14	2021	BOS	N/A
16	San Diego, CA	I–805/SR 94	10	2021	BOS	N/A
17	Vancouver, WA	SR 14	2.5	2017	BOS	Eastbound only, different portion of SR 14 than Dynamic facility
18	Portland, OR	I–205	4	2020	BOS	N/A

*Interview conducted as part of this study (seven facilities were selected from this list; the BOS network from Minnesota was added, and interviews were conducted for eight facilities).
BOS = bus-on-shoulder; I– = interstate; N/A = not applicable; PTSU = part-time shoulder use; SH = State Highway; SR = State Route; TBD = to be determined; VSL = variable speed limit.

CHAPTER 3. AGENCY INTERVIEWS AND INTERACTION

This section summarizes the results from interviews and email correspondence with agencies to assess utilization of the *Use of Freeway Shoulders* (Jenior 2016) during PTSU project planning and design. The team also gathered general information about the facilities. Through these interviews, the team determined each agency's awareness of the 2016 guide and the degree to which they consulted the guide during their PTSU facility's planning and design processes. For agencies that used the 2016 guide, the team further inquired about the agency's opinions on the quality and helpfulness of the material. The team also asked agencies to identify gaps in the topics or content covered by the 2016 guide.

DEVELOPMENT OF DISCUSSION QUESTIONS

The team prepared and sent questions to agency contact persons in advance of the interview. During the interview meeting, the team covered the following specific questions:

- Is the information emailed to you about your facility (length, year opened, VSL yes/no, etc.) correct?
- Did your agency use the 2016 informational guide in the PTSU's planning and design processes for the planned or already implemented project?
  - If yes, how was it used?
    - What was most helpful and not so helpful in the guide?
  - If no, what resources did you use for the PTSU facility's planning and design?
    - How can FHWA make the PTSU guide more helpful for your planning processes?
- Why did your agency first consider PTSU, and what process was used to select it over other capacity-increasing alternatives?
- What led you to pick dynamic operation or static operation?
- Did you change anything in the PTSU implementation after the facility opened?
- Did your agency conduct highway capacity analysis; if so, what methods/tools were used?
- Did your agency conduct safety analysis; if so, what methods/tools were used?
  - Can you share any safety results/findings?
  - Can you share before-and-after crash data? (This applies only where the PTSU operation is in use.)
- Did your agency conduct an environmental analysis? If so, what specific aspects (noise, air quality, stormwater, historic properties, environmental justice, etc.) were considered?
- What was the initial estimated cost of your agency's PTSU installation, and how did this compare with the final cost of implementation?

- What is the typical section (lane widths and shoulder widths) of your facility? Were any design exceptions obtained for any features of your facility? Were any mitigating features present?

- What specific actions do your operators take before the shoulder is opened?

- What standard operating procedures does your agency use?

DISCUSSION FINDINGS

Appendix A includes the detailed results of each agency interview along with the agency responses to each of the interview questions. This section summarizes findings for each of the interview questions that follow.

Did your agency use *Use of Freeway Shoulders* (Jenior 2016) in the PTSU's planning and design processes for the planned or already implemented project?

Most agencies relied on the experience of peer agencies (or other districts within the State) to assist in planning, designing, and implementing PTSU projects. Two of eight interviewed agencies used the guide and said the guide was helpful in understanding general PTSU concepts. One of these two agencies noted that the guide was helpful in visualizing the process of shoulder opening/closing and public/stakeholder engagement. The same agency noted that the case studies presented in the 2016 guide were helpful in understanding the PTSU facility design and operation. The other six agencies were aware of the guide but did not use it because their planning and design efforts had begun before the guide was published or because they had other examples in their State to follow. Agencies that used and did not use the guide stated it would have been helpful to have more detailed information on the following topics:

- Specific considerations for the left-side PTSU lane/facility type

- Estimate of time and effort to plan, obtain, configure, and test the TMC software that operates PTSU

- Concept of operations and maintenance agreements

- Suggestions on implementing very short (½- to 1-mile length) shoulder in between on-ramps and off-ramps on the freeway (also called dynamic drop lane)

- Insights into establishing proper communication channels among the TMC and stakeholders in the field (maintenance staff, law enforcement, emergency responders) to ensure the shoulder stays in the best condition

Why did your agency first consider PTSU, and what process was used to select it over other capacity-enhancing alternatives?

Six of eight agencies considered various alternatives that could reduce congestion. However, the PTSU implementation fit within the budget, met right-of-way constraints, was favorable with existing conditions, and preserved the shoulder when not needed for congestion reduction.

Minnesota DOT, which operates the country's largest BOS network, considers BOS implementation for locations that meet the following four criteria:

- Congestion delays must occur one or more days per week
- A minimum of six transit buses per week must use the roadway
- Expected travel time savings of using the BOS must be greater than 8 minutes per mile per week.
- The proposed BOS must have a continuous shoulder width of at least 10 feet on roadways and 11½ feet on bridges. For roadways being reconstructed, the minimum shoulder width is 12 feet.

What led you to pick dynamic versus static operation?

Five of eight agencies considered dynamic PTSU because a PTSU makes it easier to open and close a shoulder lane when needed. The agencies further stated that the dynamic operation of the PTSU lane also provides the flexibility to open the shoulder lane in response to incidents and congestion during holidays or special events.

This question was not applicable for two out of eight agencies because they use BOS operation. BOS operational rules generally permit but do not require buses to use the shoulder when the speed falls below a certain threshold. Drivers have the option of using or not using the shoulder when traffic speeds fall below this threshold at their discretion.

Did you change anything in the PTSU implementation after the facility opened?

Two agencies noted that staff operating the PTSU facility took more control and opened and closed the shoulder based on congestion levels without relying on the software's trigger alert based on volume and speed characteristics.

One agency made minor tweaks to the user interface and made the TMC software interface more user friendly. The operators and staff at this agency are working on creating an algorithm that automatically will suggest when to open the shoulder lane for traffic, depending on roadway congestion levels.

Another agency made changes to internal processes, specifically internal communications, to get information from operators or field supervisors to dispatchers on time and as appropriate.

This question was not applicable for two of the eight agencies because the PTSU facilities were still under design or construction.

Did your agency conduct highway capacity analysis?

Three of eight agencies analyzed the traffic operations of the facility using microsimulation modeling. One agency used the Highway Capacity Software™ (University of Florida McTrans Center n.d.).

This question was not applicable for two of eight agencies because they use the BOS system.

Did your agency conduct highway safety analysis?

Three of eight agencies analyzed the safety performance of the facility using *Highway Safety Manual Supplement* (HSM Supplement, AASHTO 2014) chapter 18 for freeways. These agencies analyzed the PTSU condition as an additional lane with a narrow shoulder beside it. *Use of Freeway Shoulders* (Jenior 2016) describes this analysis method as well. Indiana DOT used PTSU safety performance functions from NCHRP Project 17-89 (Jenior 2021) as a resource for evaluating safety performance. The interviewed States generally did not conduct before-and-after evaluations of PTSU safety performance following implementation.

Two of eight agencies with BOS operation looked at the historic crash data to understand and obtain insights into the safety performance of the shoulder lane.

Did your agency conduct an environmental analysis?

Four of eight agencies conducted detailed environmental analysis for the PTSU project.

One agency is currently working on the National Environmental Policy Act (NEPA) (United States Environmental Protection Agency n.d.) determination for the project proposal, as the facility has not yet been built.

One agency with a BOS operation did not conduct a detailed environmental review but will provide an early notification memo outlining the changes to be made as part of the BOS implementation.

What was the initial estimated and final cost of implementation for your agency's PTSU installation?

Table 2 presents the approximate cost of five PTSU installations that were provided during interviews. Among the facilities listed in table 2, I–90 has PTSU in both directions (16 miles in each direction), and the other facilities have a PTSU in one direction only.

Table 2. Part-time shoulder use cost summary.

State	Corridor	PTSU Type	Length (Lane-Miles)	Cost	Cost Per Mile	Notes
CA	I–580 eastbound	Static	5.5	$50M	$9.1M	Included system integration costs
OH	I–670 eastbound	Dynamic	5	$12M	$2.4M	Replaced BOS facility
IL	I–90 Illinois Tollway	Dynamic	32	$140M	$4.4M	N/A
WA	SR 14	Dynamic	1.5	$5.5M	$3.7M	N/A
WA	I–5 southbound	BOS	3.5	$3.5M	$ 1M	N/A

BOS = bus-on-shoulder; I– = interstate; N/A = not applicable; PTSU = part-time shoulder use; SR = State Route; VSL = variable speed limit.

What is the typical cross-section of your facility? Were any design exceptions obtained for any of the features of your facility?

The lane width for the shoulder lane on static and dynamic facilities ranged from 10 to 14 feet. For BOS in Clark County, WA, the minimum shoulder width is 12 feet. For BOS operation in Minnesota, the minimum shoulder width is 10 feet on roadways on grade and 11½ feet on bridges.

Ohio obtained design exceptions for the I–670 facility for the lateral offset between the PTSU lane and the median barrier and for stopping sight distance. The State used VSL to mitigate both issues. Caltrans obtained design exceptions for the I–580 facility.

What specific actions do your operators take before the facility opens?

All agencies have some variation of the following process:

- The TMC operator needs to visually sweep (i.e., inspect with closed-circuit television (CCTV) cameras) the shoulder of dynamic PTSU facilities daily, including prior to the start time.
- The maintenance and operation team or law enforcement drives the shoulder before the start time and notifies the TMC that the system is ready to turn on. If debris or disabled vehicles are present on the shoulder, the team or law enforcement coordinates vehicles' removal. The shoulder remains closed until it is no longer physically blocked.
- The TMC operator activates the system daily. Prior to activation, the TMC operator confirms the shoulder is clear.
- The system may automatically deactivate at the end time of the morning peak hour.
- If congestion is present at the end time, the TMC operator can extend the operation.
- The TMC operator may change all lane-control signs from "Open, Exit Only" to a yellow merge arrow prior to deactivating the system. The DMS signs may also change to a "Shoulder Closing" message. The TMC will determine the duration of the yellow merge arrow and may control it automatically (if applicable).
- At the end of the yellow merge arrow duration, the system switches to the standard (shoulder closed) condition with "Closed" displayed.
- The start and stop times during the morning or afternoon peak hours commute adjust based on traffic conditions once the PTSU is in operation.

The process for BOS operations is as follows: Bus drivers enter and leave the shoulder at their discretion if traffic congestion and travel speeds permit use of the shoulder.

What standard operating procedures does your agency use?

All agencies have developed their own standard operating procedures in agreement with law enforcement, operations and maintenance staff, and incident response teams. The operators delay opening the shoulder if obstacles or debris are on the shoulder. Operators typically extend shoulder use past the typical closing time if traffic is still congested on the corridor.

CHAPTER 4. CONCLUSION

An increasing number of agencies are implementing PTSU. Most new facilities are BOS or dynamic PTSU, and newer dynamic PTSU facilities often have other active transportation management (ATM) treatments such as lane control signals over all lanes or VSL. Static PTSU is becoming less common as agencies are opting to implement dynamic PTSU instead.

Agencies were typically aware of *Use of Freeway Shoulders* (Jenior 2016), but some did not use it because their projects were already in design by the time the guide was published or the agency had other examples in their States from which to draw experiences. States noted *Use of Freeway Shoulders* would be more helpful if it included more information on the following topics:

- Concept of operations activities
- TMC software for PTSU operation
- Agency standard operating procedures for day-to-day operation of PTSU
- Safety

Finally, left-side PTSU is becoming more common. *Use of Freeway Shoulders* was developed primarily based on studies, data, and experiences of right-side PTSU facilities. Some agencies noted that planning, design, implementation, and operation of left-side PTSU facilities may differ only slightly from those same activities for right-side PTSU.

APPENDIX A. AGENCY INTERACTION SUMMARY

This section contains verbatim responses that State DOTs submitted during the interview process. The views and opinions expressed in these responses are the authors' and do not necessarily reflect those of FHWA or the USDOT.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

Interview Date: 10/06/2022

Agency: WSDOT

Interview Questions and Responses

a. Please share general information on the facility (length, year opened, extents, etc.).

SR 14 is a congestion relief project that is 1½ miles, spanning from SE 164th Avenue to I–205 in the westbound direction. The facility currently operates two lanes in each direction. The proposed facility will have three lanes in each direction, and the PTSU is proposed in addition to the three lanes in the westbound direction.

b. Did your agency use the *Use of Freeway Shoulders* (Jenior 2016) in the PTSU's planning and design processes for the planned or already implemented project?

No. The staff at WSDOT attended Oregon Department of Transportation (ODOT) training on PTSU implementation.

c. What was most helpful and not so helpful in the *Use of Freeway Shoulders*?

Not applicable (N/A).

d. What other resources did you use for your PTSU facility's planning and design?

There was knowledge transfer from WSDOT staff that implemented the I–405 PTSU project in the northwest region.

e. Why did your agency first consider PTSU, and what process was used to select it over other capacity-increasing alternatives?

The staff considered various alternatives that could reduce congestion. The PTSU implementation fit within the budget and right-of-way constraints and allowed the flexibility of operating as a safety shoulder when not needed for congestion reduction.

f. What led you to pick dynamic operation or static operation?

SR 14 will be dynamic in nature; the facility has no lane control on general purpose lanes, and the lane control will be present only on the westbound direction shoulder lane. The PTSU lane will usually be in operation during the morning peak hours and when an incident occurs. If a vehicle or an object is blocking part of the shoulder lane, opening and closing sections of the PTSU lane is easier with a dynamic operation than with a static operation.

g. Did you change anything in the PTSU implementation after the facility opened?

N/A; the construction of this facility has just begun.

h. Did your agency conduct highway capacity analysis? If so, what methods/tools were used?

Yes. The staff analyzed the operations of this facility using the microsimulation modeling software. The analysis occurred primarily during the morning peak hours, as congestion in the westbound direction occurs during this time. However, the staff also looked at evening peak hour operations using the same simulation model.

i. Did your agency conduct highway safety analysis? If so, what methods/tools were used?

Yes. The staff analyzed safety performance at this facility and predicted the safety performance of the PTSU facility that will be implemented in the near term. Staff used chapters 18 and 19 in the HSM (AASHTO 2014) for freeways and interchanges, plus the Enhanced Interchange Safety Analysis Tool, to quantify the safety performance of the PTSU facility.

j. What were the safety results/findings?

The expected number of fatal and severe injury crashes for the opening and design year of the PTSU facility shows a slight increase in the overall crashes when compared with the no-project scenario.

k. Did your agency conduct an environmental analysis? If so what specific aspects (noise, air quality, stormwater, historic properties, environmental justice, etc.) were considered?

Yes. This project included a widening of the highway in addition to the PTSU implementation; hence, the staff conducted a robust environmental review with noise, air quality, stormwater, and so on.

l. What was the initial estimated cost of your agency's PTSU installation, and how did this compare with the final cost of implementation?

The full project budget was estimated at $28 million, which included widening the existing two lanes to three lanes in each direction and PTSU implementation in the westbound direction. For PTSU implementation only, the cost may be around $5–$6 million.

m. What is the typical section of your facility? Were any design exceptions obtained for any of your features of your facility?

It will be a facility with three lanes in each direction and an additional lane with PTSU facility in the westbound direction. The lane width for general purpose lanes and the PTSU lane is 11 feet. The section also includes a 2-foot-wide median and a 2-foot-wide shoulder for the westbound direction PTSU lane.

n. What specific actions do your operators take before the shoulder is opened?

- The TMC operator visually sweeps the shoulder daily, including prior to the start time.
- The maintenance and operation team will drive the shoulder before the start time and notify TMC that the system is ready to turn on.
- The TMC operator activates the system daily. Prior to the activation, the TMC operator confirms the shoulder is clear.
- System may automatically deactivate at the end time of the morning peak hour. If congestion is present at the end time, the TMC operator can extend the operation.
- The TMC operator may change all the lane-control signs from "Open, Exit Only" to a yellow merge arrow prior to deactivating the system. The DMS signs may also be changed to show a "Shoulder Closing" message. The TMC determines the duration to show the yellow merge arrow and may be controlled automatically.
- At the end of the yellow merge arrow duration, the system automatically deactivates and changes the DMS message to the default "Closed" message.
- The start and stop times during the morning peak commute hours will be adjusted by the southwest region based on the traffic conditions once the PTSU is in operation.

o. What standard operating procedures does your agency use?

The concept of operations and standard operating procedures will be modeled on the WSDOT northwest region I–405 PTSU project implementation and adjusted for WSDOT.

OHIO DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

Interview Date: 10/07/2022

Agency: Ohio DOT

Interview Questions and Responses

a. Please share general information on the facility (length, year opened, extents, etc.).

Ohio DOT commissioned an ATDM study in 2016, and I–670 had the highest potential for improvement because of congestion and favorable existing characteristics. The I–670 PTSU lane (along with VSL) is approximately 5 miles and spans from downtown to I–270 in the eastbound direction. The PTSU lane is the inside shoulder (i.e., the left-side shoulder in the eastbound direction). Ohio DOT reconstructed some of the pavement and adjusted the cross slope on the shoulder lane. There was a major reconstruction and interchange improvement at the I–670 and I–270 interchange to address a major bottleneck present at that location.

b. Did your agency use the *Use of Freeway Shoulders* (Jenior 2016) in the PTSU's planning and design processes for the planned or already implemented project?

Yes, Ohio DOT staff used the guide and went to the Lansing, MI, TMC to obtain recommendations on the PTSU implementation. Ohio DOT staff used those recommendations in the I–670 PTSU implementation project.

c. What was most helpful and not so helpful in the *Use of Freeway Shoulders*?

The staff found the guide helpful in visualizing the opening and closing of the shoulder as were the case studies and public/stakeholder engagement outlined in the guide. The guide doesn't have any information on how much time and effort some of the items require to plan and implement a PTSU facility, e.g., the software component. It would be nice to have more information on the concepts of operations and systems engineering management plans.

d. What other resources did you use for your PTSU facility's planning and design?

The project team made field visits to Indiana and Michigan TMCs, as well as to Michigan's US 23 PTSU project under construction.

e. Why did your agency first consider PTSU, and what process was used to select it over other capacity-increasing alternatives?

Ohio DOT commissioned an active transportation and demand management (ATDM) study in 2016, and the finding was that I–670 had the highest potential for improvement and application of a PTSU lane because of congestion and favorable existing characteristics.

f. What led you to pick dynamic operation or static operation?

I–670 is dynamic in nature and typically operates at 65 mph; but, when the shoulder lane opens, it operates at 55 mph. A dynamic PTSU gave Ohio DOT flexibility to open the shoulder in response to incidents. A design exception was instituted for the PTSU lane to operate at 55 mph when the lane opens to all traffic due to left-side barrier, stopping sight distances, and flooding issues.

g. Did you change anything in the PTSU implementation after the facility opened?

There was more human involvement. The staff took a bit more control of when the shoulder would be opened and did not depend so much on the system trigger to alert the operator to open the shoulder lane based on volume and speed characteristics. The speed limit changed from 45 to 55 mph for the shoulder lane.

h. Did your agency conduct highway capacity analysis? If so, what methods and tools were used?

No, the PTSU team did not look at capacity analysis in detail. The staff focused capacity analysis on the bottleneck area and the interchange modification at the end of the PTSU lane.

i. Did your agency conduct highway safety analysis? If so, what methods and tools were used?

The staff looked at the HSM crash modification factors and applied the reduced shoulder width and having an extra travel lane on the roadway.

j. What were the safety results and findings?

The staff looked at crashes that occurred Monday–Friday from 3 p.m. to 6 p.m. on I–670. The before period ranged from 2015 to 2017. The after period ranged from October 2019 to March 2020, then from May to December 2021. There were on average six crashes per month in the before period and one crash per month in the after period in this corridor.

k. Did your agency conduct an environmental analysis? If so, what specific aspects (noise, air quality, stormwater, historic properties, environmental justice, etc.) were considered?

This was a categorical exclusion; evaluated the environment for noise the whole way. Pretty standard environmental analysis was done.

l. What was the initial estimated cost of your agency's PTSU installation, and how did this compare with the final cost of implementation?

Of the $60 million budget, $30 million was spent on the I–670 and I–270 interchange improvement, and $12 million was spent on the PTSU lane implementation.

m. What is the typical section of your facility? Were any design exceptions obtained for any of your features of your facility?

The design exceptions were related to shoulder width and existing geometry deficiencies.

n. What specific actions do your operators take before the shoulder is opened?

- The TMC operator needs to sweep physically and visually the shoulder daily via CCTV, including prior to the start time.
- The traffic operator watches traffic in the afternoon and prepares to open the shoulder.
- The maintenance and operation team will check for obstacles and clear debris when needed.
- The staff at Ohio DOT provided training to operators and translated the concept of operations into a couple of one-pagers with examples of what needs to be done.

o. What standard operating procedures does your agency use?

The staff developed its own standard operating procedures in agreement with State patrol, maintenance staff, signal maintenance staff, and incident response team. PTSU operators don't usually open the shoulder during off-peak congestion. They open the shoulder for incident-response and work-zone traffic management.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

Interview Date: 10/13/2022

Agency: WSDOT

Interview Questions and Responses

a. Please share general information on the facility (length, year opened, extents, etc.).

I–405 is a capacity-enhancement project of approximately 3 miles (3 directional miles), spanning from SR 527 to I–5 in the northbound direction. The facility currently operates at three general purpose lanes in each direction. The PTSU facility added one more lane in the northbound direction, which operates in the afternoon peak hour. The approach was to restripe to narrower lanes and widen the shoulder so it can be used as a travel lane during congested travel periods. A lane-control sign and a side-mount sign indicate when the PTSU facility is open or closed.

b. Did your agency use the *Use of Freeway Shoulders* (Jenior 2016) in the PTSU's planning and design processes for the planned or already implemented project?

No. The staff at WSDOT researched international practices for PTSU implementation because this guide was not available when staff deployed the first static PTSU lane in 2011. The shoulder lane was opened by static sign and had a time-of-day operation. The staff developed concept of operations for a dynamic PTSU lane and opened it in 2015 and for all traffic in May 2017.

c. What was most helpful and not so helpful in the *Use of Freeway Shoulders*?

N/A. The WSDOT staff would like to see if we can start integrating information in the guide about analyzing and implementing a very short ½- to 1-mile shoulder—kind of like a dynamic drop lane instead of full dynamic shoulder for freeways specifically.

d. What other resources did you use for your PTSU facility's planning and design?

International research and practices on PTSU implementation.

e. Why did your agency first consider PTSU, and what process was used to select it over other capacity-increasing alternatives?

The staff considered various alternatives that could reduce congestion. The opportunities that existed with the facility included: 1) a demonstrated need to have additional and temporary lane capacity because of the recurrent congestion pattern during certain commute periods of the day, 2) the immediate availability of full-depth pavement and extra-wide shoulder in excess of 10 feet, and 3) fully instrumented corridor, i.e., closely spaced vehicle detection for monitoring flow condition and full pan-tilt-zoom camera for surveillance or visual sweep of the shoulder before opening to traffic, especially if it is a dynamic PTSU lane.

f. What led you to pick dynamic operation or static operation?

I–405 is dynamic in nature. This decision was based on the traffic flow characteristics and the level of instrumentation available on the intended corridor. The staff will open the facility when there is a crash in the corridor or on holidays if there is a need, in addition to opening the facility when there is congestion during weekdays.

g. Did you change anything in the PTSU implementation after the facility opened?

No, there were no changes in the control algorithms. The staff made minor tweaks to the user interface, which made the application more user friendly. The staff is working on creating an automatic algorithm that helps suggest when to open the shoulder lane for traffic (depending on the congestion levels on the roadway).

h. Did your agency conduct highway capacity analysis? If so, what methods and tools were used?

Yes. The staff used a simple spreadsheet and a reporting tool, which provides information in the form of plots for volumes, occupancy, and speed parameters. This analysis shows there is enough volume and congestion that a PTSU lane will be helpful. The shoulder lane carries a maximum volume of 1,400–1,500 vehicles per hour.

i. Did your agency conduct highway safety analysis? If so, what methods/tools were used?

No.

j. What were the safety results and findings?

N/A.

k. Did your agency conduct an environmental analysis? If so, what specific aspects (noise, air quality, storm-water, historic properties, environmental justice, etc.) were considered?

Yes. This project was cleared using the standard NEPA (United States Environmental Protection Agency n.d.) and State Environmental Policy Act (SEPA) (Washington State Department of Ecology n.d.) processes for any highway project.

l. What was the initial estimated cost of your agency's PTSU installation, and how did this compare with the final cost of implementation?

The staff has extensive experience with ATDM and intelligent transportation systems (ITS) deployments, so the estimated cost for the PTSU was pretty close to the final cost of the implementation.

m. What is the typical section of your facility? Were any design exceptions obtained for any of the features of your facility?

It will be a facility with three lanes in the northbound direction and an additional lane with PTSU lane in that direction. The lane width for general purpose lanes is 11 feet, and the PTSU lane is 14 feet. The section also includes a 2-foot minimum inside shoulder width in the northbound direction.

n. What specific actions do your operators take before the shoulder is opened?

- The TMC operator needs to sweep visually the shoulder daily via CCTV, including prior to the start time.
- The maintenance and operation team will check for obstacles and clear debris when needed.
- The TMC operator may change all the lane-control signs from "Open, Exit Only" to a yellow merge arrow prior to deactivating the system. At the end of the yellow merge arrow duration, the system deactivates the yellow merge arrow and displays "Do Not Drive on Shoulder."

o. What standard operating procedures does your agency use?

The staff developed its own standard operating procedures in agreement with State patrol, maintenance staff, signal maintenance staff, and incident response team. It will delay opening the shoulder if there are obstacles or debris on the shoulder. It will extend shoulder use if traffic is congested in the corridor. The staff closes the shoulder following the same procedure as in the full ATDM corridor.

CALIFORNIA STATE DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

Interview Date: 10/06/2022

Agency: California Department of Transportation (Caltrans)

Interview Questions and Responses

a. Please share general information on the facility (length, year opened, extents, etc.).

Congestion on the I–580 Richmond-San Rafael Bridge occurs mainly during the evening commute in the eastbound direction. At these times, there are significant traffic delays along the northbound ramps to U.S. Highway 101. Therefore, the peak-period capacity of the Richmond-San Rafael Bridge has been increased by adding a PTSU lane in the eastbound (lower deck) direction. The total length of the facility is approximately 5½ miles (5½ directional miles).

The bridge first opened to traffic in 1956. It connects the city of Richmond in Contra Costa County with the city of San Rafael in Marin County through a narrow section of water between the San Francisco Bay and San Pablo Bay. It was originally designed and operated as a double-deck bridge, with three lanes westbound on the upper deck and three lanes eastbound on the lower deck (no shoulders in either direction). One lane in each direction was later converted to shoulders because the traffic capacity was not needed. In recent years, the westbound (upper deck) shoulder lane was converted into a barrier-separated shared bike/pedestrian path. With the opening of the bicycle and pedestrian lane, the Richmond-San Rafael Bridge is now part of the San Francisco Bay Trail. The eastbound shoulder was converted to PTSU. Tolls are collected for only vehicles crossing in the westbound direction and it partially negates the additional capacity requirement in the westbound direction.

The PTSU facility currently operates in static hours: each week and weekend day between 2 p.m. and 7 p.m. The installed electronic traffic signs indicate whether a lane is opened or closed.

b. Did your agency use the *Use of Freeway Shoulders* (Jenior 2016) in the PTSU's planning and design processes for the planned or already implemented project?

Yes, to understand the general concepts of PTSU.

c. What was most helpful and not so helpful in the *Use of Freeway Shoulders*?

The guide really reiterates many parts of the MUTCD (FHWA 2009), and that was very useful. The guide had little information on ITS aspects, guidance about static signs and dynamic signs, and standard operating procedures (e.g., how to close a lane). Overall, it would have been helpful if the guide had the following additional information:

- When to use static signs versus relying on limited DMS and lane-control signals to provide more flexibility

- When lane control should be used over all lanes versus just over the part-time lane
- Gantry spacing
- Specific issues when PTSU is located on a bridge facility, including striping

d. What other resources did you use for your PTSU facility's planning and design?

N/A.

e. Why did your agency first consider PTSU, and what process was used to select it over other capacity-increasing alternatives?

Recurring congestion in the eastbound direction. Considered three alternatives in the assessment process.

f. What led you to pick dynamic operation or static operation?

A dynamic operation provided consistency for the drivers. Also, the need—congestion is directional and same throughout the day. It also helps the California Highway Patrol and maintenance activities going on in the bridge area daily.

g. Did you change anything in the PTSU implementation after the facility opened?

Yes, the staff made the following changes:

- Minor adjustments were made to standard operating procedures; maintenance intervals and maintenance response times were adjusted.
- Changed the lane-control patterns for the anticipated scenarios like the construction and maintenance, power outage, etc.

h. Did your agency conduct highway capacity analysis? If so, what methods/tools were used?

Yes, the agency performed a highway capacity analysis with microsimulation software and analyzed some of the local intersections using software that implements the methods of the HCM (National Academies of Sciences, Engineering, and Medicine 2022). Before-and-after operational analysis indicated the usage is not equal on the shoulder lane and the general purpose lanes.

i. Did your agency conduct highway safety analysis? If so what methods/tools were used?

Yes, Caltrans looked into the historical crash rates and performed a before-and-after safety analysis during the project completion stage.

j. What were the safety results/findings?

The before-after-studies indicated a reduction in total crashes and crash rates in the corridor. However, Caltrans has concerns regarding the drivers who don't pay attention to the overhead signs.

k. Did your agency conduct an environmental analysis? If so what specific aspects (noise, air quality, stormwater, historic properties, environmental justice, etc.) were considered?

Yes. Caltrans conducted extensive environmental analysis for the project.

l. What was the initial estimated cost of your agency's PTSU installation, and how did this compare with the final cost of implementation?

Estimated cost for the I–580 lower deck was approximately $50 million and ended up a bit higher due to adding system integration features.

m. What is the typical section of your facility? Were any design exceptions obtained for any of your features of your facility?

The lane width for general purpose lanes and the PTSU lane is 12 feet. Yes, there were some design exceptions.

n. What specific actions do your operators take before the shoulder is opened?

- Continuous camera coverage of the shoulder provides visual surveillance. TMC operators check the camera half an hour before opening the lane.
- The traffic operator communicates with tow trucks and makes sure the facility is clear before initiating the opening process.

o. What standard operating procedures does your agency use?

These are covered in the questions above.

CLARK COUNTY WASHINGTON'S PUBLIC TRANSPORTATION AGENCY INTERVIEW SUMMARY

Interview Date: 10/20/2022

Agency: Clark County Public Transportation Benefit Area (C-TRAN)

Interview Questions and Responses

a. Please share general information on the facility (length, year opened, extents, etc.).

C-TRAN has several BOS facilities, and all were discussed on the call. SR 14 is a congestion-relief project spanning from I–205 to SR 14 on-ramp to 164th Avenue off-ramp. The facility currently operates at two general purpose lanes in each direction. The BOS facility added one more lane in both eastbound and westbound directions. The westbound shoulder lane is a two-segment shoulder lane that uses the outside shoulder (i.e., the right side of the roadway). The BOS lane comes off an auxiliary lane. At the end of the first segment of that lane, the lane merges into a traffic lane across an on-ramp and then onto the second segment of that lane, which is less used than the first portion. The BOS lane in the eastbound direction is a continuous shoulder lane. WSDOT is converting the SR 14 westbound shoulder into a peak-use shoulder lane that was open to general traffic as of November 2022. The speed limit on the SR 14 BOS shoulder facility is 35 mph or 10 mph above general traffic speeds.

The C-TRAN BOS facility on I–5 southbound runs between 78th Street and the interstate bridge. It is the only shoulder segment on the inside lane (i.e., left side). C-TRAN funded the shoulder, and WSDOT constructed the BOS. The speed limit on the I–5 shoulder is 25 mph. C-TRAN also has one segment in each direction on the I–205 Glenn-Jackson Bridge that ODOT funded and constructed as a pilot project for BOS. The BOS lanes on this facility are on outside shoulders (i.e., on the right side). The speed limit on the I–205 BOS shoulder facility is 35 mph or 10 mph above general traffic speeds.

Left Versus Right Shoulder

For the most part, the decision was made on existing infrastructure conditions. For I–5, more space was available and fewer merges were possible for the inside shoulder lane.

- There is an operational restriction for I–5 and not for the I–205 or SR 14 BOS lanes, which is the speed limit. The width of the BOS lane is 12 feet for most of the corridor, but there are 8 pinch points where the width ranges from 8½ feet to 10 feet.
- The BOS lane on the bridge (i.e., I–205) occasionally is used during severe weather conditions and at night (i.e., lower use than expected because the drivers are much more exposed to the environment on the bridge).
- There is a difference in the maintenance need on the inside versus outside shoulder. On I–5, the inside shoulder is a curbed shoulder that is largely clear of debris. C-TRAN is having challenges with debris collecting on the outside shoulder, especially on I–205 because it is on a bridge and a curved shoulder segment. The shoulder lane on SR 14 is an uncurbed shoulder, so there are not as many issues with debris or maintenance on that shoulder lane.

b. Did your agency use the *Use of Freeway Shoulders* (Jenior 2016) in the PTSU's planning and design processes for the planned or already implemented project?

No. C-TRAN relied heavily on the best practices to design the corridor. C-TRAN did a regional study of BOS alternatives and implementation areas where there was congestion and existing infrastructure for BOS implementation. C-TRAN laid out operational procedures, changes, and assessments based on the results of the pilot study conducted on SR 14 and largely carried through into their subsequent BOS programs on I–5 and I–205.

c. What was most helpful and not so helpful in the *Use of Freeway Shoulders*?

Information that would have been more helpful:

- Insight into how to establish appropriate and effective communication channels to make sure that the shoulder stays in the best condition
- Information on maintenance agreements and designing a program that allows C-TRAN to use the shoulder when needed, not when it is available

d. What other resources did you use for your PTSU facility's planning and design?

Relied heavily on other States, such as Minnesota and Pittsburgh, PA, that already have BOS or other bus-only facilities implemented.

e. Why did your agency first consider PTSU, and what process was used to select it over other capacity-increasing alternatives?

Delays, inconsistencies, and reliability issues. C-TRAN uses BOS for regional and express routes. C-TRAN looked at the corridor that has the greatest need and then its right-of-way and geometry.

f. What led you to pick dynamic operation or static operation?

N/A.

g. Did you change anything in the PTSU implementation after the facility opened?

C-TRAN made several changes to internal processes:

- Ongoing training for operators and assessing their use and comfort
- Clarifying some of their internal communications processes, so they can get information from our operators or field supervisors to dispatchers as appropriate

h. What are the operating speeds for the shoulders, and what is the number of buses that use these shoulders?

The speed limit on I–205 and SR 14 BOS shoulder facility is 35 mph, or 10 mph above general traffic speeds. The speed limit on I–5 BOS shoulder facility is 25 mph, or 10 mph above general traffic speeds, because of operating and environmental constraints.

The COVID pandemic has likely affected the ongoing and regular use C-TRAN saw earlier with respect to the usage of the shoulder. Overall, on an average day of congestion

during weekdays, 5–10 vehicles per day use those shoulders. It could be much higher if there is unanticipated congestion.

i. Did your agency conduct highway safety analysis? If so, what methods and tools were used?

C-TRAN performed safety analysis when it performed the regional BOS alternatives planning process. It had not had any bus-related incidents using the shoulders as of November 2022.

j. What were the safety results/findings?

They had not had any bus-related incidents using the shoulders, as of November 2022.

k. Did your agency conduct an environmental analysis? If so what specific aspects (noise, air quality, stormwater, historic properties, environmental justice, etc.) were considered?

C-TRAN was the planning agency but not the designing and constructing agency for I–5 and SR 14. They didn't go through any NEPA processes but may have gone through SEPA (Washington State Department of Ecology n.d.) processes for I–5 and SR 14. It didn't conduct any environmental analysis for I–205 BOS facility.

l. What was the initial estimated cost of your agency's PTSU installation, and how did this compare with the final cost of implementation?

- I–5: Estimated at $5 million and ended up coming in at about $3.5 million
- I–205: Don't have design estimates; the cost was for minor signage and striping cost—$14,000 (provided by in-house ODOT staff)

m. What is the typical section of your facility? Were any design exceptions obtained for any of your features of your facility?

All BOS facilities: at least 12 feet (this is the minimum guidance for design)

n. What specific actions do your operators take before the shoulder is opened?

- Bus drivers enter and leave the shoulder at their discretion after assuming about traffic congestion and travel speeds
- If there is a period of prolonged congestion or any debris on the shoulder, the operators are required to record the shoulder use via in-vehicle app

o. What standard operating procedures does your agency use?

C-TRAN has a training, maintenance, and operations agreement in place with WSDOT for the SR 14 and I–5 shoulder facilities. C-TRAN has a training, maintenance, and operations agreement in place with ODOT for the I–205 shoulder facility.

INDIANA DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

Interview Date: 11/04/2022

Agency: Indiana DOT

Interview Questions and Responses

a. Please share general information on the facility (length, year opened, extents, etc.).

I–80 and I–94 (Borman Expressway) PTSU is a capacity-enhancement project with an approximate length of 14 miles (28 directional miles). It spans from I–65 in Indiana on the east to IL 394 on the west, with 12- or 14-foot inside shoulders and 10-foot outside shoulders. This corridor is one of the most heavily traveled interstates in the Midwest—a critical national freight corridor. The potential PTSU facility will operate not only during the weekday peak-hour periods, but also on Friday evenings and Sunday all day (11 a.m.–8 p.m.) in both eastbound and westbound directions. A robust traffic analysis conducted found that PTSU was going to provide tremendous benefit to the corridor.

For this implementation, a 12- or 14-ft shoulder was being converted to 2–4-foot shoulder with a 10-foot PTSU lane on the left-hand side. The PTSU lane will be for only passenger vehicles. Trucks will be restricted from PTSU lane (and a general traffic lane—so, two left lanes). The staff is also looking to lower the speed limit of PTSU lane to 45 or 50 mph from the usual 55 mph speed limit on Borman Expressway. The lane-control signals will be present over all lanes. The right shoulder will be used only during emergency situations and for incident management.

b. Did your agency use the *Use of Freeway Shoulders* (Jenior 2016) in the PTSU's planning and design processes for the planned or already implemented project?

Yes, the agency used *Use of Freeway Shoulders* to understand the general concepts of PTSU lane. The guide had little information on the left-hand side shoulder lanes, so that was not so helpful.

c. What was most helpful and not so helpful in the *Use of Freeway Shoulders*?

The staff used the NCHRP Project 17-89 tool to conduct safety analysis. The tool's results were not sensitive to the speed limit. The results varied based on shoulder and lane widths, which was not very helpful. Not having any information on the concept of operations in the guide made it difficult as well.

d. What other resources did you use for your PTSU facility's planning and design?

N/A.

e. Why did your agency first consider PTSU, and what process was used to select it over other capacity-increasing alternatives?

The staff considered various alternatives that could reduce congestion and extended the I–80 and I–94 corridor as much as they could by increasing the number of lanes on the

roadway. However, widening the roadway further is not possible because of businesses and right-of-way constraints. The staff wanted to see how to use the existing infrastructure to alleviate congestion, and one of the options considered was adding a PTSU lane.

f. What led you to pick dynamic operation or static operation?

Dynamic, mostly based on the congestion and time of day.

g. Did you change anything in the PTSU implementation after the facility opened?

N/A. The facility is not built yet.

h. Did your agency conduct highway capacity analysis? If so, what methods/tools were used?

Yes. The agency staff built an extensive microsimulation model for the whole corridor. It reallocated the existing demand and accounted for a slightly higher demand than the base case on this corridor and lowered the speed limit to 45 mph on the PTSU lane. The staff also assumed that no trucks use the PTSU lane that required a 45-mph speed limit when they could cruise at 55 mph in general traffic lanes.

i. Did your agency conduct highway safety analysis? If so, what methods and tools were used?

Yes. According to the tool produced by NCHRP Project 17-89, converting the 12- or 14-foot shoulder to a 2–4-foot shoulder and adding a 10-foot PTSU lane increases the expected number of crashes. This tool is not sensitive to changes in speed limit for the PTSU lane.

j. What were the safety results/findings?

Implementing a PTSU lane will increase the expected number of crashes.

k. Did your agency conduct an environmental analysis? If so what specific aspects (noise, air quality, stormwater, historic properties, environmental justice, etc.) were considered?

The actual environmental process is not yet complete. The planning and environmental linkages phase is complete. They are currently working on the NEPA process (United States Environmental Protection Agency n.d.) for the facility.

l. What was the initial estimated cost of your agency's PTSU installation, and how did this compare with the final cost of implementation?

N/A.

m. What is the typical section of your facility? Were any design exceptions obtained for any of your features of your facility?

It will be a facility with a 10-foot left-side shoulder, which will be open for all passenger cars but not for trucks or buses. The facility will also have a right-side shoulder lane that will be open only for emergency situations.

n. What specific actions do your operators take before the shoulder is opened?

The staff prepared this information as of November 2022.

o. What standard operating procedures does your agency use?

The staff is preparing this information right now, as of November 2022.

METRO TRANSIT/MINNESOTA DEPARTMENT OF TRANSPORTATION INTERVIEW SUMMARY

Interview Date: 11/14/2022

Agency: Minnesota Department of Transportation (MnDOT)/Metro Transit

Interview Questions and Responses

a. Please share general information on the facility (length, year opened, extents, etc.).

The system currently has about 334 miles of bus on shoulder (BOS). The last BOS facilities were added in 2016, and there are plans to add about 5 miles of BOS in a suburban area in 2024. Regarding shoulder usage, the BOS was not used during the pandemic but picked up after the COVID-19 pandemic. Buses use the shoulder when traffic is not moving more than 35 mph, and buses can't move more than 15 mph over the speed of traffic when in general traffic lanes.

b. Did your agency use the *Use of Freeway Shoulders* (Jenior 2016) in the PTSU's planning and design processes for the planned or already implemented project?

N/A.

c. What was most helpful and not so helpful in the *Use of Freeway Shoulders*?

Having real-world case studies in the guide that illustrate a variety of constraints and challenges would have been helpful. Recommendations on how to set the speed limit for BOS would have been helpful to include in the guide.

d. What other resources did you use for your PTSU facility's planning and design?

International research and practices on PTSU implementation.

e. Why did your agency first consider PTSU, and what process was used to select it over other capacity-increasing alternatives?

There are four criteria that need to be met according to MnDOT's road design guide:

- Congestion delays must occur one or more days per week.
- A minimum of six transit buses per week must use the proposed BOS.
- Expected travel time savings of using the BOS must be greater than 8 minutes per mile per week.
- The proposed BOS must have a continuous shoulder width of at least 10 feet on roadways and 11½ feet on bridges; for reconstruction, the minimum shoulder width is 12 feet.

f. What led you to pick dynamic operation or static operation?

N/A.

g. Did you change anything in the PTSU implementation after the facility opened?

N/A.

h. Did your agency conduct highway capacity analysis? If so, what methods and tools were used?

No, it uses the four criteria specified in MnDOT's road design guide to decide on BOS lane implementation and applicability.

i. Did your agency conduct highway safety analysis? If so, what methods and tools were used?

Yes, a staff member looked at the existing crash data from 2011 to 2015. That effort determined that BOS averaged less than one crash with injury and from three to five property-damage-only crashes per year. The crash reporting may be incomplete, as the bus drivers need to self-report the crashes because the police reports don't necessarily explicitly provide indication of BOS lane proximity.

j. What were the safety results and findings?

Yes, a staff member looked at the existing crash data from 2011 to 2015. That crash review determined that BOS averaged less than one crash with injury and from three to five property-damage-only crashes per year.

k. Did your agency conduct an environmental analysis? If so, what specific aspects (noise, air quality, stormwater, historic properties, environmental justice, etc.) were considered?

The BOS projects have historically been State funded. When they are State funded, they don't trigger a noise analysis. The environmental or project documentation team at MnDOT submits an early notification memo review, which is limited when only striping will be done as part of the BOS implementation. The early notification memo includes permits if the project includes adding or replacing the shoulder and cutting and filling in the slope, etc.

l. What was the initial estimated cost of your agency's PTSU installation, and how did the estimates compare with the final cost of implementation?

Varies.

m. What is the typical section of your facility? Were any design exceptions obtained for any of your features of your facility?

BOS facilities must have a continuous shoulder width of at least 10 feet on roadways and 11½ feet on bridges.

n. What specific actions do your operators take before the shoulder is opened?

Good camera coverage is present, and bus drivers are trained to use the shoulder based on the travel speed changes and congestion on the roadway.

o. What standard operating procedures does your agency use?

Good partnerships with maintenance, operations, and State patrol officers.

ILLINOIS TOLLWAY INTERVIEW SUMMARY

Interview Date: 11/30/2022

Agency: Illinois DOT

Interview Questions and Responses

a. Please share general information on the facility (length, year opened, extents, etc.).

Staff originally planned to have wider shoulders to accommodate light-rail and managed lane facilities. But the congestion patterns and forecasted transit demand led the Tollway to conclude using a PTSU on the I–90 with routine use of the shoulder by buses was a better solution. The total length of the facility is approximately 16 miles (32 directional miles). The construction was completed during January 2017, and the active transportation management (ATM) system was turned on during September 2017. The left shoulder can be opened at any time, but the right shoulder will be opened for incident management purposes only.

b. Did your agency use the *Use of Freeway Shoulders* (Jenior 2016) in the PTSU's planning and design processes for the planned or already implemented project?

The capacity enhancement planning for I–90 occurred in 2008.

c. What was most helpful and not so helpful in the *Use of Freeway Shoulders*?

N/A.

d. What other resources did you use for your PTSU facility's planning and design?

There was knowledge transfer from WSDOT staff who had implemented PTSU projects in their State.

e. Why did your agency first consider PTSU, and what process was used to select it over other capacity-increasing alternatives?

The staff considered various alternatives that could reduce congestion. The PTSU implementation fits within the budget and right-of-way constraints and allows the flexibility of operating as a safety shoulder when not needed for congestion reduction. The lane-control signs over all the lanes allow for incident management.

f. What led you to pick dynamic operation or static operation?

I–90 will be dynamic in nature. The facility has lane control on general purpose lanes and the PTSU lane.

g. Did you change anything in the PTSU implementation after the facility opened?

There was more human involvement. The staff took a bit more control of when the shoulder would be opened and did not rely so much on the system trigger to alert the operator to open the shoulder lane based on volume and speed characteristics.

h. Did your agency conduct highway capacity analysis? If so, what methods and tools were used?

Yes. The staff analyzed the operations of this facility using a microsimulation model. Before and after studies were also conducted with respect to the ATM system deployment—8 months of before data and 3 months of after data were used to analyze changes in operation. No definitive conclusions were derived from the data. The operations results varied in the after-months study.

i. Did your agency conduct highway safety analysis? If so, what methods/tools were used?

Before-and-after studies were conducted with respect to the ATM system deployment—8 months of before data and 3 months of after data were used to analyze change in operations. No definitive conclusions were derived from the data. The safety results varied in the after study.

j. What were the safety results and findings?

Overall, systemwide, the secondary crash rates are only 1 percent higher than before the PTSU implementation (so the system itself has good safety performance overall).

k. Did your agency conduct an environmental analysis? If so, what specific aspects (noise, air quality, stormwater, historic properties, environmental justice, etc.) were considered?

Yes. The staff conducted a robust environmental review with noise, air quality, stormwater components, and so on.

l. What was the initial estimated cost of your agency's PTSU installation, and how did this compare with the final cost of implementation?

The full project budget was estimated at $140 million, which includes widening of the roadway and ATM system.

m. What is the typical section of your facility? Were any design exceptions obtained for any of your features of your facility?

It will be a facility with four lanes in each direction and a shoulder wide enough for PTSU on each side. The left shoulder will be routinely used for BOS operation and occasionally used for PTSU during incidents. The right shoulder will occasionally be used for PTSU during incidents.

n. What specific actions do your operators take before the shoulder is opened?

- The TMC operator needs to sweep the shoulder physically and visually daily via CCTV, including prior to the start time.
- The traffic operator watches traffic in the morning and afternoon and prepares to open the shoulder
- The maintenance and operation team will check for obstacles and clear debris when needed

o. What standard operating procedures does your agency use?

The staff developed its own standard operating procedures in agreement with State patrol, operations and maintenance staff, and incident response team. The staff doesn't usually open the shoulder during off-peak congestion. They open the shoulder for incident response and work zone traffic management.

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June 2024
FHWA-HOP-23-066