U.S. Department of Transportation
Federal Highway Administration

A PRIMER

Introduction to the Role of Operations Strategies and Treatments in Complete Streets Projects

Cover image sources: pedbikeimages.com

Technical Report Documentation Page

1. Report No. FHWA-HOP-24-038	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Introduction to the Role of Operations Strategies and Treatments in Complete Streets Projects		**5. Report Date** October 2024
		6. Performing Organization Code
7. Authors Bastian Schroeder, Paul Ryus, Billy Hattaway, Kaitlyn Schaffer, David Hale, Kelley Coyner, John Hicks, Nemanja Dobrota		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Leidos, Inc. 1750 Presidents Street Reston, VA 20190		**10. Work Unit No. (TRAIS)**
		11. Contract or Grant No. 693JJ322F00111N
12. Sponsoring Agency Name and Address Federal Highway Administration 1200 New Jersey Ave., SE. Washington, DC 20590		**13. Type of Report and Period Covered** Final Report August 2022-February 2024
		14. Sponsoring Agency Code HOTM
15. Supplementary Notes Jim Hunt (jim.hunt@dot.gov) served as the government task manager.		
16. Abstract A Complete Street is safe and feels safe for everyone using the street (including pedestrians, bicyclists, public transportation users, children, older individuals, individuals with disabilities, motorists, and freight vehicles). In addition to safety and equity, Complete Streets applications may improve economic vitality. Operations addresses the intentional strategies, tools, and real-time actions needed for the roadway system to serve all road users safely and reliably as transportation agencies plan, invest in, design, construct, and maintain the system. Operations can be key considerations toward achieving safety and equity goals in a sustainable way. Operations strategies that improve mobility and traffic flow in a Complete Streets project may also enhance safety. This primer assists transportation agencies with incorporating operations considerations during the planning, design, and implementation of specific Complete Streets projects, as well as generally through their Complete Streets policies. The primer identifies operations strategies that can help to achieve Complete Streets objectives, potential performance measures, and a Complete Streets design framework that accounts for safety and operations considerations. This information can help agencies implement Complete Streets that work.		
17. Key Words Complete Streets		**18. Distribution Statement** No restrictions. No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA, 22161. http://www.ntis.gov

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No of Pages** 76	**22. Price** N/A

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 (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in.^{2}	poundforce per square inch	6.89	kilopascals	kPa

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

SI* (Modern Metric) Conversion *(continued)*

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	$in.^2$
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

3R	resurfacing, restoration, and rehabilitation
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
ADOT	Austin Department of Transportation
ADT	annual daily traffic
BIL	Bipartisan Infrastructure Law
BLOS	bicycle level of service
BLTS	bicycle level of traffic stress
CMF	crash modification factor
CMFC	Crash Modification Factor Clearinghouse
d/c	demand-to-capacity
DDOT	Washington DC, Department of Transportation
DDSA	data-driven safety analysis
DOT	department of transportation
EVP	emergency vehicle preemption
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GIS	geographic information system
GMMNC	Guidebook for Measuring Multimodal Network Connectivity
HCM	Highway Capacity Manual
HSM	Highway Safety Manual
ICE	intersection control evaluation
ICM	integrated corridor management
IIJA	Infrastructure Investment and Jobs Act
ITE	Institute of Transportation Engineers
ITS	intelligent transportation systems
LOS	level of service
KDOT	Kansas Department of Transportation
LBI	leading bicycle interval
LPI	leading pedestrian interval
MPO	metropolitan planning organization
MUTCD	Manual on Uniform Traffic Control Devices

LIST OF ACRONYMS (CONTINUED)

NACTO	National Association of City Transportation Officials
NASEM	National Academies of Sciences, Engineering, and Medicine
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NYSERDA	New York State Energy Research and Development Authority
PEDSAFE	Pedestrian Safety Guide and Countermeasure Selection System
PLOS	pedestrian level of service
PLTS	pedestrian level of traffic stress
PPEAG	Planning and Preliminary Engineering Applications Guide to the Highway Capacity Manual
PUDO	pickup and dropoff
ROW	right-of-way
RRFB	rectangular rapid-flashing beacon
RSA	road safety audit
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SHRP2	second Strategic Highway Research Program
SPF	safety performance function
SSI	Safe System for Intersections
TCeP	Traffic Calming ePrimer
TCQSM	Transit Capacity and Quality of Service Manual
TIM	traffic incident management
TLOS	truck level of service
TSMO	transportation systems management and operations
TSP	transit signal priority
TWLTL	two-way left-turn lane
V/C	volume-to-capacity
VRU	vulnerable road user

EXECUTIVE SUMMARY

This primer is intended to assist transportation agencies with incorporating operations considerations during the planning, design, and implementation of specific Complete Streets projects, as well as generally through their Complete Streets policies. The primer identifies operations strategies that can help to achieve Complete Streets objectives, potential performance measures, and a Complete Streets design framework that accounts for safety and operations considerations. This information can help agencies implement Complete Streets that balance the needs for all users.

The Infrastructure Investment and Jobs Act (IIJA), also known as the Bipartisan Infrastructure Law (BIL) (Pub. L. No. 117-58), defines Complete Streets standards or policies as "standards or policies that ensure the safe and adequate accommodation of all users of the transportation system, including pedestrians, bicyclists, public transportation users, children, older individuals, individuals with disabilities, motorists, and freight vehicles."[1] In essence, a Complete Street is safe and feels safe for all users, including pedestrians, bicyclists, public transportation users, children, seniors, people with disabilities, motorists, and freight vehicles.

Operations addresses the intentional strategies, tools, and real-time actions needed for the roadway system to provide safe and reliable mobility to all road users as transportation agencies plan, invest in, design, construct, and maintain the system. Operations can be key considerations toward achieving safety and equity goals in a sustainable way. Operations strategies that improve mobility and traffic flow in a Complete Streets project often also enhance safety.

Two key operations considerations in Complete Streets include:

- Operations data and analysis.
- Operations strategies and performance.

Introducing safety design elements for all users can affect roadway operations. In Complete Streets design, it is helpful to determine a target design speed (i.e., the highest operating speed at which vehicles should operate on a roadway in a specific context) and traffic volume, as opposed to accommodating whatever the existing traffic volumes and speeds may be. An agency may reconfigure or redesign roadways to lower speeds and remove or narrow lanes to achieve overall safety objectives. Complete Streets improvements for vulnerable road users (people walking, biking, or rolling) can reduce vehicle capacity and speeds, but implementing operations strategies can help prioritize safety objectives while maintaining the reliability of vehicle travel.

1 BIL, § 11206(a).

To enhance the effectiveness of Complete Streets improvements, transportation agencies can analyze and implement complementary operational strategies that offset the effect of reduced vehicle capacity and speed to improve reliability. Analysts can consider metrics like 24-hour performance and travel time reliability in lieu of peak hour analysis or speed-based performance measures. A roadway designer can develop a logical and defensible design using a performance based design process supplemented with operations strategies. This primer provides a Complete Streets design framework that accounts for multimodal safety and operations considerations.

This primer focuses on six groups of strategies: design treatments (e.g., space reallocation, pavement markings); traffic signal and intelligent transportation systems (ITS) (e.g., speed management, signal retiming); transit (e.g., transit signal priority, transit lanes); curbside (e.g., parking management); access management (e.g., access control); and nonphysical strategies (e.g., enforcement, education, collaboration). This primer discusses operations strategies in terms of their effects on Complete Streets and describes the safety and mobility effects of each strategy on pedestrians, bicyclists, freight, public transit, and passenger cars. The primer also provides examples of how agencies have implemented these strategies.

Performance measures can support the forecasting (during planning) and evaluation (post implementation) of effects from individual Complete Streets strategies on safety and operations. In addition to conventional operations (e.g., passenger car delay) and safety (e.g., crashes) measures, available resources help agencies estimate intersection conflict points, pedestrian/bicyclist comfort or stress, travel time reliability, pedestrian/bicyclist delay, speed reduction, multimodal level of service, bus speed or delay, pedestrian/bicycle network connectivity, and other measures. These resources provide predictive measures that forecast future performance, proxy measures that roughly estimate performance trends, and direct measures available through field data collection. This primer lists potential performance measures and high-level performance objectives and resources for each. This primer also provides Complete Streets strategies with a reference to performance measures applicable to each strategy.

1 INTRODUCTION TO OPERATIONS IN COMPLETE STREETS

A Complete Street is safe and feels safe for everyone using the street,[2] such as "pedestrians, bicyclists, public transportation users, children, older individuals, individuals with disabilities, motorists, and freight vehicles."[3] Operations addresses the intentional strategies, tools, and realtime actions needed for the roadway system to serve all road users safely and reliably as transportation agencies plan, invest in, design, construct, and maintain the system. Operations can be a key consideration toward achieving safety and equity goals in a sustainable way. Operations strategies that improve mobility and traffic flow in a Complete Streets project can be designed and implemented to enhance safety.

This primer describes how transportation agencies can integrate operations into Complete Streets during a project's developmental phases. The primer provides agencies that are considering or implementing Complete Streets with information to help them address operations during planning, design, and implementation, as well as in their policies.

1.1 Why Consider Operations in Complete Streets

Guidance on Complete Streets strategies has often focused on physical design elements and changes to the roadway cross section (e.g., road diets to reduce travel lanes to make room for bicycle lanes). Although these are important tools, they are not the only options in the toolbox. Operations not only facilitates the movement of people through the transportation system, it also actively manages the system to improve users' experiences. Strategies to enhance operations also affect roadway safety, reliability, and other aspects of the users' experiences. In turn, different types of road users often experience these effects differently. The statutory definition of transportation systems management and operations (TSMO) in title 23 of the United States Code (U.S.C.) captures these multifaceted aspects:

> To enhance vehicle operations during peak travel demand periods, the Washington, DC, Department of Transportation (DDOT) uses time-of-day left-turn restrictions on key commuting corridors. According to title 18, D.C. Municipal Regulations, § 2204: "No person shall make a left turn so as to proceed in the direction indicated from 7:00 a.m. to 9:30 a.m., or from 4:00 p.m. to 6:30 p.m., except buses at any of the specific locations listed in this subsection." This restriction results in improved vehicle operations at intersections in peak periods without the need for widening the road or installing turning pockets. This regulation enhances safety for all users through shortening crossings for pedestrians, reducing conflict points with vehicles, and providing space for on-street buffered bicycle lanes.

2 FHWA. 2022. *Moving to a Complete Streets Design Model: A Report to Congress on Opportunities and Challenges.* Washington, DC: FHWA. https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-03/Complete%20Streets%20Report%20to%20Congress.pdf.

3 BIL, § 11206(a).

> *"Integrated strategies to **optimize** the performance of existing infrastructure through the implementation of **multimodal** and intermodal, cross-jurisdictional systems, services, and projects designed to preserve capacity and **improve** security, **safety**, and reliability of the transportation system."*[4] [emphasis added]

Complete Streets strategies are integrated strategies that have the capability to improve roadway safety, operations, and other outcomes. A strategy's effects on the safety and operations of all road users can always be considered. Several operations strategies, some of which are described in chapter 4, can be applied to support Complete Streets efforts.

Example Operations Strategies To Support Complete Streets

- Active parking/traffic management
- Adaptive traffic signals
- Alternative work hours
- Automated enforcement programs
- Congestion pricing
- Construction transportation management plans
- Construction work zone management
- Dynamic lane assignment
- Enhanced data availability and application
- Freight or truck signal priority
  Interagency corridor management
- Land use development
- Onsite facilities for employees walking or biking to work
- Parallel route usage and improvements
- Proactive signal timing review and optimization
- Size and weight restrictions
- Special and planned event management
- Traffic calming
- Traffic detectors
- Traffic impact analysis and mitigation planning
- Traffic incident management coordination and operation
- Transit signal priority
- Traveler information via 511 telephone, social media, and Web applications
- Trip reduction ordinances
- Truck lane designations and restrictions
- Unbundled residential parking
- Variable message signs
- Variable speed limits

Depending on the specific strategy, operations strategies may improve efficiency, prioritize particular modes, encourage the use of alternative modes, shift travel to off-peak times, improve intermodal connections, minimize disruptions caused by nonrecurring events or construction, and create other beneficial outcomes. For example, implementing peak-period left-turn restrictions at a series of intersections may result in sufficient peak period capacity to allow a reduction in the number of vehicular travel lanes in the corridor throughout the day. Restricting left turns also provides a safety benefit, particularly for the pedestrians and bicyclists who conflict with left-turning vehicles. Chapter 3 covers these benefits, along with benefits such as access and reliability. Chapter 3 also discusses using a 24-hour framework to assess traffic operations instead of the traditional peak-hour or peak 15-minute framework. The 24-hour framework more holistically looks at capacity needs across the whole day and emphasizes the use of operations strategies to support travel when demands are highest, as opposed to general widening that may result in added capacity that is only needed for a few hours of the day. Data, analysis methods, and performance measures directly support operations strategies. Data can help transportation agencies evaluate and summarize system-level outcomes that reflect multimodal and community needs. In addition, agencies can use performance measures to connect investments to community priorities and to communicate and visualize Complete Streets project performance.

4 23 U.S.C. 101(a)(32)(A).

1.2. Goals of Complete Streets

Complete Streets policies and standards are person-focused rather than transportation mode-focused.[5] They prioritize the safe and adequate integration of all road users into the street's functions by providing strategies to connect a community through a complete network of safe and comfortable transportation facilities. Such a network includes sidewalks, bikeways, pedestrian and bicycle trails, roadways, connections to public transportation, and freight vehicles that connect neighborhoods with destinations. Context matters, and not every *street* requires facilities for every travel mode. However, a complete *network* that provides people with safe, connected options for their travel needs can be essential.[6] **Complete networks ensure that safe, continuous, efficient, and equitable facilities are provided for every mode from near one's trip origin to near one's destination**. In much the same way that transit routes do not stop in front of each home or business, not every property may have on-street parking directly in front, and not every roadway may have bike lanes. The most important consideration is that a complete network can serve all trips safely, efficiently, and equitably.

> *"In practice, it is not always possible to accommodate all modes in a single street due to right-of-way constraints, so a practical approach to Complete Streets also focuses broadly on building complete networks to provide connectivity for different modes of travel. Complete Networks may use parallel routes to facilitate access that variously prioritizes different modes throughout an area while ensuring the safety of all roadway users."*[7]

The existence of high-quality, comprehensive, accessible pedestrian facilities throughout the community is essential to a complete network. These pedestrian facilities allow travelers using other modes to connect from the nearest bike rack, bus stop, loading zone, or parking space to their final destination. A complete network supports multiple objectives:[8]

- **Safety.** Complete networks provide all road users with safe facilities that offer users multimodal options.
- **Connectivity.** Motorists take the ubiquity of the roadway network for granted. However, gaps in pedestrian, bicycle, and public transit networks discourage potential users from using these travel modes and make travel less safe, less comfortable, and inconvenient for people not able to access a car, or people with disabilities.
- **Mobility.** Complete networks allow road users to travel safely and efficiently to their destinations regardless of their mode of transportation.

---

5 FHWA. n.d. "Complete Streets in FHWA." (web page). https://highways.dot.gov/complete-streets/complete-streets-fhwa, accessed October 26, 2023.

6 FHWA. n.d. "Complete Streets in FHWA." (web page). https://highways.dot.gov/complete-streets/complete-streets-fhwa, accessed October 26, 2023.

7 FHWA. 2022. *Moving to a Complete Streets Design Model: A Report to Congress on Opportunities and Challenges*, https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-03/Complete%20Streets%20Report%20to%20Congress.pdf, accessed October 26, 2023.

8 FHWA. n.d. "Complete Streets in FHWA." (web page). https://highways.dot.gov/complete-streets/complete-streets-fhwa, accessed October 26, 2023.

- **Equity.** Traffic fatalities, air and noise pollution, and poor network connectivity are burdens that disproportionately affect underserved populations. A complete network is a fair network; Complete Streets policies consider past and current inequities as part of prioritizing projects.

Prioritizing safety, mobility, accessibility, and equity for road users of all ages and abilities involves considering these objectives throughout planning, designing, constructing, maintaining, and operating roadways and public rights-of-way (ROWs). Prioritizing these objectives can also include safety data analysis and countermeasure identification and implementation.[9] Figure 1, figure 2, and figure 3 show examples of Complete Streets design features that would help to achieve complete networks.

Source: © 2024 Kittelson and Associates, Inc., Chris Romano.

Figure 1. Photo. Fifth Street and Robinson Street in San Diego, CA.

Source: © 2024 Kittelson and Associates, Inc., Nicholas Gross.

Figure 2. Photo. Oregon Avenue in Klamath Falls, OR.

9 FHWA. 2022. Moving to a Complete Streets Design Model: A Report to Congress on Opportunities and Challenges. Washington, DC: FHWA. https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-03/Complete%20Streets%20Report%20to%20Congress.pdf, accessed June 15, 2023.

Source: © 2024 Kittelson and Associates, Inc.

Figure 3. Photo. Roundabout and raised crosswalk traffic calming in Harrisburg, PA.

1.3. Challenges to Implementing Operations Strategies to Complement Complete Streets

Transportation agencies implementing operations strategies in support of Complete Streets sometimes encounter challenges that can be perceived as barriers to implementation. This section identifies common challenges and means of overcoming them.

Balancing the Needs of Different Travel Modes

Prioritizing the safety and mobility of all users becomes challenging at times when trying to maintain the operations efficiency of arterial facilities that initially were planned and designed for regional vehicle travel (and are still used and needed for this purpose). This challenge is exacerbated when development generates more vulnerable road users (VRUs) seeking to use or cross roadways, but new or modified facilities have not been incorporated into the original design to serve those users.[10]

Transportation planning processes that identify the community's and region's desired complete network provide an important foundation for implementing Complete Streets measures. Having a plan that identifies the relative importance of a street for different modes (and describes the types of facilities to provide for each mode) helps to justify the implementation of strategies that benefit one or more modes. It is helpful in the planning process to not just look at the corridor under evaluation but the surrounding transportation network, which facilities best serve each mode, and how those facilities connect to provide for complete trips for each mode within the network.

10 VRUs include people walking, biking, or rolling.

A strategy's effect on road user safety is an essential evaluation need. Strategies that improve safety should be prioritized, particularly strategies that reduce severe injuries and fatalities, even when they result in degraded operations for some groups of road users. Operations and safety analysis may not fully capture the safety benefits of Complete Streets strategies. For example, implementing Complete Streets strategies can affect demand and route choice that may reduce exposure. Reduced exposure is a safety effect that is important but difficult to measure and is not taken into consideration in traditional operations analysis. This consideration of exposure is consistent with the recent focus on the Safe System approach to improving transportation safety and its adoption in the National Roadway Safety Strategy (NRSS).[11]

Relying on a Limited Set of Performance Measures and Analytical Capabilities

Traffic analyses historically have relied on a limited set of performance measures that focus on motor vehicle capacity and delay, given that the majority of road users have been motorists. Following the principle that "what gets measured gets attention," the lack of forecasting tools for predicting the effects of transportation projects on non-automobile modes and performance measures has often meant that project effects on safety and non-automobile operations have not been adequately considered. In recent years, more tools have become available. In the safety arena, the *Highway Safety Manual* (HSM),[12] the Crash Modification Factor (CMF) Clearinghouse (CMFC),[13] and a variety of National Cooperative Highway Research Program (NCHRP) publications, such as *Pedestrian and Bicycle Safety Performance Functions* (NCHRP Research Report 1064),[14] provide research-based methods and data that may be used for analyzing and quantifying the safety performance of many travel modes. In addition, road safety audits (RSA) provide a formal, qualitative approach to identifying road safety issues and recommending safety improvements for all road users.[15] In the operations arena, the *Highway Capacity Manual* (HCM)[16] provides methods that may be used when evaluating the operations and perceived comfort of pedestrians and bicyclists, while the *Transit Capacity and Quality of Service Manual* (TCQSM)[17] does the same for public transit passengers. Becoming familiar with these resources allows practitioners to more comprehensively evaluate a given strategy's operations and safety benefits and disbenefits at a given location and thereby make a more informed recommendation. Researchers at FHWA are also developing tools to assess and analyze safety performance in alignment with the Safe System Approach.

---

11 https://www.transportation.gov/NRSS.

12 AASHTO. 2010. *Highway Safety Manual*, 1st ed.

13 https://www.cmfclearinghouse.org.

14 D. Torbic, I. Potts, S. Guler, V. Gayah, D. Harwood, O. Grembeck, J. Griswold, and S. Turner. 2023. *NCHRP Research Report 1064: Pedestrian and Bicycle Safety Performance Functions*. Washington, DC: The National Academies Press. https://doi.org/10.17226/27294, accessed October 26, 2023.

15 FHWA. Road Safety Audits (website). https://highways.dot.gov/safety/data-analysis-tools/rsa/road-safety-audits-rsa, accessed February 9, 2024.

16 Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine (NASEM). 2022. *Highway Capacity Manual: A Guide for Multimodal Mobility Analysis*, 7th edition. Washington, DC: The National Academies Press.

17 Kittelson & Associates, Inc.; Parsons Brinckerhoff; KFH Group, Inc.; Texas A&M Transportation Institute; and Arup. 2013. *Transit Capacity and Quality of Service Manual*, 3rd ed. TCRP Report 165. Washington, DC: The National Academies Press. https://dx.doi.org/10.17226/24766, accessed October 26, 2023.

Lack of Active Transportation Data

Comprehensive and consistent data on pedestrian and bicycle volumes, crash history, trip type and length, and facility presence and condition are largely unavailable.[18] Lacking these types of data makes it challenging to assess current performance or predict future outcomes stemming from the implementation of a Complete Streets strategy. However, a lack of existing data can be overcome. Pedestrian and bicycle volumes can be collected in the field at the same time as motor vehicle volumes, and field visits can quickly gather information about facility presence and condition. Analysts may also consider using crowdsourced data to gather pedestrian, bicycle, and micromobility device volumes. Although collecting and analyzing this information may incur slightly higher costs compared with the data collection needed for a conventional, automobile centric traffic analysis, the expense is negligible when weighed against the societal cost of even a single severe injury or fatal crash.

Auto-Focused Traffic Operations and Design Standards

A community's traffic operations and design standards (e.g., maximum average vehicle delay, maximum volume-to-capacity ratio, design lane width) may operate as barriers to implementing Complete Streets strategies. For example, a strategy that fails to meet an operations standard, even if only for 15 minutes out of the day, could be considered "fatally flawed" and discarded. This approach has been justified in the past by the reasoning that once traffic operations break down, they can take far longer than 15 minutes to recover. However, such standards frequently result in a pavement area that is underused for a large portion of the day, which could be used more effectively for other purposes or not constructed at all.[19] In addition, the analysis typically assumes no change in demand after the strategy is implemented. However, as frequently can be seen when lanes or entire streets are closed for a period of time due to construction projects, and as implemented in common route-guidance tools, traffic often redistributes itself to other routes that provide faster travel times. Again, focusing analysis efforts not solely on one corridor, but instead on the entire network, is key. Agencies can consider using more than one approach to overcome this challenge:

- Apply the 24-hour evaluation framework discussed in chapter 3.
- Consider the ability of parallel routes to accommodate some of the travel demand.
- Consider the ability to restripe the existing pavement width to provide facilities that improve the street's *person* throughput.
- Apply a more comprehensive set of performance criteria, as discussed above, in which automobile operations are one criterion, but not the only criterion. (A related approach is to provide a mechanism that allows exceptions to standards in cases when safety can be maintained and implementing the exception would better meet broader agency and community objectives.)

---

18 FHWA. 2022. *Moving to a Complete Streets Design Model: A Report to Congress on Opportunities and Challenges*.

19 C. Semler, M. Sanders, C. Dartnell, M. Alston, S. Semensky, L. Ahramjian, K. Taylor, R. Sanders, M. Elbech, and Z. Vanderkooy. 2022. *NCHRP Research Report 1036: Roadway Cross-Section Reallocation: A Guide*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26788, accessed October 26, 2023.

Design Vehicle Types

The choice of design vehicle can affect the real or perceived constraints of a Complete Streets strategy. Design vehicles, including trucks, buses, and emergency services, affect curb radii, lane widths, and sight distance requirements. Adjacent land uses may require consideration of curb space needs for goods deliveries or shared-ride vehicle pickups and dropoffs. Flexible design processes that consider a location's specific transportation and land-use context can help overcome this challenge. Design variances or exceptions may be used, resulting in a geometric design that does not meet every established design standard but produces a design that satisfies road user needs at the specific location.[20] Having designated truck and bus routes is key in the selection process.

1.4. Applications and Policies

Implementing Complete Streets can be an incremental process.[21] Rather than trying to achieve everything in one project, transportation agencies can look for opportunities to integrate Complete Streets principles incrementally within smaller projects. Agencies can also adopt policies requiring or supporting the application of Complete Streets principles throughout planning, design, construction, operations, and maintenance. Other existing agency policies, such as a Vision Zero policy or a policy requiring that transportation analyses evaluate multimodal safety and operations performance, may also support the implementation of Complete Streets strategies. It is also helpful to ensure that local land development patterns support the transportation design that the agency establishes. This approach is where the context of the built environment can support the street design. This approach can help avoid building isolated islands of Complete Street-rich environments neighbored by locations that have little to no elements supporting it. Examples of project types where Complete Streets operations strategies can be applied include, but are not limited to:

> The Flint Hills Metropolitan Planning Organization (MPO) in Kansas supported more than 40 demonstration projects with Complete Streets design elements. These low-cost, temporary projects (e.g., common projects such as crosswalk improvements, curb extensions, and pedestrian islands) showed how agencies can gradually build confidence in Complete Streets road designs that better serve all users.

- **New construction or reconstruction.** Construction projects may introduce a new roadway where none has existed before. Agencies can include Complete Streets design elements and operations strategies in the project. Agencies may also introduce an alignment when removing an existing roadway or developing a new roadway cross section. In a reconstruction project, the agency could change the basic cross section or modify a substantial proportion of the existing alignment, which would allow Complete Streets strategies to be incorporated in the design.

20 C. Semler, M. Sanders, C. Dartnell, M. Alston, S. Semensky, L. Ahramjian, K. Taylor, R. Sanders, M. Elbech, and Z. Vanderkooy. 2022. *NCHRP Research Report 1036: Roadway Cross-Section Reallocation: A Guide*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26788, accessed October 26, 2023.

21 https://www.flinthillsmpo.org/demoprojects.

- **Resurfacing, restoration, and rehabilitation (3R) projects.** 3R projects include "placement of additional surface material and/or other work necessary to return an existing roadway, including shoulders, bridges, the roadside, and appurtenances to a condition of structural or functional adequacy."[22] 3R projects "preserve and extend the service life of the existing road and enhance highway safety without making changes, such as adding through motor vehicle lanes, that change the basic roadway type."[23] 3R projects provide opportunities to incorporate Complete Streets strategies, such as adding facilities for walking or bicycling, implementing road diets, and implementing access management. By incorporating Complete Streets elements into a larger project, the community benefits from less construction disruption compared with individual projects.
- **Intersection and corridor improvements.** These projects focus specifically on intersections or segments of a corridor and typically undergo processes from planning to design to implementation. These projects can incorporate Complete Streets principles, such as reallocating the cross section among different modes using the roadway as well as acquiring right-of-way for intersection or corridor enhancements for all users.[24] These projects may also provide an opportunity to modify land development regulations to support these improvements.
- **Pedestrian and bicycle projects.** Operations strategies that also improve safety for persons walking and bicycling can be implemented as part of general improvements to pedestrian or bicycle facilities or a more targeted project, such as one implementing a Safe Routes to School plan.
- **Day-to-day facility operations.** Personnel operating facilities on a day-to-day basis often observe trends and operational issues that can be addressed in large capital projects as well as by minor changes using operations funding. Examples could include changes in delineation, signing, signal configurations/timing, etc. If coordinated, many times, these changes can be implemented by partnering with maintenance staff as they conduct routine maintenance projects, at minimal-to-low differences in cost.

22 23 CFR 625.2(b).

23 Federal Highway Administration (FHWA) Office of Preconstruction, Construction and Pavements Director Brian J. Fouch to Division Administrators, Directors of Field Services, and Division Directors; March 1, 2023. Subject: Guidance – Information: Review of State Geometric Design Procedures or Design Criteria for Resurfacing, Restoration, and Rehabilitation Projects on the NHS. https://www.fhwa.dot.gov/design/rrrguidance230301.pdf, accessed August 22, 2023.

24 R. Lyles, M. Siddiqui, W. Taylor, B. Malik, G. Siviy, and T. Haan. 2012. *Safety and Operational Analysis of 4-Lane to 3-Lane Conversions (Road Diets) in Michigan*. East Lansing, MI: Michigan Department of Transportation. https://rosap.ntl.bts.gov/view/dot/23856, accessed June 15, 2023.

1.5. Primer Purpose and Organization

The Kansas DOT Active Transportation Planning Toolkit for Small- and Mid-Sized Communities was developed as part of the Kansas Active Transportation Plan. The toolkit is designed to help small and mid sized communities (populations up to 20,000) to develop their own active transportation plans.

This primer is intended to complement other sources of information about Complete Streets by presenting practitioners with tools and information for evaluating and using TSMO (generally, "operations") strategies in a Complete Streets context. For operations personnel at transportation agencies that have recently adopted or are considering adopting a Complete Streets policy, the primer provides information on readily implementable operations strategies to support the policy, along with information about the effects of these strategies on the operations and safety of all road users. For operations personnel at agencies with established Complete Streets policies, the primer provides information on performance measures and tools for evaluating the effects of a wide range of potential operations strategies on road users. Table 1 summarizes the primer's contents and can help direct readers to the appropriate chapter for information of interest.

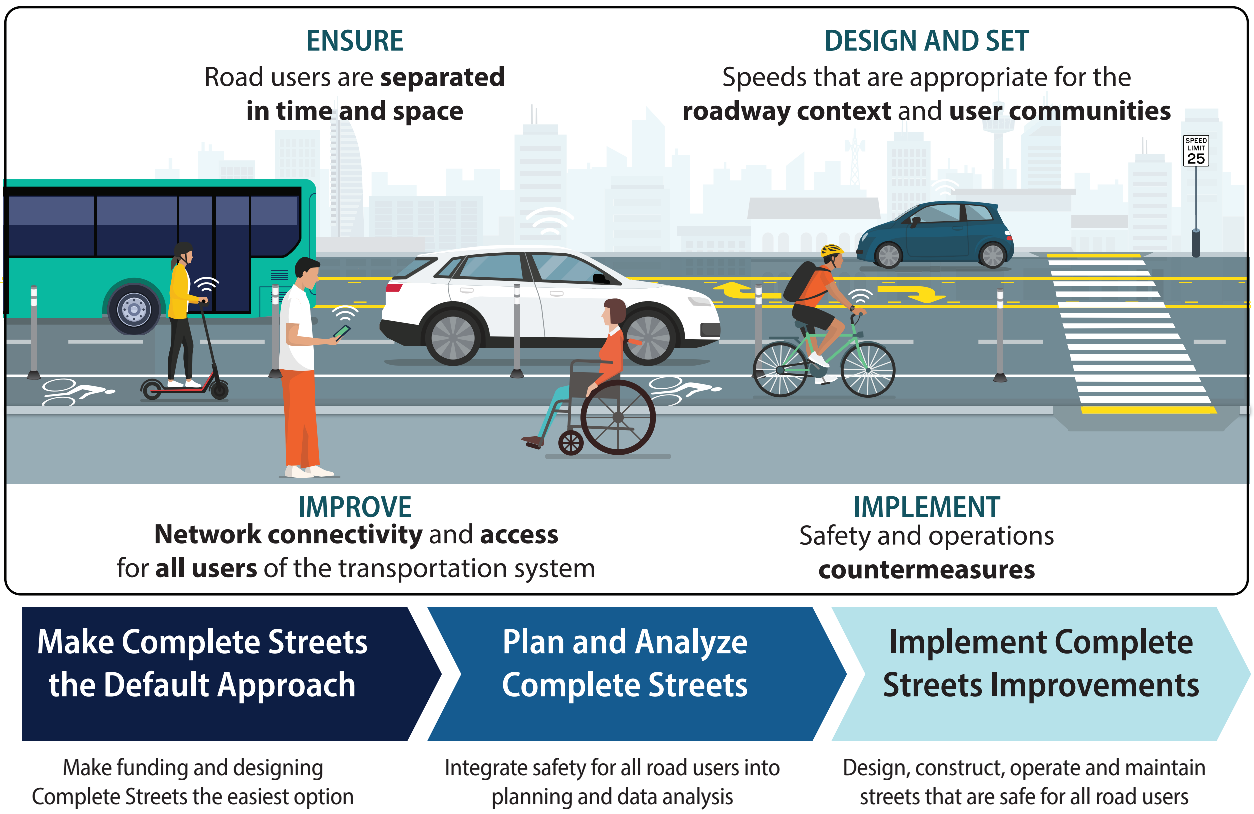
Table 1. Information on each chapter's purpose and what a user can learn.

CHAPTER	PURPOSE
1. Introduction to Operations in Complete Streets	■ Introduces Complete Streets principles and how Complete Streets and operations strategies can be integrated to improve safety and reliability. ■ Presents examples of operations strategies, potential applications, and ways to overcome possible challenges. ■ Defines "complete networks." ■ Provides an overview of the primer's contents.
2. Integrating Operations in Complete Streets	■ Introduces the Complete Streets design model and steps within the model where operations can be integrated. ■ Describes a performance-based multimodal safety and operations decisionmaking framework. ■ Discusses how typical Complete Streets elements affect multimodal operations.
3. Operations Performance Measures in the Complete Streets Context	■ Summarizes available resources for quantifying the safety and operations effects of operations strategies. ■ Lists potential performance measures and the resource(s) providing details about data needs and calculation methods and tools. ■ Introduces the concept of evaluating operations over a 24-hour period rather than the traditional peak hour. ■ Provides examples of how operations strategies can be modeled
4. Strategies for Operations in Complete Streets	■ Links potential design, control, management, and other strategies to operations objectives. ■ Summarizes key operations strategies, their potential effects on multimodal safety and operations, and performance measures used for analyzing them.

2 INTEGRATING OPERATIONS IN COMPLETE STREETS PROJECTS

2.1. The Complete Streets Design Model

As noted and defined in chapter 1, a Complete Street is safe, and feels safe, for everyone using the street,[25] including pedestrians, bicyclists, public transportation users, children, older individuals, individuals with disabilities, motorists, and freight vehicles. As a result, the design model for developing Complete Streets prioritizes the safety, comfort, and connectivity of all road users. Figure 4 illustrates the design model.



Source: FHWA.

Figure 4. Diagram. Complete Streets design model.

25 FHWA. 2022. *Moving to a Complete Streets Design Model: A Report to Congress on Opportunities and Challenges*. Washington, DC: FHWA. https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-03/Complete%20Streets%20Report%20to%20Congress.pdf, accessed October 23, 2023.

2.2. Operations Elements in Complete Streets

Operations strategies support each aspect of the Complete Streets design model. As described in greater detail in chapter 4, these strategies can be categorized into design, control, management, and other (e.g., education, agency coordination) strategies. In general, strategies from multiple categories are available to support a particular aspect of the design model, giving practitioners the flexibility to choose one or more strategies most suited to a particular location, context, and agency capability. For example:

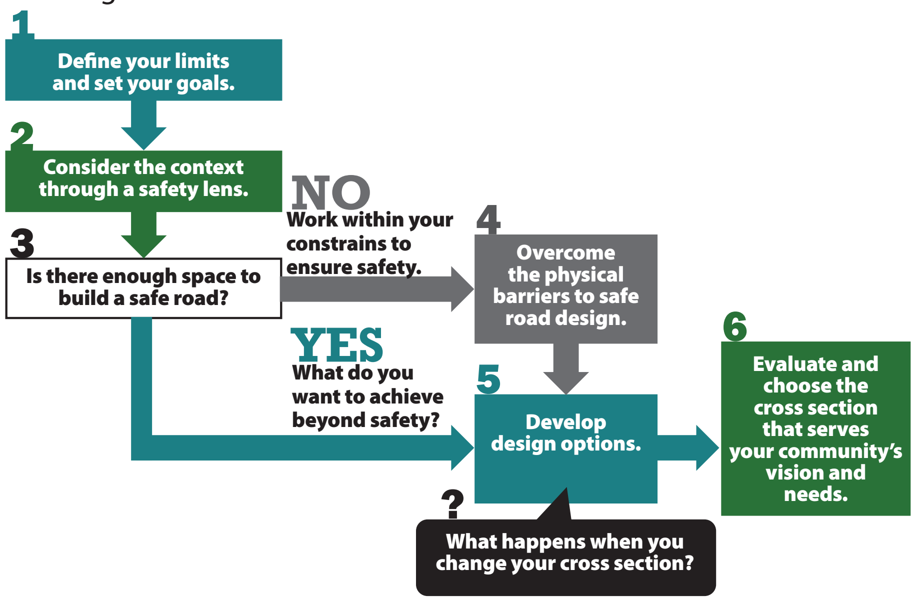
- **Set and design appropriate speeds.** Developing traffic signal timing that progresses traffic at an appropriate speed for the roadway's context, installing dynamic speed monitoring displays that remind drivers when they drive too fast, constructing road diets that visually narrow the roadway and free up space for implementing other speed management strategies, and installing traffic-calming measures that encourage driving at an appropriate speed are examples of very different operations strategies that all support the same speed-related objective.
- **Separate road users in time and space.** Constructing nontraversable medians provides opportunities to reduce pedestrian exposure while crossing a street and can also reduce pedestrian and motor vehicle delay; implementing leading pedestrian intervals (LPIs), leading bicycle intervals (LBIs), or both gives VRUs a head start into an intersection before conflicting traffic begins to move; reallocating road space from motor vehicles can provide safer, better operating facilities for other modes using the roadway; and implementing time-of-day turn restrictions both reduces intersection conflict points at high-volume times of day and reduces delay to through vehicles. As these examples suggest, many kinds of operations strategies also improve roadway safety.
- **Improve connectivity and access for all users.** Reallocating road space to fill gaps in the complete network directly improves connectivity for nonmotorized users. Access management techniques reduce the number of conflict points between VRUs and motor vehicles along a roadway. Installing green bicycle lanes, bike boxes, and shared lane symbols underscores the need to share the roadway. The resulting improved VRU safety and comfort on the facility make it a more usable and desirable connection in the complete network.
- **Implement safety and operations countermeasures.** Converting a signalized intersection to a single-lane roundabout and installing rectangular rapid-flashing beacons (RRFBs) at midblock crosswalks are examples of proven safety countermeasures[26] that can also improve operations. Roundabouts generally produce fewer total person-hours of delay when considered over an entire day that includes nonpeak hours than do traffic signals, and RRFBs improve driver yielding, resulting in lower pedestrian delay at unsignalized midblock crossings.

26 https://highways.dot.gov/safety/proven-safety-countermeasures.

- **Recognize opportunities to integrate operations into projects and processes.** Coordinating the projects and activities of different departments within a transportation agency, as well as coordinating with other transportation agencies (e.g., neighboring city, the county, or State departments of transportation (DOT) owning an intersecting roadway, transit providers) can provide opportunities to implement operations strategies at a lower cost than a stand-alone project or activity. Identifying the complete network in transportation plans may be a prerequisite for obtaining grant funding to implement operations strategies supporting the complete network, while updating design manuals to explicitly include information about operations strategies can help mainstream use of these strategies within the agency.

2.3. Multimodal Safety and Operations Framework for Complete Streets

A performance-based design process, such as that described in NCHRP Report 785, can assist practitioners in making decisions on which elements to include within the roadway cross section.[27]NCHRP Report 1036 adapted the performance-based design process specifically to road cross section reallocation, which is a common way for agencies to implement Complete Streets. Figure 5 illustrates that report's cross section decisionmaking framework.[28] Although not explicitly called out as a step in this process, public involvement at the local and regional level is an overarching element.



Source: © 2023The National Academies of Sciences, Engineering, and Medicine.

Figure 5. Diagram. Cross section decisionmaking framework.

27 B. Ray, E. Ferguson, J. Knudsen, R. Porter, and J. Mason. 2014. *Performance-Based Analysis of Geometric Design of Highways and Streets*. NCHRP Report 785. Washington, DC: The National Academies Press. https://www.trb.org/Publications/Blurbs/171431.aspx, accessed June 16, 2023.

28 C. Semler, M. Sanders, C. Dartnell, M. Alston, S. Semensky, L. Ahramjian, K. Taylor, R. Sanders, M. Elbech, and Z. Vanderkooy. 2023. *Roadway Cross-Section Reallocation: A Guide*. NCHRP Research Report 1036. Washington, DC: The National Academies Press. https://doi.org/10.17226/26788, accessed October 26, 2023.

Although the decisionmaking framework in figure 5 was developed specifically for use with cross section reallocations, the framework is applicable to all Complete Streets projects and can help agencies make informed decisions when balancing project objectives. Full details about each step in the framework are provided in NCHRP Report 1036. The following summarizes the six steps and identifies the specific points where operations considerations are applicable:

- **Step 1: Define limits and set goals.** Practitioners can familiarize themselves with agency, community, and regional needs, goals, plans, and policies that would support or discourage the use of particular strategies. The type of project being undertaken (e.g., 3R) may constrain the types of strategies that are feasible, while the roadway's functional class will help inform the degree to which operations should be prioritized. Data collection (e.g., multimodal traffic counts, forecasted volumes, motorized traffic speeds, crash history) also occurs during step 1.
- **Step 2: Consider the context through a safety lens.** The practitioner identifies a "minimum safe design" for each mode that specifies minimum cross-sectional dimensions relevant to each travel mode using the roadway.[29] These dimensions depend primarily on traffic volumes and speeds but also consider the land use context. Dimensions to consider include:
    - Pedestrians: sidewalk width, horizontal separation from traffic lanes, and other design elements to accommodate people with disabilities.
    - Bicyclists and micromobility users: facility type (e.g., shared traffic lane, bicycle lane, buffered bicycle lane), facility width, horizontal and vertical separation from traffic lanes and parked cars.
    - Transit: lane width, need for pullouts at bus stops.
    - Freight and emergency vehicles: design vehicle, lane width, curb space radii.
    - Automobiles: lane width, intersection type/configuration, curb space parking for short-term access to businesses, curb space for ridehailing services.
- **Step 3: Is there enough space to build a safe road for all modes?** The practitioner determines whether the minimum safe design for the facility—considering the needs for each mode determined in step 2—"fits" or is feasible within the constraints identified in step 1. This step also determines the number of travel lanes needed to achieve operations objectives. Transportation agencies can consider evaluating operations over 24 hours instead of using the traditional peak-hour analysis approach to identify the percentage of the day that all travel lanes are needed to accommodate motor vehicle operations.
- **Step 4: Overcome the physical barriers to safe road design.** If there is not enough roadway space to safely accommodate all modes, an agency can consider options that would allow the dimensions needed for driving, walking, bicycling, and transit to be reduced safely. Possible options include:
    - Implementing strategies that reduce motor vehicle speeds, which could allow lane widths and horizontal buffer dimensions to be reduced.

29 Chapter 7 of NCHRP Report 1036 provides guidance on minimum dimensions by mode, based on motorized vehicle travel speeds and volumes and the land use context.

- Implementing strategies (e.g., time-of-day restrictions) that encourage motor vehicle traffic to shift to parallel facilities or less busy times of day, which could allow horizontal buffer dimensions to be reduced and could potentially reduce the number of travel lanes needed.
- Considering alternate parking options, such as moving parking spaces behind buildings.
- Developing safe parallel facilities for one or more travel modes that provide comparable levels of access and mobility.
- Converting a two-way street to one-way to reduce the required travel lanes.

- **Step 5: Develop design options.** The practitioner considers the ways the available roadway or right-of-way width (depending on the type of project) can be allocated among the travel modes while maintaining the minimum dimensions from step 3 or, if necessary, step 4. The review of agency, community, and regional needs, goals, plans, and policies from step 1 helps inform which modes and facility types to prioritize.
- **Step 6: Evaluate and choose the cross section that serves the community's vision and needs.** The performance of each design option developed in step 5 is compared using performance measures reflective of agency, community, and regional goals. Chapter 3 of this primer provides examples of performance measures that can be used to evaluate the safety and operations performance of various operations, safety, and design strategies. NCHRP Report 1036 also provides guidance on the economic, environmental, social, and mode-shift effects of various strategies. Chapter 3 also provides examples of how transportation agencies have evaluated cross section reallocation alternatives.

2.4. Balancing Strategy Effects on Operations

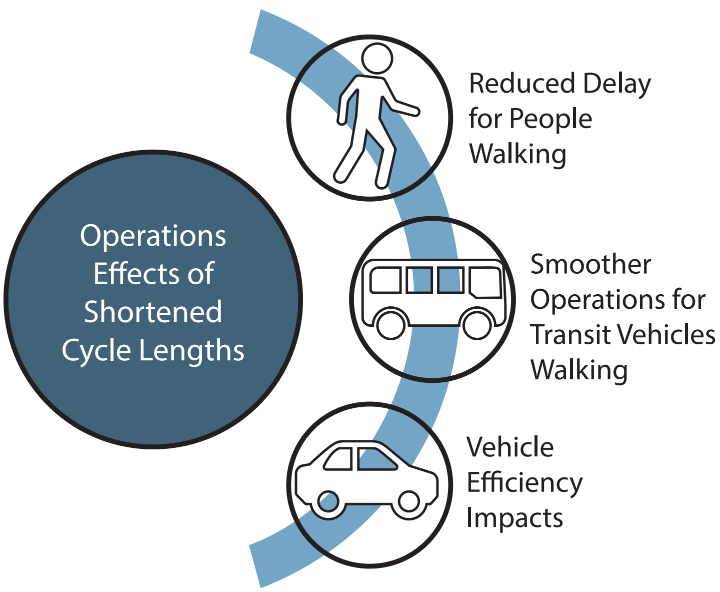
A variety of Complete Street strategies and design elements can achieve a given objective, such as improving safety and operations of a given travel mode. However, strategies that produce positive safety, operations, and other effects for one mode can produce positive, neutral, or negative effects to other modes, adjacent land uses, or the community. Consequently, evaluating strategies' effects on all road users and stakeholders when selecting strategies to achieve agency, community, and regional goals and objectives is key. NCHRP Report 1036 provides information about strategy effects on considerations other than operations.[30] This primer complements that framework by focusing on operations effects while also considering safety.

30 C. Semler, M. Sanders, C. Dartnell, M. Alston, S. Semensky, L. Ahramjian, K. Taylor, R. Sanders, M. Elbech, and Z. Vanderkooy. 2023. *Roadway Cross-Section Reallocation: A Guide*. NCHRP Research Report 1036. Washington, DC: The National Academies Press. https://doi.org/10.17226/26788, accessed October 26, 2023.

Examples of How Strategies Influence Operations in Different Ways

As an example of how a strategy can affect the operations of different road users in different ways, consider the effects of shortening a traffic signal's cycle length summarized in figure 6:

- **Pedestrians and bicyclists** benefit from the delay reduction produced by shorter cycle lengths. At the same time, minimum pedestrian walk and change interval requirements to accommodate slower moving individuals constrain how much the cycle length can be reduced.
- **Transit** passengers also benefit from the reduced delay. In addition, transit agencies can use the time saved over a series of intersections to expand the area a route serves in a given period of time, provide more schedule recovery time at the ends of the route or, on very frequent routes, possibly reduce the number of buses required to provide a particular service frequency. On frequent routes, reduced cycle lengths also help reduce the incidence of bus bunching, where one bus catches up to another.
- **Automobile and freight vehicle** delay follows a U-shaped curve, with delay minimized at a particular cycle length determined by an intersection's traffic patterns and geometric features and increasing as the cycle length is either shortened or lengthened from that point. If the cycle length is too short, the vehicle queue on one or more intersection approaches may not always be able to be cleared during the approach's green interval. This persistent queuing condition, in turn, may make it more difficult for **emergency vehicles** to get to and through the intersection, block access to businesses and residences, and cause spillback through other intersections.



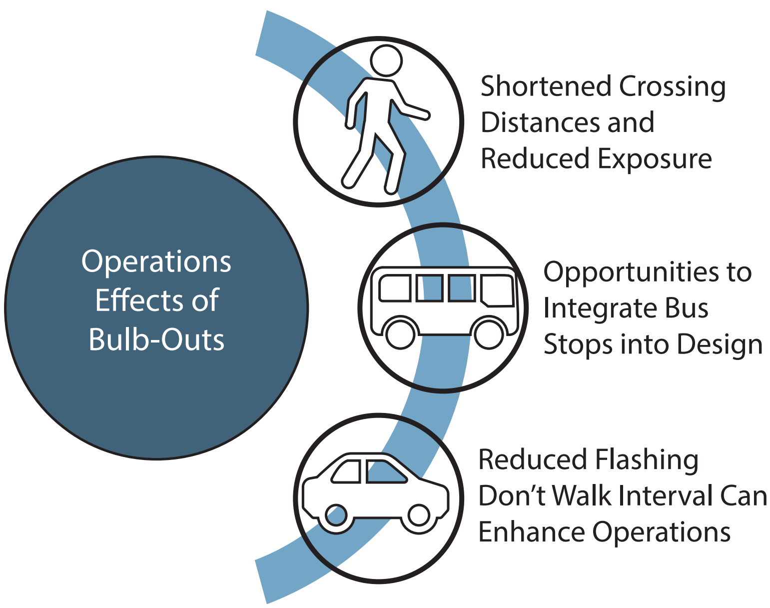
Source: FHWA.

Figure 6. Illustration. Effects of shortened cycle lengths on multimodal operations.[31]

31 Vehicle operations efficiency may increase or decrease depending on various factors including the proportion of major-street vehicles arriving on green, the turning movement volumes, and saturation flow rates.

As a second example, consider a traffic signal where pedestrian timing requirements constrain the cycle length. To achieve the operations benefits, shortening crosswalk lengths could reduce the minimum pedestrian change intervals. For example, corner bulb-outs could be within the streets' parking lanes.[32] These could affect different road users as follows (figure 7):

- **Pedestrian** safety could be improved through shorter exposure to conflicting motor vehicle traffic and improved sightlines between pedestrians waiting on street corners and potentially conflicting vehicles.
- **Bicyclists** would not be directly affected, but bicycle lane presence may constrain the sidewalk bulb-out distance so as not to narrow the bicycle lanes' effective width.
- **Large vehicle** turning radius needs (e.g., transit buses, delivery vehicles, emergency vehicles) could constrain the design of the bulb-outs.
- **Automobiles** would not be directly affected unless the parking lane were to be used as a right-turn lane on one or more intersection approaches. Shortened crosswalks do tend to allow for reduced flashing don't walk intervals, which can improve vehicle operations.
- Transit buses could leverage a lengthened bulb-out on the intersection's near side as a bus stop. Doing so would eliminate delay to buses pulling back into the travel lane after serving the stop. At the same time, a bus stopped in the travel lane would delay motor vehicles and bicyclists behind it, which would either need to change lanes (on a multilane street) or wait for the bus to finish serving passengers.



Source: FHWA.

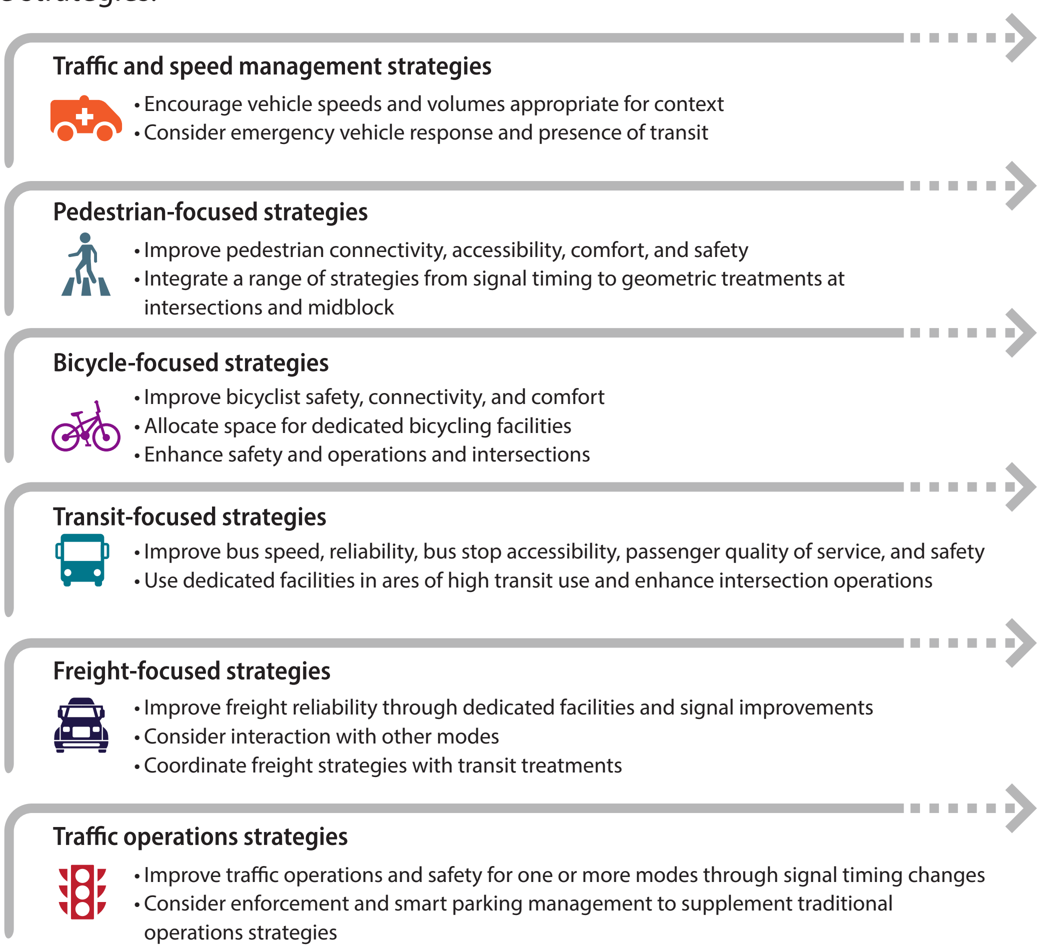
Figure 7. Illustration. Effects of bulb-outs on multimodal operations.

32 There are other considerations that could be assessed before selecting this strategy, such as drainage and wayfinding for persons with impaired vision, but for simplicity of presentation, the example focuses on operations and safety considerations.

These two examples demonstrate that Complete Streets strategies can interact with each other in complicated ways and that performance outcomes to different road users should be carefully evaluated and balanced. Strategies will rarely, if ever, produce outcomes viewed as improvements across all agency, community, and regional goals to all road users. Furthermore, strategies that are appropriate in one set of circumstances (e.g., traffic volume, land-use context) may not be appropriate in another.

Common Effects of Strategies on Operations

Figure 8 summarizes common categories of Complete Streets strategies and potential effects on operations, followed by a discussion of typical desired outcomes when implementing these strategies.



Source: FHWA.

Figure 8. Diagram. Example of operations strategies and effects.

- **Traffic and speed management strategies** include horizontal and vertical deflection techniques, roadway narrowing (e.g., narrower lanes, fewer travel lanes), street diversions and closures, and roundabouts. These strategies are typically implemented to encourage traffic speeds and volumes appropriate for a street's context and functional class. The primary operations considerations are frequency of emergency vehicle responses on the street, bicycle bypass provisions, and the presence of transit service on the street.

- **Pedestrian-focused strategies** include sidewalks, midblock crosswalks, crossing safety countermeasures (e.g., refuge islands, enhanced signing and striping, beacons), LPIs, implementing the pedestrian recall setting in signal controllers, intersection corner bulbouts, and upgrading infrastructure to meet Americans with Disabilities Act (ADA) requirements. These strategies are typically implemented to improve pedestrian connectivity, accessibility, comfort, and safety. Pedestrian recall benefits pedestrian operations by not requiring pedestrians to remember to push a button but increases other modes' delay during phases when no pedestrians are present (which may be the majority of the time in certain places). Passive pedestrian detection (i.e., a sensor that detects the presence of a pedestrian without pushing the button) can also provide benefits by providing pedestrian service when needed. Midblock crosswalks introduce additional locations where vehicular traffic may need to stop, but they improve pedestrian connectivity. LPIs reserve a portion of the cycle length for pedestrians' exclusive use, which reduces the time available to serve other modes. Dedicated right-turn phases, with right-turns-on-red prohibited, reduce pedestrian–vehicle conflicts but may also require a portion of the cycle length if no cross street left-turn phase is available to overlap.
- **Bicyclist-focused strategies** include bike boulevards and neighborhood greenways, bike lanes with various degrees of separation from motor vehicle traffic, shared-use paths, LBIs, bicycle detection and detection feedback displays at signals, and onstreet parking removal. These strategies are typically implemented to improve bicyclist safety, connectivity, and comfort; bicycle detection improves bicyclist operations. Bike boulevards typically provide a lower stress bicycling environment but may require bicyclists to stop at more intersections, relative to a bike facility on a higher order street. Traffic management strategies to minimize through traffic on bike boulevards, such as diverters, can affect automobile operations and connectivity but are typically designed to accommodate emergency vehicles. Shared-use paths can consider potential interactions between bicyclists and pedestrians as well as how frequently bicyclists will encounter cross streets requiring them to stop. Reallocating roadway space to develop bike lanes may affect other modes' operations, including transit and freight, depending on the previous use of the space. Leading bicycle intervals reserve a portion of the cycle length for the exclusive use of bicyclists, which can affect other modes' operations.

The City of Austin, TX, installed bicycle signals and implemented LBIs. These changes benefited all travel modes, and surveys indicated they were well-received by travelers using all modes.

- **Transit-focused strategies** include bulb-outs and ADA improvements at transit stops, bus pullouts on higher speed roadways, exclusive transit lanes, queue jump lanes (that combine short, dedicated transit lanes with either a leading bus interval or active signal priority to allow buses to easily enter or reenter the traffic flow), transit signal priority (TSP), and real-time bus arrival displays. These strategies are implemented for a variety of reasons, including improving bus speed and reliability, improving stop accessibility, improving passenger quality of service, and increased safety. Bus lanes that are developed by converting travel or parking lanes may affect the operation of other vehicular modes (including bicyclists), although some bus lanes are designed to allow bicyclist use. TSP often benefits traffic moving parallel with the transit vehicle receiving priority, although side-street delay may increase. Queue jumps reduce the length of the parallel green phase; bus, parallel bicyclist, and parallel pedestrian delay is reduced during the phases when a queue jump interval is provided, while parallel automobile delay is increased.

- **Freight-focused strategies** include exclusive truck lanes, truck signal priority, and delivery parking. They are designed to improve the speed and reliability of freight movement. The effects on other modes are similar to those for exclusive transit lanes and TSP.
- **Traffic operations strategies** include signal-timing changes (e.g., reducing cycle lengths, signal coordination, protecting left-turn phases, adding dedicated turning phases, providing flashing yellow arrow left-turn operations), speed-limit reductions, automated traffic enforcement, and "smart" parking-management systems. These strategies may be implemented to improve traffic operations generally or to improve the operations of a specific mode (e.g., signal progression timed for bicyclists). Others may be implemented with safety as the primary objective (e.g., protecting left turns reduces conflicts with motor vehicles, bicyclists, and pedestrians in the opposite direction). These strategies may need to be implemented in coordination with operations or improvements on other routes or parallel facilities to serve regional and through movements.

Chapter 4 provides more details about Complete Streets strategies that typically produce positive operations and safety outcomes.

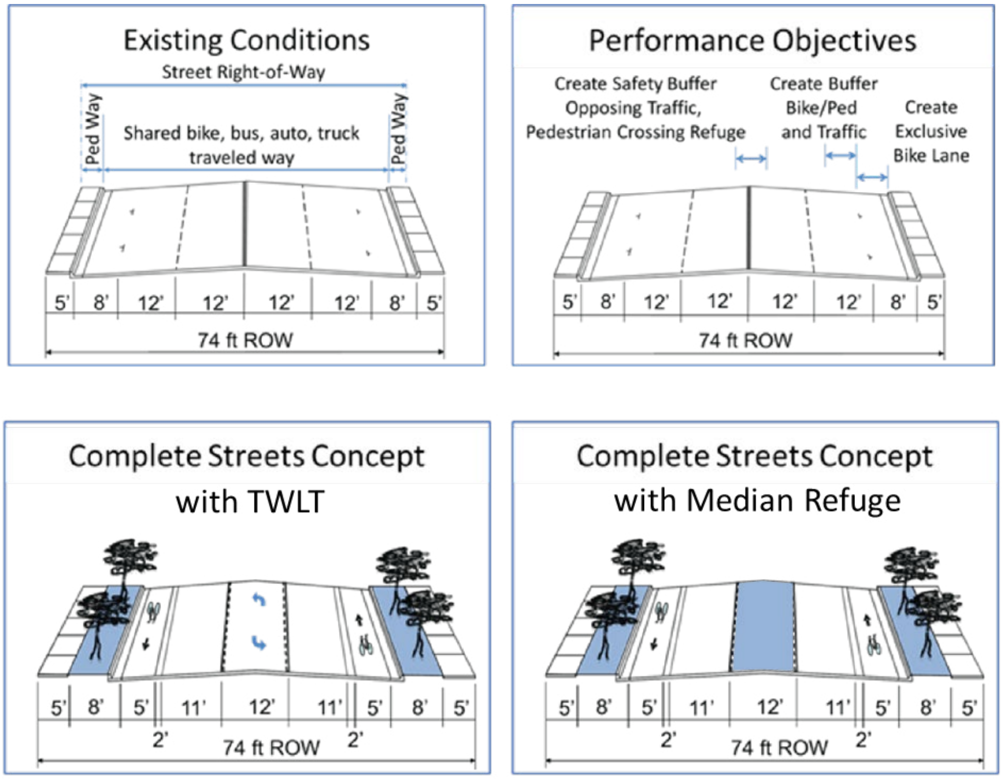
Example of Balancing Strategy Effects With Operations Considerations

Figure 9 illustrates a common Complete Streets strategy, a road diet that converts a four-lane roadway with onstreet parking and sidewalks to a facility that better accommodates multimodal travel. In this example, one travel lane in each direction and the parking lanes were repurposed to provide buffered bicycle lanes, a landscape strip between the sidewalk and the street, and a two way left-turn lane (TWLTL). Where block lengths are long, agencies can replace the TWLTL with a raised median at key locations to create safer midblock crossing opportunities for pedestrians. In addition, the remaining travel lanes were reduced in width from 12 ft to 11 ft. An additional measure that might have been employed is consolidation of driveways to reduce conflict and delay for the one lane of through travel.

A common perceived challenge to implementing this strategy is the reduction in the number of travel lanes from two to one in each direction. However, the constraints on capacity often occur at the controlled intersections (e.g., traffic signals, all-way stops, roundabouts) at either end of the segment rather than the number of lanes in the middle of the segment. If, for example, traffic signals bounded the segment, the left lanes at the intersections would not provide much extra capacity during peak periods because through vehicles would often be blocked by left-turning vehicles waiting for a gap. Depending on how frequently the onstreet parking spaces turned over, the right lane could also be frequently blocked, constraining the amount of traffic that could reach the intersection. Double-parking may also become a concern, especially if the road has frequent freight deliveries or rideshare stops. There could also be significant lane-changing activity during peak periods as motorists shift lanes back and forth to avoid turning and parking vehicles. As a result, creating left-turn lanes and, if necessary, implementing protected left-turn phases at the intersections could provide sufficient capacity to serve the traffic that currently uses two lanes without left-turn lanes being provided. A traffic analysis would provide insights into what is feasible. FHWA's *Road Diet Case Studies* describes safety, operations, and other outcomes of 24 successful road diet projects.[33]

---

33 FHWA. 2015. *Road Diet Case Studies.* Publication FHWA-SA-15-052. https://safety.fhwa.dot.gov/road_diets/case_studies/roaddiet_cs.pdf, accessed February 9, 2024.



Source: FHWA.

TWLT = two-way left-turn lane.

Figure 9. Diagrams. Evolution from existing conditions to a Complete Streets concept.

Another consideration when performing traffic analysis is that if motor vehicle delay is forecast to increase because of the road diet, some motorists may use alternative parallel routes (if they exist) or choose to travel at nonpeak/less congested times or use another mode. Making improvements to alternative routes can further induce motor vehicle traffic away from the study roadway. Experience with long-term construction projects that close lanes or entire roadways shows that motor vehicle traffic will redistribute itself if needed and that demand is not fixed. Similarly, car navigation devices and applications (apps) will look for the fastest route in realtime. As a result, roadway and intersection demand cannot be assumed to be fixed.

In this example, motor vehicle operations along the street may degrade due to the road diet but still operate acceptably. However, this tradeoff opens the door to a variety of benefits for other modes, and operations strategies may be able to mitigate some of the operational effects to motor vehicles. Table 2 lists the effects of the proposed street configuration. Each roadway has its unique characteristics, and road diets (or most any other strategy) will not always be suitable at every location. However, as this example has demonstrated, practitioners may have more flexibility than they initially think to develop a set of Complete Streets strategies that provide an overall improvement in the safety and operations of all road users.

Table 2. Example effects of a road diet Complete Streets strategy on safety and operations.

STRATEGY	EXAMPLE EFFECTS ON SAFETY AND OPERATIONS
	▪ Pedestrians have a shorter distance to cross, reducing their delay and exposure to traffic. Removing onstreet parking and the number of travel lanes also improves sightlines between motorists and pedestrians. Pedestrians benefit from the comfortable environment provided by the separation from motor vehicle traffic.
	▪ Bicyclists receive their own buffered space and no longer experience conflicts with parked cars and car doors. At intersections, the bike lane stop bar could be placed beyond the motor vehicle stop bar to improve motorists' awareness of stopped bicyclists.
	▪ Freight vehicles no longer experience the stop-and-start turbulence left turning and parking vehicles cause. Freight vehicles making deliveries to businesses lacking offstreet parking will need to park farther away if onstreet parking or loading areas are removed.
	▪ Buses also benefit from the reduced turbulence. On the other hand, bus stop locations may be affected because buses will no longer be able to pull into the parking lane to stop. At these locations, the landscape strip could be converted into a bus pullout. The interactions between buses and bicyclists could be considered at the stops; however, similar interactions occur in the existing condition.
	▪ Emergency vehicles might benefit from traffic signal preemption, if not already provided, if there are concerns about reduced maneuvering room through intersections.
	▪ Motor vehicle drivers also benefit from the reduced turbulence and the safety effects of reduced travel speeds. On the other hand, motor vehicles may experience increased delay depending on the implemented strategies.

3 OPERATIONS PERFORMANCE MEASURES IN THE COMPLETE STREETS CONTEXT

3.1. Performance Measure Applications

Performance measures can be used during the planning phase of a Complete Streets project to evaluate strategies and to help identify one or more strategies that produce the best overall safety and operations conditions for all road users. Performance measures can also be applied after implementation to assess a project's outcomes. Post-implementation evaluation is particularly useful for building support for future Complete Streets efforts by demonstrating the outcomes that occurred in initial projects and, potentially, to adjust future street designs based on the experience and lessons gained from initial projects.

Three types of performance measures applicable to Complete Streets efforts are as follows:

- **Field assessments and measurements** can take place in the field before and after a change occurs and are the preferred way to evaluate and document the outcomes of Complete Streets projects. Assessments can include RSAs, which are formal qualitative assessments of safety performance.
- **Predictive measures** are output by analysis methods that forecast future roadway performance given a change in conditions (e.g., strategy implementation, changed roadway demand). In the absence of direct field measurements, predictive measures can also estimate outcomes after a change has occurred.
- **Proxy or surrogate measures** take the place of predictive measures when input data needed to apply a predictive measure is lacking, or when researchers have not yet developed a predictive method applicable to a Complete Streets strategy. Proxy measures give a general indication of the expected future trend in conditions. For example, reducing the number of intersection conflict points, installing pedestrian crossing countermeasures that improve motorist yielding, or shortening crossing distances could all improve safety, even though it might not always be possible to quantify the magnitude of the improvement.

3.2. Overview of Analysis Resources

As discussed in section 1.3, comprehensively evaluating Complete Streets strategies and their effects on a range of performance measures supports decisionmaking for a successful implementation. This entails analyzing a set of performance measures that, in combination, allow a strategy's effects on all road users to be understood. Conducting an operational analysis at the local and regional levels is helpful in understanding expected effects of a Complete Streets project and select appropriate strategies. Public engagement with both local and regional stakeholders can provide additional insights into the context and purpose of the roadway. This section presents resources for estimating strategy performance in the following areas:

- Road user safety.
- Road user operations.
- Bicyclist-perceived comfort and safety.
- Pedestrian-perceived comfort and safety.
- Transit and freight operations.
- Network connectivity.

These resources provide detailed information about performance measure definitions, data needs, estimation methods, and potential calculation aids applicable to each of these areas. Section 3.3 suggests specific performance measures that can be used to estimate or measure the effects of a Complete Streets strategy in each of these areas, along with the analysis resources that support each measure.

Road User Safety

There are many tools, policies, and procedures to analyze the safety performance of facilities and projects and to determine project alternatives and countermeasures that yield optimal safety performance, thus contributing to reduced fatalities and serious injuries on the systems. These tools, policies, and procedures include the use of data-driven safety analysis (DDSA) techniques and RSAs that inform State DOTs' and local agencies' decisionmaking and how they target investments to improve safety and equity. DDSA is the application of evidence-based tools and approaches to assess an existing or proposed transportation facility's future safety performance, including the use of the American Association of State Highway and Transportation Officials' (AASHTO) HSM. There is more research for the effects of strategies on motor vehicle crashes than on crashes involving other road users. The following resources provide example approaches, methods, and tools for assessing the effect of a Complete Streets strategy on the frequency and severity of crashes (potentially by crash or road user type):

- HSM, 1st edition:[34] provides crash modification factors (CMFs) and safety performance functions (SPFs) for a variety of strategies, along with guidance on applying them.
- CMFC:[35] FHWA-sponsored website containing up-to-date CMFs and SPFs, which are rated based on each study's rigor and statistical significance of results, among other factors.
- RSAs: an independent, multidisciplinary team's formal safety performance examination of an existing or future road or intersection. An RSA qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users.
- Systemic Analysis: uses crash and roadway data in combination to identify high-risk roadway features that correlate with particular crash types.

34 AASHTO. 2010. *Highway Safety Manual,* 1st edition. Washington, DC: AASHTO.

35 "Crash Modification Factors Clearinghouse." n.d. (website). https://www.cmfclearinghouse.org.

- *Guide for the Analysis of Multimodal Corridor Access Management* (NCHRP 900):[36] provides information about the effects of selected access management strategies on pedestrian and bicyclist safety that is not available in the two resources above.
- Virginia DOT innovative intersections and interchanges website:[37] provides conflict diagrams for a variety of innovative intersection and interchange forms, along with comparisons with conventional forms.
- FHWA's Safe System Project-Based Alignment Framework: provides a systematic basis for assessing existing conditions and comparing proposed project alternatives through a Safe System lens by scoring crash exposure, likelihood, and severity. The tool identifies risk factors and infrastructure elements that affect safety at a location and provides strategies to improve Safe System approach alignment across all five SSA elements.
- FHWA's Safe System for Intersections (SSI) approach:[38] applies an SSI score ranging from 0 to 100 that incorporates an intersection's number and type of conflict points, conflict point exposure and severity, and movement complexity. The higher the SSI score, the lower the chance of fatalities and serious injuries for a given combination of intersection form and control.

Road User Operations

The following resources provide methods for estimating the effects of strategies on road user delay, speed, level of service (LOS), and travel time reliability:

- *Highway Capacity Manual*, 7th edition (HCM):[39] provides methods for estimating the effects of strategies on motorized vehicle (including buses and trucks) and pedestrian operations and, to a much lesser extent, bicycle operations. The manual also contains methods for estimating travel time reliability on urban streets.
- *Planning and Preliminary Engineering Applications Guide to the* Highway Capacity Manual (PPEAG):[40] provides simplified HCM-based methods to evaluate intersection operations along with a truck LOS method for estimating effects on freight movement. The PPEAG further contains planning-level methods to estimate travel time reliability.

---

36 M. Butorac, J. Bonneson, K. Connolly, P. Ryus, B. Schroeder, K. Williams, Z. Wang, S. Ozkul, and J. Gluck. 2018. *Guide for the Analysis of Multimodal Corridor Access Management.* NCHRP Report 900. Washington, DC: The National Academies Press.

37 Virginia DOT. n.d. "Virginia iCAP." (website). https://www.virginiadot.org/innovativeintersections/, accessed June 18, 2023.

38 R. J. Porter, M. Dunn, J. Soika, I. Huang, D. Coley, A. Gross, W. Kumfer, and S. Heiny. 2021. *A Safe-System Based Framework and Analytical Methodology for Assessing Intersections.* Report No. FHWA-SA-21-008. Washington, DC: Federal Highway Administration, Office of Safety. https://safety.fhwa.dot.gov/intersection/ssi/fhwasa21008.pdf.

39 TRB of the NASEM. 2022. *Highway Capacity Manual: A Guide for Multimodal Mobility Analysis,*7th edition. Washington, DC: The National Academies Press.

40 R. Dowling, P. Ryus, B. Schroeder, M. Kyte, and T. Creasey. 2016. *NCHRP Report 825: Planning and Preliminary Engineering Applications Guide to the* Highway Capacity Manual. Washington, DC: The National Academies Press.

- HCM Volume 4,[41] a free website, provides access to spreadsheet tools for estimating motor vehicle and bicycle delay at traffic signals and pedestrian delay at signalized and unsignalized crossings.
- *Traffic Calming ePrimer* (TCeP),[42] a resource that FHWA and ITE cosponsored, describes the observed speed-reduction effects of selected traffic calming strategies.
- Appendix C of *Improving Transportation Network Efficiency Through Implementation of Transit-Supportive Roadway Strategies* (TCRP WOD 66)[43] provides a method for estimating the effect of transit signal priority on side-street motorized vehicle delay (transit signal priority typically has no to a small beneficial effect on motorized vehicle delay for the street with transit service).
- *Performance-Based Management of Traffic Signals* (NCHRP 954)[44] describes automated traffic signal performance measures that can be used to evaluate the outcomes of strategies that affect traffic signal timing.
- FHWA's Tool for Operations Benefit Cost Analysis[45] provides order-of-magnitude estimates of the benefits and costs associated with a range of TSMO strategies.
- The second Strategic Highway Research Program (SHRP2) developed several analytic tools to analyze travel time reliability.

Bicyclist-Perceived Comfort and Safety

The following resources consider street characteristics such as separation from motor vehicles and traffic speeds, among other factors, in evaluating a street's suitability for bicyclists.

- Bicycle level of traffic stress (BLTS)[46,47]—a table-based expert system for estimating the suitability of streets for use by bicyclists of different levels of experience and confidence.
- Bicycle level of service (BLOS)—an analytical method presented in the HCM and PPEAG for estimating a typical bicyclist's rating of a street for bicycling, using a best-to-worst A–F scale.

---

41 TRB of the NASEM. n.d. "Volume 4: Applications Guide." In *Highway Capacity Manual,* 7th ed. https://www.hcmvolume4.org, accessed June 18, 2023.

42 FHWA. n.d. *Traffic Calming ePrimer*. https://highways.dot.gov/safety/speed-management/traffic-calming-eprimer, accessed June 18, 2023.

43 P. Ryus, K. Laustsen, K. Blume, K. Lee, S. Beaird, E. Lindstrom, J. Crisafi, Z. Bugg, A. Skabardonis, and S. Langdon. 2016. *Improving Transportation Network Efficiency Through Implementation of Transit-Supportive Roadway Strategies.* TCRP Web-Only Document 66. Washington, DC: The National Academies Press.

44 B. Nevers, T. Urbanik, K. Lee, B. Cesme, J. Musselman, L. Zhao, D. Bullock, H. Li, A. Tanaka, C. Day, and L. Richardson. 2020. *Performance-Based Management of Traffic Signals.* NCHRP Report 954. Washington, DC: The National Academies Press.

45 FHWA. n.d. "Tool for Operations Benefit Cost Analysis (TOPS-BC)" (website). https://ops.fhwa.dot.gov/plan4ops/topsbctool/, accessed November 30, 2023.

46 M. C. Mekuria, P. G. Furth, and H. Nixon. 2012. *Low-Stress Bicycling and Network Connectivity.* MTI Report 11-19. San Jose, CA: Mineta Transportation Institute.

47 Updates to the original BLTS criteria at https://peterfurth.sites.northeastern.edu/level-of-traffic-stress/.

Pedestrian-Perceived Comfort and Safety

Similar to the resources for estimating bicyclist-perceived comfort and safety, the following resources consider separation from traffic, traffic speeds, and other factors in evaluating a street's suitability for pedestrians:

- Pedestrian level of service (PLOS)—an analytical method presented in the HCM and PPEAG for estimating a typical pedestrian's rating of a street for walking, using a best-to-worst A–F scale.
- Pedestrian level of traffic stress (PLTS)—although researchers proposed pedestrian counterparts to BLTS, use is not widespread. An example is the PLTS method that the Oregon DOT developed.[48]

Transit Operations

The following resources can be used to evaluate the effects of selected transit-focused strategies on bus speed and delay:

- *Transit Capacity and Quality of Service Manual*, 3rd edition (TCQSM)[49]—provides methods to estimate bus lane effects on bus speeds, estimate bus delay incurred when reentering traffic from a bus stop, and estimate LOS for transit passengers. The TCQSM includes a discussion and metrics for travel time reliability of transit trips.
- *A Guidebook on Transit-Supportive Roadway Strategies* (TCRP 183)[50]—describes the effects of selected transit-focused strategies on bus speed and delay.

Network Connectivity

The following resources provide guidance on measuring how well a broader network of modal facilities serves mobility and accessibility needs.

- FHWA's *Guidebook for Measuring Multimodal Network Connectivity* (GMMNC)[51] —provides guidance on measuring pedestrian and bicycle network connectivity.

---

48 Oregon Department of Transportation. 2020. "Chapter 14 - Multimodal Analysis." In *Analysis Procedures Manual*, Version 2. Salem, OR.

49 Kittelson & Associates, Inc.; Parsons Brinckerhoff; KFH Group, Inc.; Texas A&M Transportation Institute; and Arup. 2013. *Transit Capacity and Quality of Service Manual,* 3rd edition. TCRP Report 165. Washington, DC: The National Academies Press.

50 P. Ryus, K. Laustsen, K. Blume, S. Beaird, and S. Langdon. 2016. *A Guidebook on Transit-Supportive Roadway Strategies.* TCRP Report 183. Washington, DC: The National Academies Press.

51 H. Twaddell, E. Rose, J. Broach, J. Dill, K. Clifton, C. Lust, K. Voros, H. Louch, and E. David. 2018. *Guidebook for Measuring Multimodal Network Connectivity.* Report No. FHWA-HEP-18-032. Washington, DC: FHWA.

- *Guide to Pedestrian Analysis* (NCHRP Research Report 992)[52] —combines network connectivity principles from the FHWA guidebook with pedestrian-perceived comfort and safety measures to measure connectivity; the same approach could also be applied to bicyclist connectivity. The report also summarizes common pedestrian safety and operations measures.

3.3. Performance Measures

Table 3 suggests performance measures that can support a Complete Streets effort to forecast or evaluate the effect of a project on road user safety, road user operations, bicyclist comfort and safety, pedestrian comfort and safety, transit operations, and network connectivity. The table lists resources for each measure that provide details about measure definitions, data needs, calculation methods, and potential calculation tools.

The process to apply these measures is as follows:

1. Based upon the Complete Streets project's identified goals and objectives, develop a set of potential strategies appropriate for the roadway's context and functional classifications.
2. Use table 3 to identify safety and operations performance measures for each road-user type (e.g., automobiles, freight, pedestrians, bicyclists). Performance measures may not be available for each road-user type due to a lack of research or because a given strategy would not be expected to affect that road-user type.
3. Refer to the resources associated with the selected performance measures to identify data needs and details on how to forecast or field-measure these performance measures. If the resources (e.g., data, software tools) needed to evaluate a particular measure are lacking, select an alternative measure, which could involve using a proxy measure.
4. Estimate the change in operations and safety due to the proposed strategies and compare with project goals.
5. Adjust the strategies if the goals are unmet and repeat the evaluation.

Table 3. Complete Streets performance measures and associated resources.

CATEGORY	APPLICATION	PERFORMANCE MEASURES	RESOURCES
Road user safety	Predictive	Severity and number of crashes Systemic safety	HSM, CMFC SSA tools
	Proxy	Number of conflict points Motorist yielding rate BLTS, PLTS BLOS, PLOS Pedestrian exposure Near-miss data (conflicts)	SSA, Virginia DOT HCM BLTS, Oregon DOT HCM/PPEAG NCHRP 992 MTES*

52 P. Ryus, A. Musunuru, J. Bonneson, S. Kothuri, C. Monsere, N. McNeil, S. LaJeunesse, K. Nordback, W. Kumfer, and S. Currin. 2022. *Guide to Pedestrian Analysis.* NCHRP Report 992. Washington, DC: The National Academies Press.

Table 3. Complete Streets performance measures and associated resources. (continued)

CATEGORY	APPLICATION	PERFORMANCE MEASURES	RESOURCES
Road user safety	Measurement	RSAs Percentage of vehicles stopping	RSA guidelines NCHRP 954
Road user operations	Predictive	Person throughput, pedestrian space Vehicle delay and speed Volume-to-capacity ratio Planning time index, buffer time Bicycle delay, bicycle travel speed Pedestrian crossing delay Truck LOS	HCM/PPEAG HCM/PPEAG, TCeP HCM/PPEAG HCM HCM HCM/NCHRP 992 PPEAG
	Measurement	Person throughput, parking occupancy and turnover, double-parking activity, percentile speeds Purdue Coordination Diagram Pedestrian/bicycle signal metrics	MTES MTES MTES NCHRP 954 NCHRP 969
Bicyclist comfort and safety	Predictive	BLTS, BLOS	BLTS, HCM, PPEAG
	Measurement	Parking occupancy and turnover Traffic volume and travel speed	MTES MTES
Pedestrian comfort and safety	Predictive	PLOS, PLTS Pedestrian crashes	HCM, Oregon DOT PBCAT
Transit operations	Predictive	Bus speed and reentry delay TLOS	TCQSM, TCRP 183 TCQSM/HCM/PPEAG
	Measurement	Ontime performance Headway adherence	TCQSM TCQSM
Network connectivity	Predictive	Network density and completeness Route directness, access to destinations, network quality Intersection spacing, block size	GMMNC, NCHRP 992 GMMNC, NCHRP 992 GMMNC, NCHRP 992 GMMNC

BLOS = bicycle LOS; BLTS = bicycle level of traffic stress; CMFC = Crash Modification Factor Clearinghouse; DOT = department of transportation; GMMNC = *Guidebook for Measuring Multimodal Network Connectivity*; HCM = *Highway Capacity Manual*; HSM = *Highway Safety Manual*; LOS = level of service; MTES = *Manual of Traffic Engineering Studies*; NCHRP = National Cooperative Highway Research Program; PBCAT = Pedestrian and Bicycle Crash Analysis Tool; PLOS = pedestrian LOS; PLTS = pedestrian level of traffic stress; PPEAG = *Planning and Preliminary Engineering Applications Guide*; RSA = road safety audit; SSA = Safe System Approach; TLOS = transit LOS; TCeP = Traffic Calming ePrimer; TCQSM = *Transit Capacity and Quality of Service Manual*, TCRP = Transit Cooperative Research Program.

*Institute of Transportation Engineers (ITE). 2010. *Manual of Traffic Engineering Studies*. Washington, DC.

3.4. Evaluating Operations in a 24-Hour Framework

The all-day operations evaluation method from NCHRP Report 1036 offers a holistic perspective on corridor delay and travel time, enabling practitioners to accurately communicate the costs and benefits of different approaches to decisionmakers, stakeholders, and community groups.

As discussed in section 1.3, a common challenge to implementing operations in Complete Streets has been the reliance on autofocused traffic operations standards. These standards typically define the maximum motor vehicle delay, travel time, or volume-to-capacity ratio during the peak 15 minutes of the peak hour. As a result, roadways are often overbuilt to accommodate one set of road users (motorists) during a relatively short time period, to the detriment of other users. NCHRP Report 1036 presents a 24-hour decisionmaking framework for understanding the relationship between roadway design changes and motor vehicle operations by time of day.[53] The framework adapts existing operations screening tools to account for time-of-day effects. The framework's holistic perspective on corridor delay and travel time helps practitioners better evaluate and communicate the costs and benefits of different design approaches to decisionmakers, stakeholders, and community groups. The all-day operations framework builds on the planning-level daily service volume tables presented in section G of NCHRP Report 825, *Planning and Preliminary Engineering Applications Guide to the* Highway Capacity Manual.[54] The guide estimates hourly directional roadway volumes using either a user-defined or a default hourly demand profile. Based on the number of through lanes and traffic control at the critical intersection, the framework assesses 24-hour operations using four performance measures:

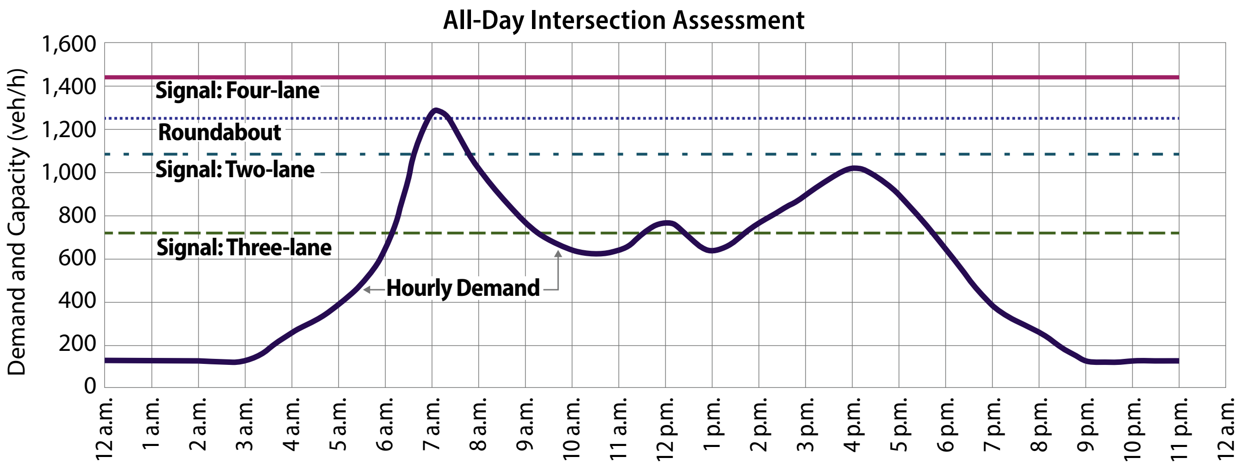
1. **Hourly demand-to-capacity (d/c) ratio** allows practitioners to assess whether demand exceeds capacity during any hour of the day and, if so, for how many hours. The highest d/c ratio should also be noted as the period that may result in the maximum delay. A max d/c of slightly above 1.0 may be acceptable (especially if based on a multiyear forecast and if only occurring for short duration), while very high d/c ratios well in excess of 1.0 are likely to result in significant delays.
2. **Sixteen-hour efficiency** calculates the percentage of hours between 5 a.m. and 9 p.m. during which the street uses at least 60 percent of its potential capacity. This metric excludes the remaining 8 overnight hours of the day, during which a roadway is unlikely to approach capacity. An efficiency score of 100 percent indicates that at least 60 percent of the roadway's capacity is used during every hour of the analysis range, while 75 percent would indicate that the roadway's capacity is well-used for at least 12 hours of the day.
3. **Sixteen-hour excess capacity** measures the roadway capacity provided that goes unused during the day by measuring units of lane-hours of capacity. A value of 16 indicates that the capacity provided by one through lane goes unused throughout the entire 16-hour analysis range, while a value of 0 indicates that all available lane capacity is being used to meet demand during the entire 16-hour analysis range.

53 C. Semler, M. Sanders, C. Dartnell, M. Alston, S. Semensky, L. Ahramjian, K. Taylor, R. Sanders, M. Elbech, and Z. Vanderkooy. 2023. *Roadway Cross-Section Reallocation: A Guide*. NCHRP Research Report 1036. Washington, DC: The National Academies Press. https://doi.org/10.17226/26788, accessed October 26, 2023.

54 R. Dowling, et al. 2016. *Planning and Preliminary Engineering Applications Guide to the* Highway Capacity Manual. NCHRP Report 825. Washington, DC: The National Academies Press.

4. **Total hours below capacity** measures the number of hours (out of 24) during the day when the street operates below capacity.

Figure 10 and table 4 provide an example of applying the 24-hour evaluation framework to different scenarios representing combinations of roadway cross section and intersection control types. The figure compares hourly demand with the planning-level hourly capacity provided by each scenario. The comparison shows that the capacity of a signalized intersection on a four-lane roadway exceeds demand throughout the day. A single-lane roundabout's capacity could be sufficient to meet demand during all but the peak 15 minutes of a day, while a traffic signal on a 3-lane roadway would meet demand during all but 1 hour of the day. In contrast, a traffic signal on a two-lane roadway would provide insufficient capacity during many hours of the day. Table 4 presents more detail for the situation depicted in figure 10, using the 4 metrics presented above. The analysis should use a representative analysis period that represents typical performance on the corridor. The analysis may include both existing and future-year scenarios consistent with a more traditional traffic study and local practices. The need for separate AM and PM peak hour analysis goes away with a comprehensive look at the 24-hour performance. However, separate weekend or special event scenarios may be included based on local context. The results indicate that although the capacity provided by the scenario with a 4-lane cross section and a traffic signal meets demand throughout the day, it provides 1 lane's worth of extra capacity throughout nearly all of the 16-hour analysis range and is only 31 percent efficient. In contrast, both the 3-lane cross section with a traffic signal and a single-lane roundabout provide sufficient capacity to meet demand during all but 1 hour of the day, and both are 50 percent efficient. The 3-lane cross section with a traffic signal would result in roughly half the excess capacity of the 4-lane cross section, while a single-lane roundabout would result in nearly 60 percent less excess capacity.



Source: © 2023 The National Academies of Sciences, Engineering, and Medicine.[55]

Figure 10. Graph. A 24-hour capacity framework illustrated for 4 intersection alternatives.

55 C. Semler, M. Sanders, C. Dartnell, M. Alston, S. Semensky, L. Ahramjian, K. Taylor, R. Sanders, M. Elbech, and Z. Vanderkooy. 2023. *Roadway Cross-Section Reallocation: A Guide.* Washington, DC: The National Academies Press. NCHRP Research Report 1036. https://doi.org/10.17226/26788, accessed October 26, 2023.

Table 4. The 24-hour performance measures calculated for 4 intersection alternatives.

INTERSECTION CONTROL	MAXIMUM DEMAND-TO-CAPACITY RATIO	16-HOUR EFFICIENCY	16-HOUR EXCESS CAPACITY (LANE HOURS)	TOTAL HOURS BELOW CAPACITY PER DAY
Signal – Four-Lane	0.89	31.3%	15.9	24
Signal – Two-Lane	1.77	81.3%	2.2	16
Signal – Three-Lane	1.18	50.0%	8.2	23
Roundabout	1.02	50.0%	6.7	23

Source: © 2023 The National Academies of Sciences, Engineering, and Medicine.[56]

In a traditional traffic operations analysis, only the four-lane cross section with a traffic signal could be considered acceptable, because it is the only scenario where the maximum demandtocapacity ratio is less than one. However, the capacity this scenario would provide is not needed during most of the day, resulting in excess roadway width that potentially could be better used in other ways.

Under a 24-hour evaluation, both the 3-lane cross section with a traffic signal and a single-lane roundabout could also be considered as potential options. The potential disbenefit to motor vehicle traffic (including transit) during the peak hour (e.g., delay, queuing) could be balanced against the 24-hour safety and operations benefits (e.g., shorter crossing distances, ability to provide better facilities for other road users) provided by the other scenarios as part of developing a recommended roadway design.

Other performance measures, particularly corridor travel time or speed and intersection person delay, also lend themselves to a 24-hour evaluation framework. Vehicle probe data, for example, are a source of vehicle travel times throughout the day, particularly for the 16 highest volume hours of the day. Person delay can be used to illustrate that pedestrian and bicyclist demand often peak at different times of the day from motor vehicle traffic and that longer pedestrian crossing distances on wider streets, in particular, strongly affect pedestrian crossing delay at all times.

3.5. Illustrative Example

The Rainier Avenue corridor in Seattle, WA, illustrates certain aspects of the chapter 2 design model and chapter 3 performance measures.[57] Although the design model illustrated in figure 4 contains discrete steps, transportation agencies can implement these steps in a continuous, iterative process.

56 C. Semler, M. Sanders, C. Dartnell, M. Alston, S. Semensky, L. Ahramjian, K. Taylor, R. Sanders, M. Elbech, and Z. Vanderkooy. 2023. *Roadway Cross-Section Reallocation: A Guide*. Washington, DC: The National Academies Press. NCHRP Research Report 1036. https://doi.org/10.17226/26788, accessed October 26, 2023.

57 Seattle Department of Transportation. 2017. *Rainier Avenue South Safety Corridor – Rainier Pilot Project Evaluation: S Alaska Street to S Kenny Street*.

Set Speeds Appropriate for Context and Users

Rainier Avenue is a principal arterial street connecting businesses, schools, and communities in southeast Seattle to the city center. The street also has some of the highest bus ridership in Seattle. The corridor's users thus include high volumes of buses, pedestrians, and passenger cars. Seattle DOT's speed studies showed up to 2,000 vehicles per day traveling over 40 mph despite a posted speed limit of 30 mph, while the agency's review of available research studies showed that pedestrians hit at 40 mph have a 10-percent chance of surviving. The corridor also led the city in crashes. Given the context and blend of users, the agency reduced speed limits from 30 mph to 25 mph. Beforeafter analysis showed that 50th percentile speeds, speed limit violators, and travel above 40 mph decreased by up to 16 percent, 52 percent, and 80 percent respectively. In a continuous, iterative process, the agency potentially could reevaluate its target speeds during the connectivity step.

Separate Users in Time and Space

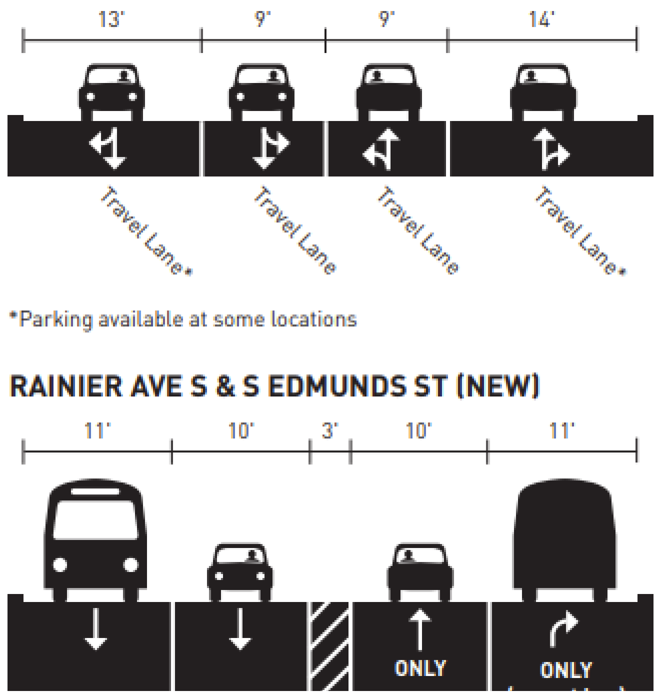
Spatial separation of road users included adding bus lanes and a center turn lane to a portion of the corridor. This design reduced the number of general travel lanes to 1 in each direction (figure 11). Adding LPIs to traffic signal timing plans achieved, in part, temporal separation of road users, helping improve crossing safety.

Improve Connectivity and Access for All Modes

Considering connectivity and access (from the chapter 2 design model) presents an opportunity to leverage performance measurement ideas and concepts. In the case of Rainier Avenue, better connectivity and access for transit was a key driver for the project. For example, Seattle DOT could periodically reassess which sections of Rainier Avenue could be top priorities for improved transit capabilities to serve the broader area. Next, the agency could select analysis methods (e.g., TCQSM, GMMNC) and performance measures (e.g., bus headway adherence, multimodal LOS) to scan for deficiencies along those sections. Finally, if the analysis methods and performance measures identified significant deficiencies, the agency could pursue solutions during the next step.

Implement Safety and Operations Countermeasures

At the time of writing this document, Seattle DOT had already installed bulb-outs and exclusive bus lanes along portions of Rainier Avenue. Bulb-outs are a safety countermeasure to reduce vehicle speed and shorten pedestrian crossing distances, while exclusive bus lanes enhance operations for transit vehicles. For future consideration, other transit-oriented solutions could include ADA improvements at transit stops, queue jump lanes, TSP, real-time bus arrival displays, reduced cycle lengths, and signal timing optimization based on multimodal objective functions. These strategies would not preclude other pedestrian-oriented solutions (e.g., midblock RRFBs, reduced VRU conflict points) or automobile-oriented solutions (e.g., improved traffic signal timing coordination for all vehicles) that would not necessarily degrade bus riders' experience.



Source: © 2017 Seattle Department of Transportation.

Note: Rainier Avenue and South Edmunds Street is an example intersection. The project consisted of several different lane configurations along the 8-mile corridor with a 45footwide cross section in before and after conditions.

Figure 11. Illustration. Lane configurations before and after Rainier Avenue pilot project.

Recognize Opportunities To Integrate Operations

Intraagency, interagency, and public collaboration can facilitate the success of Complete Streets efforts. The Rainier Avenue South Pilot Project in 2015 exemplified this. The Rainier Avenue corridor spans several neighborhoods and affects several agencies. This situation motivated the Seattle DOT to perform public outreach to all stakeholders while pursuing a multifaceted plan to reduce collisions. Moreover, the integrated operations and safety objectives benefited from collaboration between employees within the same agency. Going forward, the Seattle DOT and its peer agencies can consider operations technologies and strategies that offer both operations and safety benefits. Applying the Complete Streets design model offers opportunities to leverage operations strategies such as transit signal priority, signal improvements, and other ITS strategies to enhance operations on the corridor.

4 STRATEGIES FOR OPERATIONS IN COMPLETE STREETS

4.1. Operations Strategies to Achieve Complete Streets Objectives

This chapter highlights selected operations strategies that can support Complete Streets projects and summarizes their potential operations and safety benefits. These strategies include the following:

- Curbside management.
- Access management.
- Roundabouts.
- Road diets.
- Bicycle-focused intersection improvements.
- Pedestrian crossing improvements.
- Speed management strategies.
- Time-of-day turn restrictions.
- Signal retiming—shortening cycle lengths.
- Enhanced real-time data and travel information.
- Traffic calming—vertical deflection measures.

It is not possible in this introductory primer to identify all the possible strategies or situations where a given strategy may or may not be appropriate. Therefore, this chapter also provides an extensive list of references that provide more information about implementing operations strategies and assessing their potential safety and mobility benefits. This chapter also discusses the need to consider whether a particular strategy is appropriate to implement immediately or whether other strategies may need to be implemented first to see if their effects address concerns or to prepare for better implementation (e.g., lower operating speeds to an appropriate level for implementing the strategy). Finally, the chapter briefly discusses references and tools for conducting speed studies and setting speed limits.

4.2. Selected Strategies to Support Operations in Complete Streets

Curbside Management

Curbside management (figure 12) is a data-driven approach to evaluating and allocating curb space to increase the curb's functionality and improve safety and access for all users. Dynamic curbside management leverages technology to adjust curb uses based on real-time demands and agency priorities. Both forms of curbside management can align how the curb is organized with its uses over time by different modes. Data can be collected via manual field observation, video, citation data, or data on parking usage patterns. The data inform a flexible allocation and regulation of the curb to meet evolving demands over the course of a day. For example, a portion of the curb may be dedicated to only freight loading/unloading in the early mornings, restricted to no parking during peak hours, passenger loading in evenings, and longterm parking overnight. Curbside management provides operations efficiency and safety when needed, while allowing access and other uses of the curb outside of peak vehicle travel demands.

Source: © 2024 Kittelson and Associates, Inc.

Figure 12. Photo. Example of curbside management applied in Washington, DC, to manage curb space for parking, micromobility, and other uses.

Use Curbside Management To…

Agencies can use curbside management to do the following:

- Manage use of the curb to streamline corridor operations by dedicating specific sections for parking, freight deliveries, dropoffs, etc.
- Reduce conflicts and congestion from double-parked vehicles blocking vehicle travel lanes, bike lanes, or crosswalks during deliveries or pickup/dropoff.
- Reallocate space for non-single-occupancy automobile modes (e.g., dedicated transitonly lanes, transit shelters and boarding locations, separated bike lanes, loading zones, transportation network company pickup/dropoff).
- Restrict parking and other uses during peak vehicle travel demand periods to gain additional capacity.

Strategy in Action

The Washington DC, Department of Transportation (DDOT) piloted demand-based parking pricing for onstreet spaces by block, side of street, day of the week, and time of day. Using funding from the FHWA Value Pricing Pilot Program, DDOT planned and implemented a demand-based parkingpricing pilot program in the Penn Quarter and Chinatown neighborhoods. Dynamic pricing for onstreet parking during the pilot program reduced cruising by 15 percent and time to find parking by 7 minutes.[58]

Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Vehicle parking turnover rate and occupancy.
- Loading area turnover rate and occupancy.
- Double-parking activity rate.
- Bicyclist and pedestrian perceived comfort (level of traffic stress).

Access Management

Access management (figure 13) in the context of Complete Streets refers to balancing the safety and mobility of users accessing the roadway and adjacent land uses. Adjacent uses may include intersections with other roadways or driveways serving destinations along the roadway.

The location, frequency, and design of access points affects all users' safety and operations in unique ways. Effective access management can improve safety and mobility for all users and provide access to nearby destinations. One access management strategy is to reduce the frequency and width of driveway access through closure, narrowing, consolidation, or relocation. The design of driveway access points can also include raised islands to delineate a clear path for left- and right-turning vehicles and may include signalization to balance demand. Driveway modification can also correct adverse cross slopes and reduce overly wide or continuous driveways to improve ADA access or reduce potential conflicts for pedestrians crossing the driveway.

---

58 District Department of Transportation. 2019. *Penn Quarter/Chinatown Parking Pricing Pilot.* Final report. Washington, DC.

Source: © 2024 Kittelson and Associates, Inc.

Figure 13. Photo. Example of access management treatments as part of a road diet project that reduces friction and enhances travel and reliability of traffic.

Use Access Management To…

Agencies can use access management to do the following:

- Improve travel time reliability.
- Reduce turning conflicts with vehicles, pedestrians, and bicyclists.
- Reduce disruption to traffic flow from frequently entering/exiting traffic.
- Give road users more predictable and easily identifiable entry and exit points.
- Reduce density through driveway closure, consolidation, or relocation.
- Manage spacing of intersection and access points.
- Limit allowable movements at driveways (such as right-in/right-out only).
- Place driveways on an intersection approach corner rather than a receiving corner, which could be expected to have fewer total crashes.
- Implement raised medians that preclude across-roadway movements.
- Use designs such as roundabouts or reduced left-turn conflicts (such as restricted crossing U-turn, median U-turns, etc.).
- Provide turn lanes (i.e., left-only, right-only, or interior two-way left).
- Use lower speed one-way or two-way off-arterial circulation roads.

Strategy in Action

NCHRP Research Report 1032 provides information on how to measure and communicate the value of access management with respect to safety, mobility, the economy, and livability. As driveway density increases, crash rates increase.[59] In urban areas, the crash rate for a roadway with 60 or more access points per mile was 4.1 times as high as the crash rate for a roadway with 10 access points.

Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Perceived comfort of drivers, bicyclists, and pedestrians.
- Speed differential.
- Crashes.
- Truck LOS (truck speeds are affected more than automobile speeds by turning traffic due to trucks' slower acceleration).
- Bus speeds (bus speeds are affected more than automobile speeds by turning traffic due to buses' slower acceleration).

Roundabouts

A roundabout (figure 14) is an intersection with a circular configuration that safely and efficiently moves traffic. Roundabouts feature channelized, curved approaches that reduce vehicle speed, entry yield control that gives right-of-way to circulating traffic, and counterclockwise flow around a central island that minimizes conflict points. Lower speeds reduce fatal and serious injury crashes relative to two-way stop-controlled and signalized intersections.[60] Roundabouts, particularly single-lane designs, have proven safety benefits for motorized vehicles due to their use of low-speed design features and effective management of conflicts, which are principles of a safe system. Multilane roundabouts, however, can pose safety and accessibility challenges for pedestrians and bicyclists if improperly designed. Following a performance-based design process, as described in FHWA's *Roundabouts: An Informational Guide*, is important to control vehicle speeds and ensure that proper sight distances are provided. Higher speed, multilane roundabout design should consider the use of pedestrian hybrid beacons, RRFBs, or raised crosswalks to enhance pedestrian safety and provide an accessible crossing environment for people who are blind or have vision impairments.

---

59 NASEM; Center for Urban Transportation Research; Texas A&M Transportation Institute; AECOM; and Teach America Corporation. 2023. *How to Measure and Communicate the Value of Access Management*. NCHRP Research Report 1032. Washington, DC: National Academies Press.

60 FHWA. 2021. *Proven Safety Countermeasures: Roundabouts*. Publication FHWA-SA-21-042. Washington, DC: FHWA.

Source: © 2024 Kittelson and Associates, Inc.

Figure 14. Photo. Example of a modern roundabout in Bend, OR, that provides safe and efficient operations for all users, including people walking and bicycling.

Use Roundabouts To…

Agencies can use roundabouts to do the following:

- Enhance operational efficiency throughout many hours of the day.
- Provide effective and safe U-turn opportunities on corridors with access management treatments.
- Reduce motor vehicle crashes compared with two-way stop-controlled or signalized intersections.
- Promote lower speeds and traffic calming.
- Improve travel time reliability.

Strategy in Action

Roundabouts are recognized as one of FHWA's proven safety countermeasures,[61] combining both safety performance and efficiency in this low-speed intersection treatment. Converting a two-way stop-controlled intersection or a signalized intersection to a single-lane roundabout can result in a reduction in fatal and injury crashes by 82 percent and 78 percent, respectively. Modern roundabouts can readily adapt to changing traffic demands by time of day and have both traffic-calming and aesthetic-landscaping benefits in a Complete Streets application.

61 https://highways.dot.gov/sites/fhwa.dot.gov/files/Roundabouts_508.pdf, accessed May 21, 2024.

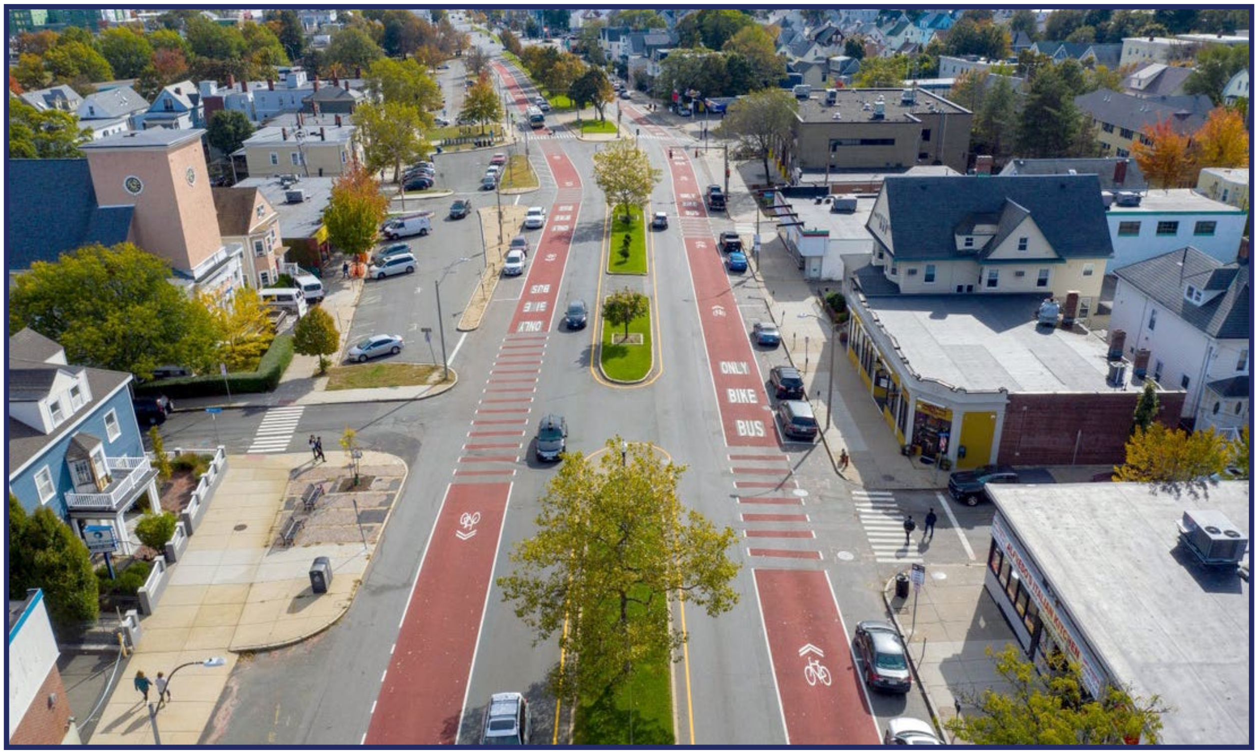
Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Crashes.
- Vehicle speeds.
- Perceived comfort of drivers, bicyclists, and pedestrians.
- Delay and queue length.

Road Diets (Roadway Reconfiguration)

A road diet (figure 15) reduces the number of travel lanes and reallocates the space for other uses, such as bike lanes, pedestrian refuge islands, and transit uses. A road diet often involves converting an existing four-lane undivided roadway to a three-lane roadway consisting of two through lanes and a center TWLTL. Other reallocation projects include five-lane to four-lane conversions. A road diet can be a low-cost safety solution when planned in conjunction with a pavement overlay, and the reconfiguration can be accomplished at little to no additional cost.



Source: © 2024 Kittelson and Associates, Inc.

Figure 15. Photo. Example of a roadway reconfiguration in Somerville, MA, that reallocates space to transit and bicycle users.

Use Road Diets To…

Agencies can use road diets to do the following:

- Improve operations for nonmotorized modes through the Complete Streets corridor.
- Reduce crash severity through reduced vehicle speeds.
- Improve pedestrian and bicyclist safety by reducing crossing distance.
- Reduce vehicle speeds.
- Implement pedestrian islands, bicycle lanes, onstreet parking, or transit stops.
- Better integrate the needs of all road users in the street design.

Strategy in Action

Soapstone Road (Reston, VA) converted from two travel lanes in each direction to one travel and one bike lane with a center TWLTL. In addition to a dedicated space for bicyclists, the road diet provides more separation between vehicles and pedestrians along Soapstone Road.

Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Vehicle and VRU crashes.
- Vehicle speeds.
- Perceived comfort of drivers, bicyclists, and pedestrians.
- Bicyclist and pedestrian volumes.

Bicycle-Focused Intersection Improvements

Bicycle-focused intersection improvements (figure 16), such as bike boxes and LBIs, can be implemented to expand protected bikeway networks and to improve bicyclist safety. A bike box is a dedicated area in front of the stop bar at a signalized intersection that provides bicyclists with a queuing area during the red signal phase. LBI is a signal-timing treatment that allows bicyclists to move through the intersection before turning vehicles. Other intersection treatments include signage and colored pavement markings to distinguish space allocated to bicyclists.

Bicycle detection at traffic signals can improve safety for bicyclists and reduce delays experienced by bicyclists.[62] Bicycle detectors can extend green times at traffic signals to ensure that bicyclists have enough time to get through the intersection. At intersections where the traffic signal is resting in green on the major street, bicycle detectors can place calls for service like a pedestrian pushbutton. It is also possible to design arterial signal timings to specifically achieve a smooth progression of bicycle platoons through multiple intersections without stopping.

62 https://nacto.org/publication/urban-bikeway-design-guide/bicycle-signals/signal-detection-and-actuation/, accessed May 26, 2024.

Source: © 2024 Kittelson and Associates, Inc.

Figure 16. Photo. Example of bicycle-focused intersection improvements in San Diego, CA, with two-stage left-turn boxes providing safe and efficient left-turn opportunities for bicyclists.

Use Bicycle-Focused Intersection Improvements To…

Agencies can use bicycle-focused intersection improvements to do the following:

- Manage bicycle flow through intersections and reduce conflicts with motorized vehicles.
- Improve bicyclist safety and reduce delays experienced by bicyclists.
- Reduce vehicle speeds and minimize potential conflicts with vehicles.
- Provide clear movements for bicyclists through intersections.

Strategy in Action

Boulder, CO, improved walking and biking conditions on 17th Street by strategically pairing the installation of striping and pavement markings with annual street resurfacing. Bike boxes added during the installation facilitated bikes making left turns without having to leave the bike lane. The bike boxes also helped to reduce the level of traffic stress on 17th Street. As part of Boulder's Low-Stress Bike Network Plan, 17th Street was identified for improvements.[63]

63 City of Boulder. 2024. "A 'New-to-Boulder' Bike Facility for Low-Stress Left Turns" (website). https://bouldercolorado.gov/news/new-boulder-bike-facility-low-stress-left-turns, accessed December 8, 2023.

Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Vehicle and VRU crashes.
- Vehicle speeds.
- Bicyclist volumes and perceived comfort.

Pedestrian Crossing Improvements

Pedestrian crossing improvements (figure 17) at intersections or midblock locations can improve the safety and visibility of pedestrians plus overall operations of the crossing location.

Source: © 2024 Kittelson and Associates, Inc.

Figure 17. Photo. Example of pedestrian crossing improvements with a rectangular rapidflashing beacons installed at a crossing, along with a pedestrian refuge island.

Crosswalk improvements, such as raised crosswalks or high-visibility markings, help to slow vehicles and increase the visibility of people crossing the street. LPIs at signalized intersections give people walking a headstart on entering the crosswalk before vehicles receive a green light, which increases turning motorists' awareness of pedestrians. RRFBs or pedestrian hybrid beacons at midblock locations can be used to indicate the presence of a person in the crosswalk and improve driver yielding behavior. Reducing crossing distances improves safety and convenience for people walking and can be implemented through refuge islands and curb extensions (bulb-outs).

Use Pedestrian Intersection Improvements To…

Agencies can use pedestrian intersection improvements to do the following:

- Improve safety, comfort, and convenience for people walking.
- Reduce vehicle speeds and improve driver yielding, thus reducing potential pedestrian conflicts with vehicles.
- Improve the visibility of people crossing roadways.

Strategy in Action

The Seattle DOT developed an engineering toolkit for its Safe Routes to School program. The toolkit described strategies used to make streets safer and more comfortable for children walking and biking to school, such as crossing islands, curb extensions, marked crosswalks, and beacons. According to the city's 2021–2025 action plan, Seattle is implementing 9–12 pedestrian-focused projects per year.[64]

Recommended Performance Measures

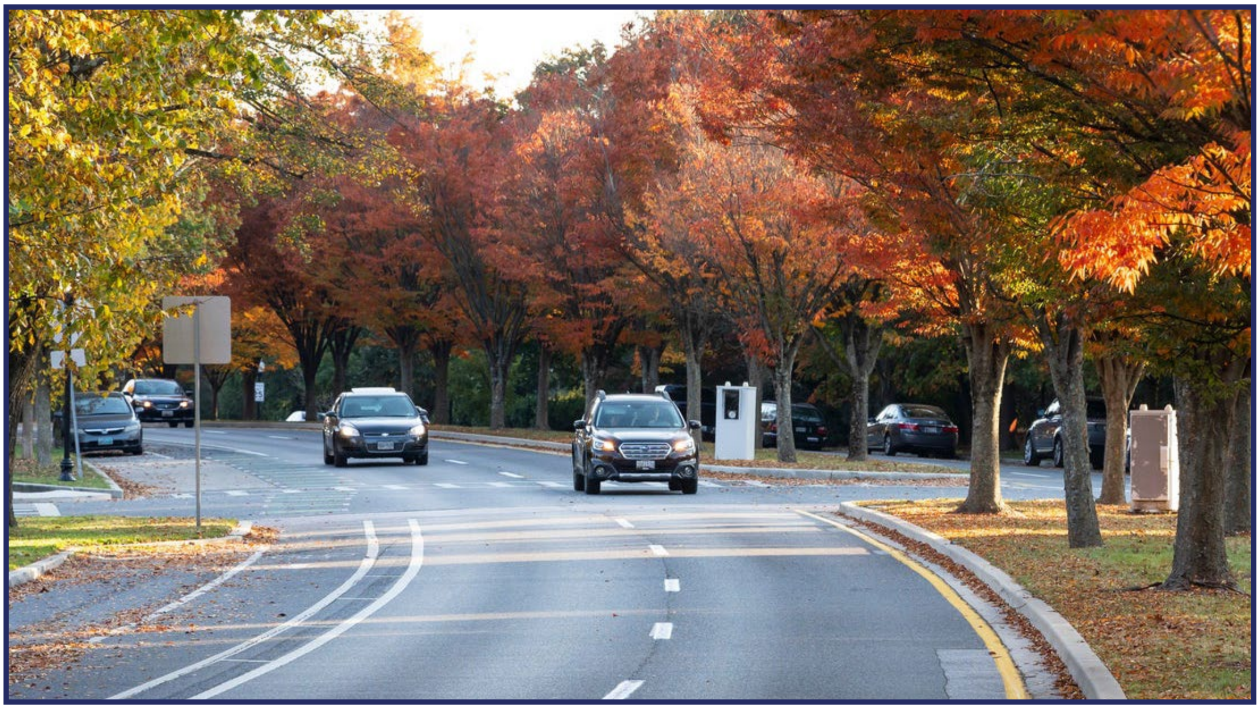
The following performance measures can help to assess the benefits of this strategy:

- Vehicle and VRU crashes.
- Vehicle speeds.
- Perceived comfort of drivers and pedestrians.
- Pedestrian volumes.
- Pedestrian level of service and level of traffic stress.
- Crossing distances.

Speed Management

Speed management strategies (figure 18) include driver awareness, enforcing existing laws, and issuing penalties for drivers exceeding the speed limit to deter risky behavior. An example of bringing awareness to a high pedestrian area or a time-of-day altered speed is flashers and signing in school zones. Other areas of high pedestrian presence may use speed monitoring displays to provide real-time feedback to drivers on their current speed and may flash if the observed speed is higher than the posted speed limit, drawing the attention of drivers to their speeds and encouraging them to slow down. Variable speed limits may be adjusted based on current weather conditions, traffic congestion, or other conditions to optimize traffic flow and slow traffic as it approaches congestion ahead to avoid stop-and-go or hard-braking events.

64 Seattle DOT. 2021. *Safe Routes to Schools 5 Year Action Plan 2021–2025.* Seattle, WA: Seattle DOT.



Source: © 2024 Kittelson and Associates, Inc.

Figure 18. Photo. Example of speed management using an automated speed enforcement camera system to encourage safe speeds for all users.

Use Speed Management To…

Agencies can use speed management to do the following:

- Enhance travel time reliability by managing speeds through a corridor.
- Reduce vehicle speeds.
- Reduce the number and severity of crashes that can disrupt operations.

Strategy in Action

The New Mexico DOT and FHWA awarded a grant to the Pueblo of Jemez to mitigate speeding along New Mexico State Route 4 (NM 4) by installing traffic-calming measures. The trafficcalming measures included gateway treatment signs at each entrance to the Pueblo of Jemez on NM 4 and a solar-powered speed display/radar feedback sign on each direction of NM 4 through the pueblo.[65] A 2016 FHWA study found a reduction in roadway departures on twolane rural curves that have high crash histories after installation of speed feedback signs.[66]

65 Pueblo of Jemez. 2020. "Planning, Development and Transportation Department Project Updates." *The Walatowan*.

66 A. Zineddin, S. Hallmark, O. Smadi, and N. Hawkins. 2016. "Spotlighting Speed Feedback Signs." *Public Roads,* Vol. 79, No. 5, March/April 2016.

Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Change in vehicle and VRU crashes.
- Change in vehicle speeds.

Time-of-Day Turn Restrictions

Time-of-day turn restrictions (figure 19) prohibit specific turning movements when necessary, such as during specific times of day (e.g., rush hour, school dismissal) or under specific traffic conditions. Restrictions could include prohibiting left turns to prevent congestion, prohibiting Uturns, or limiting right turns to a green arrow phase to eliminate conflicts with left-turning vehicles. Signs, signals, or both indicate restrictions. Restricting turning movements during periods of peak vehicle volume can simplify the signal phasing. The added efficiency from not providing a left-turn phase may provide sufficient through capacity to avoid a need to widen the intersection. Alternatively, space needed for a turn lane could provide space for protected bike lanes or other strategies that enhance the operations and safety of all users. Time-of-day restrictions also reduce the number of conflict points between vehicles and pedestrians.

Source: © 2024 Kittelson and Associates, Inc.

Figure 19. Photo. Example of time-of-day turn restrictions in Washington, DC.

Use Time-of-Day Turn Restrictions To…

Agencies can use time-of-day turn restrictions to do the following:

- Improve travel time reliability for peak periods.
- Avoid widening for periods where added capacity is not needed.
- Reduce conflicts and crashes during peak hours to minimize disruptions.
- Improve traffic flow for primary movements during peak periods.
- Maintain full access of movements during nonpeak periods.

Strategy in Action

To enhance vehicle operations during peak travel demand periods, DDOT uses time-of-day leftturn restrictions on key commuting corridors. According to title 18, D.C. Municipal Regulations, § 2204: "No person shall make a left turn so as to proceed in the direction indicated from 7:00 a.m. to 9:30 a.m., or from 4:00 p.m. to 6:30 p.m., except buses at any of the specific locations listed in this subsection." This restriction results in improved vehicle operations at these intersections during peak periods without the need for road widening or installing left-turn pockets.

Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Vehicle and VRU crashes.
- Vehicle delay.

Signal Retiming: Shortening Cycle Lengths

Shortening cycle lengths (figure 20) is an important Complete Streets strategy that not only improves multimodal access at intersections but also helps create a complete network. Shorter cycle lengths reduce pedestrian wait times, which can also encourage pedestrian activity in urban areas. Longer pedestrian wait times are recognized to lead to pedestrians increasing risk-taking behavior. Coordinated signal timing in conjunction with shorter cycle lengths can influence a corridor's progression speed. Care should be taken to not shorten cycle lengths too much so as to result in excessive queuing on the major roadway. Cycle lengths should also be sensitive to minimum pedestrian clearance times, so there is a balance between keeping cycle lengths short while providing for the necessary minimum phase times.

Use Shorter Cycle Lengths To…

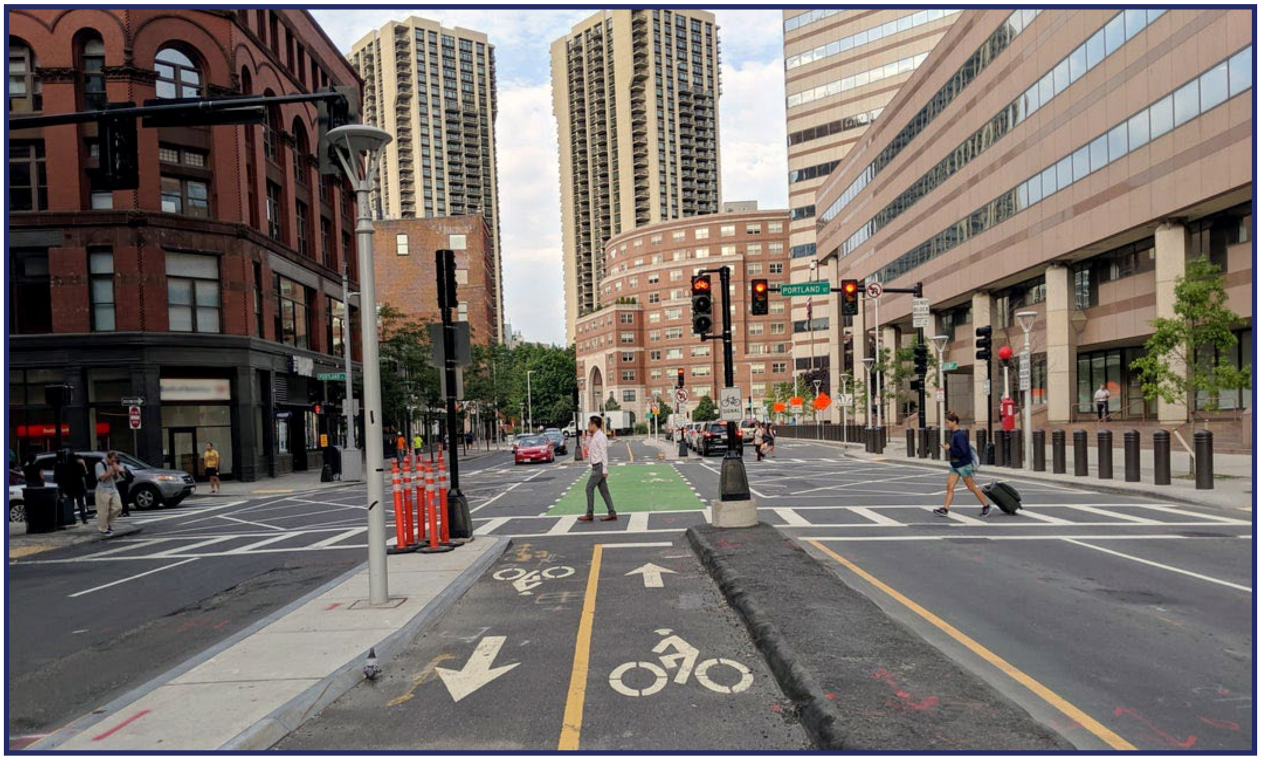
Agencies can use shorter cycle lengths to do the following:

- Improve operations for side-street vehicle movements through reduced wait times.
- Reduce pedestrian wait times to cross major streets.
- Add efficiency for bicycle movements through reduced wait times.

- Encourage pedestrian and bicyclist activity through more efficient phasing.
- Reduce vehicle speeds.

Strategy in Action

The City of Portland, OR, uses a signal progression speed of 13 mph in its dense, one-way downtown grid. This progression speed slows vehicles and provides speeds that cyclists can achieve. This strategy also generates "reverse progression" for pedestrians traveling at 4 mph opposite to the direction of vehicular traffic. The reverse progression means pedestrians do not have to stop at multiple signals in a row.[67]



Source: © 2024 Kittelson and Associates, Inc.

Figure 20. Photo. Shorter cycle lengths at signalized intersections can reduce wait times and enhance operational efficiency for all users.

Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Pedestrian and bicyclist wait times.
- Pedestrian and bicyclist volumes.
- Side street delays for motor vehicles.
- Vehicle speeds.

67 P. Koonce. 2011. "Transforming Traffic Signals to Support Sustainability: Applications, Ideas, & Research." Presentation. https://nacto.org/wp-content/uploads/2016/04/1-1_Koonce-Transforming-Traffic-Signals-to-Support-Sustainability_2011.pdf, accessed December 8, 2023.

Enhanced Real-Time Data and Travel Information

Enhancing an agency's ability to gather and apply real-time data can benefit agencies and travelers in many ways. Example applications include providing real-time traveler information, supporting multimodal trip planning, and identifying construction and work zone locations and road closures. An agency can also make agency-owned real-time data available via a centralized platform or to third-party application or data providers to support additional uses. Real-time data can help prioritize Complete Streets investments and efficiently manage supply and demand within the transportation system by optimizing service, routes, traffic signals, pricing, or scheduling, as needed.

Use Real-Time Data and Travel Information To…

Agencies can use real-time data and travel information to do the following:

- Improve travel time reliability.
- Reduce congestion.
- Improve interagency and intraagency coordination.

Strategy in Action

Integrated corridor management (ICM) is an approach to transportation management in which all existing modes and assets are managed holistically to mitigate the effects of atypical events, reduce congestion, and give travelers alternative transportation options—even during a trip—in response to changing traffic conditions. Real-time data support dynamic, proactive decisionmaking to improve the overall efficiency of the transportation network. Enhanced data support many Complete Streets strategies. For example, data can be used to identify areas with high pedestrian and bicycle activity, recurring congestion, crashes, or speeding. For example, the City of Chicago uses mobility data such as percentage of vehicles exceeding the speed limit and number, type, and severity of crashes (particularly those involving VRU volumes) to identify, evaluate, and prioritize Complete Streets investments.[68]

Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Vehicle delay and travel time.
- Travel time reliability/ontime performance.
- Bottleneck duration/number of congested hours.

68 L. Hamilton. 2013. "Complete Streets Chicago: Data-Driven Design." Presentation, Designing Cities Conference, Phoenix, AZ. https://nacto.org/wp-content/uploads/2013/10/HamiltonLuann_DesigningCitiesPHX.pdf, accessed December 8, 2023.

Static Traffic Calming: Vertical Deflection Measures

Traffic calming (figure 21) uses design elements, such as introducing vertical deflection to the roadway, to reduce vehicle speeds. Vertical deflection measures, such as speed humps, raised crosswalks, and raised intersections, change the height of the roadway and force motorists to slow down. This strategy specifically focuses on the use of vertical design elements to calm traffic flow, which is different from broader speed management treatments discussed earlier that can include posted speeds, horizontal design changes, transition zones, and other strategies. Vertical deflection is a more low-cost and easily installed way to manage speeds in the appropriate context.

Source: © 2024 Kittelson and Associates, Inc.

Figure 21. Photo. Raised pedestrian crossings provide traffic calming at midblock pedestrian hybrid beacon in Orlando, FL.

Use Static Traffic Calming To…

Agencies can use static traffic calming to do the following:

- Reduce vehicle speeds.
- Improve pedestrian and bicyclist safety.
- Increase pedestrian and bicyclist visibility at intersections.

Strategy in Action

Raised crosswalks are elevated crosswalks often placed at midblock locations or in areas with high pedestrian volumes to slow vehicles and enhance pedestrian visibility. Raised crosswalks can reduce pedestrian crashes by 45 percent.[69] The Chicago DOT converted two midblock crosswalks on the north side of Palmer Square Park to raised crosswalks, reducing speeds on Palmer Boulevard. After the installation, only about 38 percent of vehicles were observed exceeding the 25-mph speed limit, compared to 75 percent prior to the installation.[70]

Recommended Performance Measures

The following performance measures can help to assess the benefits of this strategy:

- Vehicle speeds.
- Number and severity of crashes.
- Pedestrian and bicyclist activity.

4.3. Target Speeds and Speed Limit Setting

A roadway's current operating speed and its target speed are key considerations when selecting Complete Streets strategies. The target speed is the jurisdiction's highest desired operating speed given land-use contexts, multimodal activity, and vehicular mobility.[71] Current operating speeds may constrain the types of speed-management strategies (e.g., vertical deflection) that can be safely implemented at the present time. The target speed is used to identify appropriate speedmanagement measures to reduce operating speeds to the desired level and in setting speed limits.

---

69 FHWA. 2018. *Safe Transportation for Every Pedestrian: Raised Crosswalk*. Publication FHWA-SA-18-063. Washington, DC: FHWA. https://safety.fhwa.dot.gov/ped_bike/step/docs/techSheet_RaisedCW2018.pdf, accessed December 8, 2023.

70 J. Greenfield. 2016. "Raised Crosswalks Have Dramatically Reduced Speeding by Palmer Square." *Streetsblog Chicago,* April 5, 2016. https://chi.streetsblog.org/2016/04/05/raised-crosswalks-have-dramatically-reduced-speeding-by-palmer-square, accessed December 8, 2023.

71 K. Fitzpatrick, S. Das, M. Pratt, K. Dixon, and T. Gates. 2021. *Posted Speed Limit Setting Procedure and Tool: User Guide*. NCHRP Research Report 966. Washington, DC: National Academies Press. https://doi.org/10.17226/26216, accessed October 10, 2023.

The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) presents requirements and guidance for conducting speed studies.[72] Expert systems, such as USLIMITS 2 and the Speed Limit Setting Tool,[73,74] consider a variety of factors when recommending speed limits. These tools can be used to provide a second opinion for a proposed speed limit on an existing roadway and to identify a potential speed limit for a planned new roadway (where no speed study is possible). Although road user safety is a primary consideration when setting speed limits, mobility and traffic flow are also important considerations.[75] As a result, reducing a street's posted speed may be an iterative process that involves posting a speed limit lower than the original operating speed but higher than the desired target speed as an interim measure until additional speed-management strategies can be implemented.

72 FHWA. 2023. *Manual on Uniform Traffic Control Devices for Streets and Highways, 11th Edition.* . Washington, DC: FHWA.

73 FHWA. n.d. "USLIMITS2: A Tool to Aid Practitioners in Determining Appropriate Speed Limit Recommendations." (web page). https://safety.fhwa.dot.gov/uslimits/, accessed October 15, 2023.

74 K. Fitzpatrick, S. Das, M. Pratt, K. Dixon, and T. Gates. 2021. *Posted Speed Limit Setting Procedure and Tool: User Guide*. NCHRP Research Report 966. Washington, DC: TRB of the NASEM.

75 D. Warren, G. Xu, and R. Srinivasan. 2013. "Setting Speed Limits for Safety." *Public Roads Magazine.* FHWA-HRT-13-006. https://highways.dot.gov/public-roads/septemberoctober-2013/setting-speed-limits-safety, accessed October 15, 2023.

A APPENDIX: FURTHER READING

Complete Streets Design

- Barbara McCann and Suzanne Rynne, ed. 2010. *Complete Streets: Best Policy and Implementation Practices*. Chicago, IL: American Planning Association. https://planning-org-uploaded-media.s3.amazonaws.com/publication/online/PAS-Report-559.pdf.
- Knapp, K., B. Chandler, J. Atkinson, T. Welch, H. Rigdon, R. Retting, S. Meekins, E. Widstrand, and R. Porter. 2014. *Road Diet Informational Guide*. Report No. FHWA-SA-14-028. Washington, DC: FHWA. https://safety.fhwa.dot.gov/road_diets/guidance/info_guide/.
- Smart Growth America. 2024. "Complete Streets Resources" (web page). https://smartgrowthamerica.org/what-are-complete-streets/.
- National Association of City Transportation Officials (NACTO). 2012. *Urban Street Design Guide*. New York, NY: NACTO. https://www.nyc.gov/html/dot/downloads/pdf/2012-nacto-urban-street-design-guide.pdf.
- Florida DOT (FDOT) Transportation Statistics Office. 2014. *Statewide Lane Elimination Guide*. Tallahassee, FL: FDOT. https://www.fdot.gov/docs/default-source/planning/fto/mobility/Task23-leguide1.pdf.
- FHWA. 2016. *Incorporating On-Road Bicycle Networks into Resurfacing Projects*. Publication No. FHWA-HEP-16-025. Washington, DC: FHWA.
- New York City DOT. 2020. *Street Design Manual*, 3rd ed. New York, NY: New York City DOT. https://www.nycstreetdesign.info.
- Los Angeles County. 2011. *Model Design Manual for Living Streets*. Los Angeles, CA: Los Angeles County. http://modelstreetdesignmanual.com/model_street_design_manual.pdf.
- City of Charlotte (NC). 2007. *Urban Street Design Guidelines*. Charlotte, NC: City of Charlotte. https://www.charlottenc.gov/files/sharedassets/city/growth-and-development/documents/dev-center-fees/manual/usdg-full-document.pdf.
- FDOT. *FDOT Context Classification Guide*. 2020. Tallahassee, FL: FDOT. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/completestreets/files/fdot-context-classification.pdf.

Complete Street and Road Diet Case Studies

- *Road Diet Case Studies* (FHWA-SA-15-052) describes two dozen case studies of road diets in the United States. Additional information about road diets is available at the FHWA Office of Safety "Road Diets" website at http://safety.fhwa.dot.gov/road_diets.
- The Minnesota DOT research report *Complete Streets from Policy to Project: The Planning and Implementation of Complete Streets at Multiple Scales* is available at: https://mdl.mndot.gov/items/201330.
- Livability initiative http://www.fhwa.dot.gov/livability/case_studies.

Operations Strategies

- R. Lyles, M. Siddiqui, W. Taylor, B. Malik, G. Siviy, and T. Haan. 2012. *Safety and Operational Analysis of 4-Lane to 3-Lane Conversions (Road Diets) in Michigan*. Report No. RC-1555. Lansing, MI: Michigan DOT. https://nacto.org/wp-content/uploads/2015/04/safety_and_operation_analysis_lyles.pdf, accessed June 18, 2023.
- K. Knapp, B. Chandler, J. Atkinson, T. Welch, H. Rigdon, R. Retting, S. Meekins, E. Widstrand, and R. Porter. 2014. *Road Diet Informational Guide*. Report No. FHWA-SA-14-028. Washington, DC: FHWA. https://safety.fhwa.dot.gov/road_diets/guidance/info_guide/, accessed June 18, 2023.
- FHWA. 2022. *Road Diets (Roadway Reconfiguration)*. Publication No. FHWA-SA-21-046. Washington, DC: FHWA. https://highways.dot.gov/safety/proven-safety-countermeasures/road-diets-roadway-configuration, accessed June 18, 2023.
- New York State Energy Research and Development Authority (NYSERDA). "Street Design and Management Considerations." In *Complete Streets Considerations for Freight and Emergency Vehicle Operations*. Albany, NY: NYSERDA. https://www.metrans.org/assets/research/complete%20streets%20freight%20booklet_v6_hires-0.pdf, accessed June 18, 2023.
- W. Riggs, B. Appleyard, and M. Johnson. 2018. "A Design Framework for Livable Streets in the Era of Autonomous Vehicles." *Urban, Planning and Transport Research* 8 (1): 125–137. https://www.researchgate.net/publication/327299881_A_Design_Framework_for_Livable_Streets_in_the_Era_of_Autonomous_Vehicles, accessed June 18, 2023.
- NASEM. 2022. *Dynamic Curbside Management: Keeping Pace with New and Emerging Mobility and Technology in the Public Right-of-Way, Part 1: Dynamic Curbside Management Guide and Part 2: Conduct of Research Report*. NCHRP Web-Only Document 340. Washington, DC: The National Academies Press. https://doi.org/10.17226/26718, accessed June 18, 2023.
- L. Thomas, P. Ryus, C. Semler, N. Thirsk, K. Krizek, and C. Zegeer. 2015. *Delivering Safe, Comfortable, and Connected Pedestrian and Bicycle Networks: A Review of International Practices*. Report No. FHWA-15-051. https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/global_benchmarking/page00.cfm, accessed June 18, 2023.
- L. Sandt, L. Thomas, K. Langford, and D. Nabors. 2015. *A Resident's Guide for Creating Safer Communities for Walking and Biking*. Report No. FHWA-SA-14-099. https://safety.fhwa.dot.gov/ped_bike/ped_cmnity/ped_walkguide/residents_guide2014_final.pdf, accessed June 18, 2023.
- M. Butorac, J. Bonneson, K. Connolly, P. Ryus, B. Schroeder, K. Williams, Z. Wang, S. Ozkul, and J. Gluck. 2018. *Guide for the Analysis of Multimodal Corridor Access Management*. NCHRP Research Report 900. https://nap.nationalacademies.org/catalog/25342/guide-for-the-analysis-of-multimodal-corridor-access-management, accessed June 18, 2023.
- American Association of State Highway and Transportation Officials. 2021. *AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities*, 2nd ed.

- NASEM. 2022. *Traffic Signal Control Strategies for Pedestrians and Bicyclists*. NCHRP Report 969. Washington, DC: The National Academies Press. https://nap.nationalacademies.org/catalog/26491/traffic-signal-control-strategies-for-pedestrians-and-bicyclists, accessed June 18, 2023.
- E. Goughnour, T. Bonner, E. Sweetser, and D. Smith. 2022. *Improving Safety for Pedestrians and Bicyclists Accessing Transit*. Report No. FHWA-SA-21-130. Washington, DC: FHWA. https://safety.fhwa.dot.gov/ped_bike/ped_transit/fhwasa21130_PedBike_Access_to_transit.pdf, accessed June 18, 2023.
- NACTO. 2012. *Urban Street Design Guide*. New York, NY: NACTO. https://nacto.org/publication/urban-street-design-guide/, accessed June 18, 2023.
- FHWA. 2013. Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE). http://www.pedbikesafe.org/PEDSAFE/index.cfm, accessed June 18, 2023.
- FHWA. 2014. Bicycle Safety Guide and Countermeasure Selection System. http://www.pedbikesafe.org/BIKESAFE/index.cfm, accessed June 18, 2023.
- D. Platman, R. Hurtado, C. Muhs, D. Whitt, J. Peters, J. Bachman, J. Bauer, D. Gopalakrishna, and M. Grant. 2018. *Model Transportation Systems Management and Operations: Deployments in Corridors and Subareas Primer.* Report No. FHWA-HOP-18-026. Washington, DC: FHWA. https://ops.fhwa.dot.gov/publications/fhwahop18026/fhwahop18026.pdf, accessed June 18, 2023.
- Washington State DOT. 2022. "Transportation Systems Management and Operations Strategies and Concepts" (web page). https://tsmowa.org/strategies-and-concepts.
- FHWA. 2023. *Operations and Safety: Operations Strategies to Improve Safety*. https://ops.fhwa.dot.gov/publications/fhwahop22017/fhwahop22017.pdf, accessed June 18, 2023.

Safety and Mobility Effects

- Transportation Research Board of the NASEM. 2022. *Highway Capacity Manual: A Guide for Multimodal Mobility Analysis,* 7th edition. Washington, DC: The National Academies Press.
- AASHTO. 2010. *Highway Safety Manual,* 1st edition. Washington, DC: AASHTO.
- Kittelson & Associates, Inc.; Parsons Brinckerhoff; KFH Group, Inc.; Texas A&M Transportation Institute; and Arup. 2013. *Transit Capacity and Quality of Service Manual,* 3rd edition. TCRP Report 165. Washington, DC: The National Academies Press.
- P. Ryus, A. Musunuru, J. Bonneson, S. Kothuri, C. Monsere, N. McNeil, S. LaJeunesse, K. Nordback, W. Kumfer, and S. Currin. 2022. *Guide to Pedestrian Analysis.* NCHRP Report 992. Washington, DC: The National Academies Press.
- H. Twaddell, E. Rose, J. Broach, J. Dill, K. Clifton, C. Lust, K. Voros, H. Louch, and E. David. 2018. *Guidebook for Measuring Multimodal Network Connectivity.* Report No. FHWA-HEP-18-032. Washington, DC: FHWA.
- ITE. 2010. *Manual of Traffic Engineering Studies.* Washington, DC.
- FHWA. n.d. "Proven Safety Countermeasures" (website). https://highways.dot.gov/safety/proven-safety-countermeasures, accessed February 27, 2024.

- FHWA. n.d. “Road Safety Audits (RSA)” (website). https://highways.dot.gov/safety/data-analysis-tools/rsa/road-safety-audits-rsa, accessed February 27, 2024.
- FHWA. n.d. “Data-Driven Safety Analysis (DDSA)” (website). https://highways.dot.gov/safety/data-analysis-tools/rsdp/data-driven-safety-analysis-ddsa, accessed February 27, 2024.
- FHWA. n.d. “Crash Modification Factors Clearinghouse” (website). https://www.cmfclearinghouse.org/, accessed February 27, 2024.
- E. Goughnour, K. Peach, M. Dunn, M. Mitman, and D. Gelinne. 2021. *Primer on Safe System Approach for Pedestrians and Bicyclists*. Report No. FHWA-SA-21-065. Washington, DC: FHWA. https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/fhwasa21065.pdf, accessed February 27, 2024.
- National Highway Traffic Safety Administration (NHTSA). *Fatality and Injury Reporting System Tool (FIRST)*. v. 7.1. NHTSA. 2024.
- USDOT and University of North Carolina Highway Safety Research Center. n.d. “Pedestrian and Bicycle Information Center” (website). https://www.pedbikeinfo.org/, accessed February 27, 2024.
- FHWA. n.d. “Equity in Roadway Safety” (website). https://highways.dot.gov/safety/zero-deaths/equity-roadway-safety, accessed February 27, 2024.
- USDOT. n.d. “What Is a Safe System Approach?” (website). https://www.transportation.gov/NRSS/SafeSystem, accessed February 27, 2024.

U.S. Department of Transportation
Federal Highway Administration
Office of Operations
1200 New Jersey Avenue, SE
Washington, DC 20590

Office of Operations Web Site
https://ops.fhwa.dot.gov
October 2024
FHWA-HOP-24-038

U.S. Department of Transportation
Federal Highway Administration