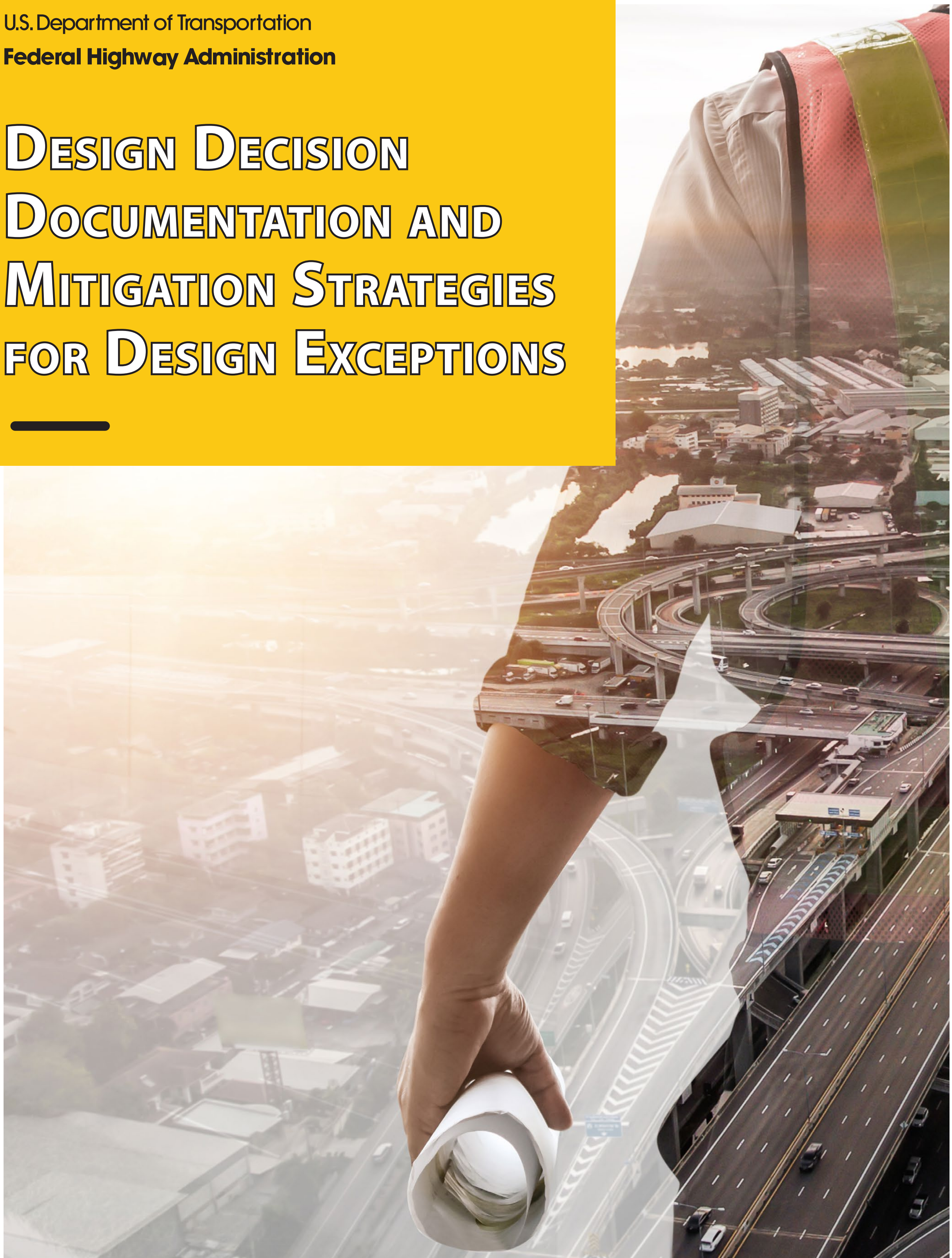
U.S. Department of Transportation
Federal Highway Administration

Design Decision Documentation and Mitigation Strategies for Design Exceptions



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16. Abstract This resource is an update to FHWA's *Mitigation Strategies for Design Exceptions*, which was based on the historical design exception practice and design controlling criteria. Since 2007, there have been changes in FHWA's controlling design criteria and in the project development philosophies of many departments of transportation (DOTs). These changes have resulted in DOTs shifting from standards-driven design toward context-based and performance-based decision-making, all of which can add value for road users and flexibility during project development. This resource provides information to transportation practitioners, especially planners and designers, about FHWA's 10 controlling criteria. The information in this resource includes definitions, impacts on safety and operations, interrelationships with other controlling criteria, and potential mitigation strategies for design exceptions. The resource also describes concepts that are important for practitioners to understand when making design decisions. The appendix includes noteworthy practices that demonstrate concepts described in this resource.			
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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)

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List of Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
BOD	basis of design
CBD	commercial business district
CMAR	Context and Modal Accommodation Report
DOT	department of transportation
FHWA	Federal Highway Administration
GIS	geographic information system
HCM	*Highway Capacity Manual*
HFST	high friction surface treatment
HOT	high-occupancy toll
I-35W	Interstate 35W
I-94	Interstate 94
IHSDM	Interactive Highway Safety Design Model
ITS	intelligent transportation system
KYTC	Kentucky Transportation Cabinet
LiDAR	light detection and ranging
LRFD	Load and Resistance Factor Design
MassDOT	Massachusetts Department of Transportation
MDNR	Michigan Department of Natural Resources
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
mph	mile per hour
MUTCD	*Manual on Uniform Traffic Control Devices*
NHS	National Highway System
ODOT	Oregon Department of Transportation
RaDAR	radio detection and ranging
STRAHNET	Strategic Highway Network
TSMO	transportation systems management and operations
U.S. 60	U.S. Route 60
U.S. 89	U.S. Route 89
U.S. 31	U.S. Route 31
USDOT	U.S. Department of Transportation
WSDOT	Washington State Department of Transportation

Chapter 1. Introduction

Transportation systems throughout the United States have evolved into multipurpose and multimodal networks. These facilities are more than pavement and traffic control devices, as they serve to move goods and people, contribute to public health, and support economic development while providing equitable and safe options for all users. Planning and designing roadway projects have become more than following standards. Practitioners assess and make design decisions based on safety, operations, multimodal aspects, equity and social impacts, environment, economic effects, and benefit-costs.

Nevertheless, the design standards for highways on the National Highway System (NHS) are defined in 23 CFR Part 625—Design Standards for Highways. This regulation lists AASHTO's *A Policy on Geometric Design of Highways and Streets, and A Policy on Design Standards— Interstate System* as the standards for highway design.[1] Any failure of a particular design element to meet these standards must be approved by FHWA or its designee—a design exception.[2]

This resource is an update to the Federal Highway Administration's (FHWA) *Mitigation Strategies for Design Exceptions*,[3] which was based on the historical design exception practice and design controlling criteria. Since 2007, there have been changes in FHWA's controlling design criteria and in the project development philosophies of many transportation agencies. These changes have resulted in a shift from standards-driven design toward an emphasis on context-based and performance-based decision-making, all of which can add value for road users and flexibility during project development.

This resource provides information to transportation practitioners, especially planners and designers, about controlling criteria, context-based design and decision-making, assessment and evaluation methods, mitigation strategies, documentation practices, risk management, and real-world examples highlighting States' projects and procedures.

The remainder of this resource is organized as follows:

- **Chapter 2,** Evolution of Design Decisions, describes key concepts that are important for practitioners to understand when making design decisions. These concepts include nominal and substantive safety, performance-based design, context-based design, transportation equity, Complete Streets, transportation systems management and operations (TSMO), and the Safe System Approach.
- **Chapters 3–12** provide technical information about FHWA's 10 controlling criteria, including definitions, impacts on substantive safety and traffic operations, and interrelationships with other controlling criteria. Safety effects may include expected or predicted changes in crash frequency, severity, or both associated with an incremental change in a design dimension. Operational effects may include the influence of a change in a design dimension on the facility's capacity or speed, or usability for different modes of transportation. For safety and operational impacts, these chapters represent a synthesis of research and technical literature. Chapters 3–12 also describe potential mitigation strategies for design exceptions impacts. The chapters do not include every possible mitigation strategy; they are intended to present common and innovative alternatives. The mitigation strategies may be used together or separately as part of an overall approach.

1 23 CFR Part 625.4.

2 23 CFR Part 625.3.

3 FHWA, *Mitigation Strategies for Design Exceptions,* FHWA-SA-07-011 (Washington, DC: USDOT, 2007).

- **Chapter 13**, Risk Management, discusses benefits of practices agencies can implement to mitigate risk.
- **Chapter 14**, Design Decision Documentation, Approvals, and Post-construction Evaluation, discusses documenting design decisions throughout planning and project development. The chapter also describes the information to include in design exception documentation.
- **Appendix A** highlights noteworthy practices and States' programs, approaches, and projects that demonstrate concepts described in this resource.

TERMINOLOGY

Design exception, design variance, design deviation, design justification, and design waiver are examples of the terminology transportation agencies use in design policies. The terminology used in this resource is defined below, recognizing that organizations may use other terms:

- **Design exception** – Refers to variances from NHS standards on high-speed roadways (i.e., interstate highways, other freeways, and roadways with design speed greater than or equal to 50 miles per hour [mph]) on the NHS for the 10 controlling criteria: design speed, lane width, shoulder width, horizontal curve radius, superelevation rate, maximum grade, stopping sight distance, cross slope, vertical clearance, and design loading structural capacity. Design exception also refers to variances from NHS standards on low-speed roadways (i.e., non-freeways with design speed less than 50 mph) on the NHS for design speed and design loading structural capacity.
- **Design deviation** – Refers to all other variances from standards or criteria that States developed or defined in their policies.

Transportation organizations and agencies may also define thresholds for high speed and low speed differently. The terminology used in this resource is defined as shown:

- **High-speed roadway** – Refers to interstate highways, other freeways, and roadways with a design speed greater than or equal to 50 mph.
- **Low-speed roadway** – Refers to non-freeway roadways with a design speed less than 50 mph.

Source: Getty Images.

Chapter 2. Evolution of Design Decisions

Planning and designing the transportation system has come a long way since the automobile was invented in the early 1900s. Advances in vehicles, shifts in population and mode choice, environmental and social concerns, data access, and technological and research innovations have influenced the transportation practitioner's design decisions.

Since their establishment, transportation standards and policies have shaped how practitioners make design decisions, which is still true today. For many years, the project development process involved applying design standards solely based on practitioners gathering information, making independent decisions, and announcing plans to the public without considering additional factors and community concerns.[4] As design practices evolved, practitioners understood that quality design fosters creative thinking and incorporates more elements into the decision-making process, in addition to engineering standards.

Today, practitioners consider safety, mobility, cost, environmental, historical, and cultural impacts in the project development process. They also consider a variety of users and multimodal elements, equity and social aspects, safety and operational performance factors, and energy consumption and emissions. Navigating and balancing the relationships among these intertwined factors can help practitioners achieve a project's goals and intentions.

This chapter describes the following key concepts for practitioners to understand when making design decisions:

- Nominal and substantive safety
- Performance-based design
- Context-based design
- Equity in transportation
- Complete Streets
- TSMO
- Safe System Approach

NOMINAL AND SUBSTANTIVE SAFETY

Safety is a key consideration in all design decisions. Practitioners should understand the relationship of safety to the design criteria, process, and outcomes for all road users. Nominal and substantive safety are fundamental to design decisions, design exceptions, and mitigation strategies.

[4] Keith Harrison and Stephanie Roth, "Risking Success Through Flexible Design," *Public Roads* 73, no. 4 (2010), FHWA-HRT-10-002, https://highways.dot.gov/public-roads/janfeb-2010/risking-success-through-flexible-design.

▸ Nominal Safety

Nominal safety is a safety performance evaluation of whether a roadway, design alternative, or design element meets the design criteria. Nominal safety is measured by comparing design element dimensions (e.g., lane width, shoulder width, stopping sight distance) to the adopted design criteria and engineering standards referenced in manuals.

When practitioners design roadways that meet the design criteria, they are using values that will produce a nominally-safe-designed roadway. However, practitioners should not assume that a design is less safe if a design element does not meet design criteria. Nominal safety does not examine or express the actual or expected safety performance of a highway. The safety effects of incremental differences in a design dimension can be expected to produce an incremental, not absolute, change in safety. Designing to criteria does not guarantee or optimize the safety of the roadway in relation to measured crash experience. Assessing the nominal safety condition is a factor in determining what solution is designed, but practitioners should also understand the expected substantive safety performance when making decisions about design exceptions.

▸ Substantive Safety

Substantive safety is the actual or expected safety performance of a roadway. Safety performance is measured by quantitative data reported from crashes at a location. These quantitative measures of substantive safety include:

- Crash frequency (number of crashes per mile or location over a specified time period)
- Crash type (roadway departure, intersection, pedestrian, bicyclist)
- Crash severity (fatality, injury, property damage only)

When assessing safety performance, it is key for practitioners to understand the relationships contributing to crashes and how they vary by crash type, roadway type, and site type. Substantive safety varies by context, such as types of users, volume, prevailing speeds, and roadway features. For example, the frequency and other characteristics of crashes differ among a two-lane road in rolling rural terrain, a multilane urban arterial, and a freeway interchange. Substantive safety can also be influenced by the presence or absence of a design feature, and by the roadway's three-dimensional elements (profile, alignment, and cross section).

Science-based methods and models are useful tools for agencies to assess substantive safety. The *Highway Safety Manual*[5] and FHWA's Roadway Safety Data Program are suggested resources for agencies to use for data-driven safety analysis. These resources include both predictive and systemic analyses methods that State and local agencies can implement to quantify safety performance. Predictive analysis identifies roadway sites with the greatest potential for improvement by combining crash, roadway inventory, and traffic volume data to quantify the expected safety performance of different design alternatives. Systemic analysis uses crash and roadway data with high-risk roadway features to target particular crash types. Since severe crashes are widely dispersed over roadway networks, and their location and frequency change over time, systemic analysis identifies locations at risk for severe crashes even if there is not a high crash frequency. Practitioners can use predictive and systemic analyses to inform decision-making, optimize funding, and select the most appropriate design elements and project sites to improve safety.

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5 American Association of State Highway and Transportation Officials (AASHTO), *Highway Safety Manual* (Washington, DC: AASHTO, 2010).

There are evolving methods for characterizing a location's substantive safety, which generally include applying statistical models of crash experience from broader databases (safety performance functions and crash modification factor analysis). Many safety models are developed using research data from motor vehicle crashes; however, models for nonmotorized users are under development as more research and information on safety performance becomes available.

▸ Comparing Nominal and Substantive Safety

The substantive safety performance of a roadway does not always directly correspond to its level of nominal safety. A roadway can be nominally safe (i.e., all design elements meet design criteria) and substantively less safe (i.e., demonstrates a high crash problem relative to expectations) at the same time. Conversely, roadways that are nominally less safe can function at a high level of substantive safety. This relationship is shown in figure 1.

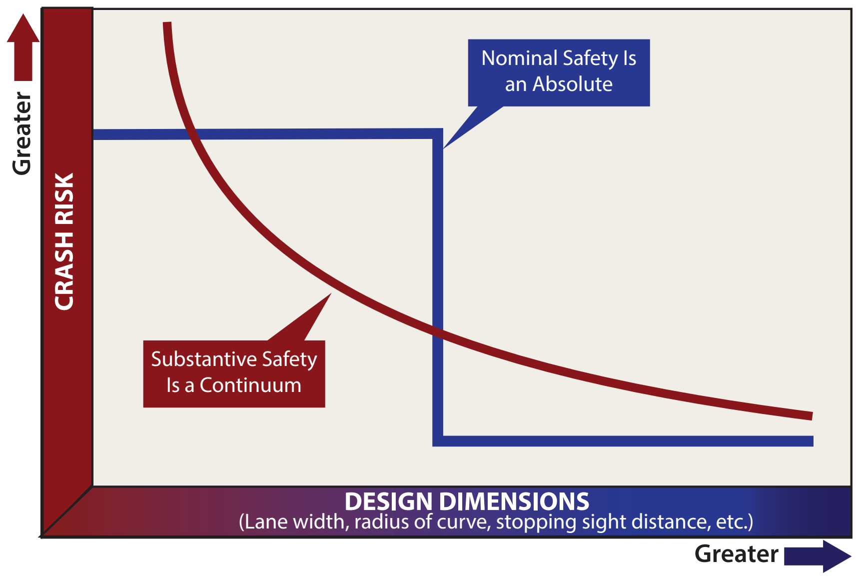

Figure 1. Illustration. Comparison of nominal and substantive concepts of safety.

When applying design standards and criteria, practitioners might presume the resulting highway will perform in a safe (acceptable) manner and be substantively safe in the long term. In actuality, the level of performance will vary based on the context and type of highway. When deciding to incorporate one or more design exceptions, practitioners should assess whether the design exception will influence substantive safety, and, if so, to what extent. Practitioners should seek information that characterizes the long-term substantive safety risk of that exception (frequency, type, and severity of crashes).

Practitioners can consider the following questions when contemplating a design exception:

- If this is an existing location and a design exception is being considered, how good (or poor) is the existing substantive safety performance for all users of the facility?
- If this is new construction or a reconstruction and a design exception is being considered, what should be the long-term safety performance of the roadway for all users of the facility?
- Given the specifics of the design exception (e.g., geometric element, degree/magnitude of the variance, length of highway over which it is applied, traffic volume), what is the difference in expected substantive safety for all users if the exception is implemented?

Throughout the design process, practitioners should apply the flexibility inherent in the adopted criteria to achieve a balanced, safe, and context sensitive design with satisfactory anticipated performance for all users. When design exceptions are necessary to achieve desired results, the substantive safety performance of various design options is a key factor in documenting the design decisions made.

PERFORMANCE-BASED PLANNING AND DESIGN

Performance-based planning and design, also known as performance-based practical design, is a multimodal decision-making process to help agencies better manage project investments and achieve systemwide performance goals. Performance-based planning and design should involve interdisciplinary teams that can provide diverse inputs and perspectives to guide and document planning and design decisions. Dating back to AASHTO's 1973 publication, A *Policy on Design of Urban Highways and Arterial Streets* (referred to as Red Book), AASHTO encouraged a tailored approach to roadway design that fits the unique set of conditions along the segment.[6] Performance-based planning and design emphasizes substantive safety, which refers to the predicted or actual safety performance of the design or roadway. The performance-based planning and design approach follows these overall steps:

> **"Good design will not necessarily result from direct use of the policy values. To form a segment of highway that will be truly efficient and safe in operation, be well fitted to the terrain and other site controls, and be acceptably amenable to the community environment, it must be a carefully tailor-made design for the unique set of conditions along the segment."**
>
> **—1973 AASHTO Red Book**

- Identify desired project outcomes and performance metrics for all users.
- Establish geometric design decisions based on the desired outcomes.
- Evaluate the performance of the design.
- Refine the design to align solutions with desired outcomes.
- Assess the financial feasibility of the alternatives.
- Select a design that best aligns with the desired outcomes for all users.
- Reassess desired outcomes if no acceptable solution is identified.

With this approach, practitioners clearly outline the intended outcomes of a project for all users and select performance measures that align with those outcomes.

This approach also:

- Allows for more informed design flexibility for projects with varying contexts, diverse range of users, and varying community needs and goals
- Creates a method for analyzing and documenting planning and design choices when considering a design exception
- Provides a decision-making framework for documenting planning and design decisions and solutions

[6] AASHTO, *A Policy on Design of Urban Highways and Arterial Streets, 1st ed.* (Washington, DC: AASHTO, 1973).

CONTEXT-BASED DESIGN

Context-based design, also known as context sensitive solutions or context sensitive design, uses a collaborative, multidisciplinary approach to tailor a transportation facility to the context of the project and local characteristics. This approach creates transportation elements that support and complement the current and future land use vision in the project area. Context-based design balances a variety of elements beyond just engineering principles to preserve and enhance scenic, aesthetic, historic, community, and environmental resources.

The 7th edition of *A Policy on Geometric Design of Highways and Streets*,[7] (commonly referred to as the Green Book) expanded the design framework beyond the former urban and rural by including a broader set of contexts for geometric design and emphasizing the consideration of multimodal needs in design for each context. These context classifications are:

- Rural
- Rural town
- Suburban
- Urban
- Urban core

Because transportation facilities, their users, and the surrounding land use can change over time, it is important for practitioners to understand the appropriate context classification both now and in the future during project planning and design.

For example:

- Rural locations that are urbanizing may have new demands for nonmotorized travel that had not been anticipated when the roadway was originally constructed, and these demands may continue to change over the design life of the project.
- Small communities that were once distant and separate from larger metropolitan areas may now be connected by suburban development. A transportation system that had functioned adequately as an isolated community may not function as well as part of a larger suburban area.
- Land uses may have been industrial or agricultural at the time the transportation system was developed, but may have evolved into commercial employment, housing, mixed-use redevelopments, or other urban uses.
- Interchanges may have been constructed with only the service of vehicle traffic in mind, incorporating free-flow movements at ramp terminal intersections, and without considering bicycle, pedestrian, or transit vehicle travel. Land use changes around interchanges may now require design changes to integrate other modes of travel.

Practitioners should identify context classification (existing and future) and other key assessment factors or performance measures. This helps establish initial project design features. The context classification of a project plays a key role in determining the factors to be assessed, acceptable levels of performance for each mode, and relative importance of each assessment factor in the decision process.

7 AASHTO, *A Policy on Geometric Design of Highways and Streets* (Green Book), 7th ed. (Washington, DC: AASHTO, 2018).

Context-based design and performance-based planning and design help transportation agencies improve the transportation system and meet the needs of the road users and the surrounding communities. The 8th edition of the AASHTO Green Book[8] is further expected to transform how performance-based planning and design and context-based design are used in the project development process.

TRANSPORTATION EQUITY

Executive Order 13985 is a policy to advance equity for all, including people of color and others who have been historically underserved, marginalized, and adversely affected by persistent poverty and inequality.[9] Equity in transportation seeks fairness in mobility and accessibility to meet the needs of all community members. A goal of transportation is to facilitate social and economic opportunities by providing equitable levels of access to affordable, reliable, and accessible transportation options based on the needs of the populations being served, particularly traditionally underserved populations.

To determine the measures needed to develop an equitable transportation network, practitioners can consider the circumstances impacting a community's mobility and connectivity needs. Considering equity early and often, through methods such as public engagement and data collection and analysis, can help improve a transportation agency's ability to adequately respond to the community's needs. Data analysis can identify equity gaps to help transportation agencies make informed decisions and overcome the existing disparities found in the communities they serve. A transportation equity analysis begins by identifying populations using a combination of demographics and social data and public engagement techniques. For example, demographic and social data can be used to proactively identify locations with disproportionate crash risk for underserved communities, as well as a need for active transportation facilities. Agencies can use data sources such as the U.S. Census Bureau;[10] the annual American Community Survey,[11] which includes current data on limited-English-speaking households, household income, and race and ethnic populations; and the Environmental Protection Agency's EJScreen[12] mapping and screening tool, which provides demographic and environmental information.

During project planning, agencies can perform an in-depth analysis to identify population groups and high priority areas for each population group to understand an area's demographic changes. Agencies can use geographic information systems to visualize the data from the equity analysis by developing heat maps and dot-density maps of the demographic and social data. This analysis, in addition to intentional public outreach and engagement, can help identify the specific needs and concerns of these individuals and groups. Equity gaps will not improve if the actual inequities that are unique to the underserved communities are not first understood. Involving the community in this process is a strategy that may increase a community's sense of ownership and comfort. The impacts of the agency's proposed plans, programs, and projects on the underserved populations should be assessed, including the disproportion experienced among these different population groups. Agencies can then begin to develop strategies and countermeasures that avoid or mitigate transportation inequities among communities that are disproportionately burdened.[13]

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8 National Cooperative Highway Research Program (NCHRP), "Development of the 8th Edition of AASHTO's A Policy on the Geometric Design of Highways and Streets (Green Book)," https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4944.

9 "Executive Order 13985: Advancing Racial Equity and Support for Underserved Communities Through the Federal Government," *Federal Register* (January 25, 2021), https://www.federalregister.gov/documents/2021/01/25/2021-01753/advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government.

10 United States Census Bureau, "Data" (web page), page last revised December 6, 2022, https://www.census.gov/data.html.

11 United States Census Bureau, "American Community Survey (ACS)," page last revised December 2, 2022, https://www.census.gov/programs-surveys/acs.

12 Environmental Protection Agency, EJScreen: Environmental Justice Screening and Mapping Tool, https://www.epa.gov/ejscreen.

13 Hannah Twaddle and Beth Zgoda, *Transit Cooperative Research Program Report 214: Equity Analysis in Regional Transportation Planning Processes—Volume 1: Guide* (Washington, DC: The National Academies Press, 2020).

Considering equity early may also improve project delivery by preventing costly and time-consuming delays that could arise from previously unrecognized conflicts as projects move from planning into implementation.[14] For information on noteworthy transportation equity practices, the Boston Region Metropolitan Planning Organization[15] and the District Department of Transportation[16] provide their communities with community-centric transportation planning that considers equity in project decision-making.

COMPLETE STREETS

FHWA encourages States and communities to adopt and implement Complete Streets policies that prioritize the safety of all users in transportation network planning, design, construction, and operations. Section 11206 of the Bipartisan Infrastructure Law defines Complete Streets standards or policies as those which "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."[17] There is not a one-size-fits-all approach. Identification of community context and needs is necessary to provide equitable streets and networks that prioritize safety, comfort,and connectivity for all road users.

Designs that prioritize safety and access to all road users may include features such as sidewalks, bicycle lanes, dedicated bus lanes, accessible public transportation stops, safe and accessible crossing options, median refuge islands, pedestrian and bicycle signals, curb extensions, narrower travel lanes, and roundabouts.

A Complete Streets design model includes:

- Measures to set and design for appropriate speeds
- Separation of various users in time and space
- Improvement of connectivity and access for pedestrians, bicyclists, and transit riders, including for people with disabilities
- Implementation of Proven Safety Countermeasures to address safety issues[18,19]

Complete Streets can help improve safe access for all users, particularly on urban and suburban non-freeway arterials, and on rural arterials that serve as main streets in smaller communities.

14 USDOT, "Equity" (web page), https://www.transportation.gov/priorities/equity.

15 Boston Region Metropolitan Planning Organization, *Transportation Equity Needs* (2019), https://www.bostonmpo.org/data/html/plans/LRTP/destination/Destination_2040_Needs_Assessment_CH8.html.

16 District Department of Transportation, "The Equity Scorecard," https://storymaps.arcgis.com/stories/8ce1d5c8b4644a7cbff0467d68bf7c6b.

17 Infrastructure Investment and Jobs Act of 2021, Pub. L. No. 117-58, § 11206 (2021).

18 Cheryl J. Walker to Division Administrators, "ACTION: Vulnerable Road User Safety Assessment Guidance," memorandum (Washington, DC: USDOT, October 21, 2022), https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-10/VRU%20Safety%20Assessment%20Guidance%20FINAL_508.pdf.

19 FHWA, "Proven Safety Countermeasures," https://highways.dot.gov/safety/proven-safety-countermeasures.

TRANSPORTATION SYSTEMS MANAGEMENT AND OPERATIONS

TSMO is the use of strategies, technologies, mobility services, and programs to optimize the safety, mobility, and reliability of the existing and planned transportation system.[20] The goal is to get the most performance out of the existing transportation facilities. TSMO may enable transportation agencies to stretch their funding, provide flexible solutions, and meet their transportation network needs. TSMO strategies may also help reduce roadway injuries and fatalities and support overall safety goals.

TSMO implements multimodal and intermodal systems, services, and projects across jurisdictional boundaries to manage travel demand of all modes. With TSMO, agencies look beyond a singular strategy, project, or corridor and consider the impacts of the entire transportation system. The overall system performance relies on the various transportation modes and facilities to work together and ultimately perform better. This involves coordinating and collaborating across multiple jurisdictions, agencies, and modes to integrate strategies to achieve greater performance on the entire system.

Practitioners can incorporate TSMO strategies into roadway design to help reduce right-of-way, social, and environmental impacts, as well as reduce project costs and improve system performance. When TSMO strategies are considered during the planning and design stages, practitioners expand the variety of design options available and may reduce the need for larger capital improvement projects. Practitioners may also use TSMO strategies as mitigation strategies when design criteria are not met. Although not all TSMO strategies are intelligent transportation system (ITS)-related, the data available from ITS devices (e.g., camera feeds, traffic volumes, speed) may also help inform practitioners' design decisions and documentation.

SAFE SYSTEM APPROACH

The U.S. Department of Transportation (USDOT) adopts the Safe System Approach as the guiding paradigm to address roadway safety and achieve zero deaths and serious injuries.[21,22] Figure 2 shows an overview of the Safe System Approach. The basis of the Safe System Approach is formed by six principles: deaths and serious injuries are unacceptable, humans make mistakes, humans are vulnerable, responsibility is shared, safety is proactive, and redundancy is crucial. Achieving zero traffic deaths means addressing every aspect of crash risks through the five elements of a Safe System. The five Safe System elements are: safe roads, safe speeds, safe road users, safe vehicles, and post-crash care.[23]

Source: FHWA.

Figure 2. Illustration. Overview of the Safe System Approach.

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20 FHWA, "What is TSMO?," https://ops.fhwa.dot.gov/tsmo/.

21 USDOT, "What is a Safe System Approach?," https://www.transportation.gov/NRSS/SafeSystem.

22 FHWA, "Zero Deaths and Safe System," https://highways.dot.gov/safety/zero-deaths.

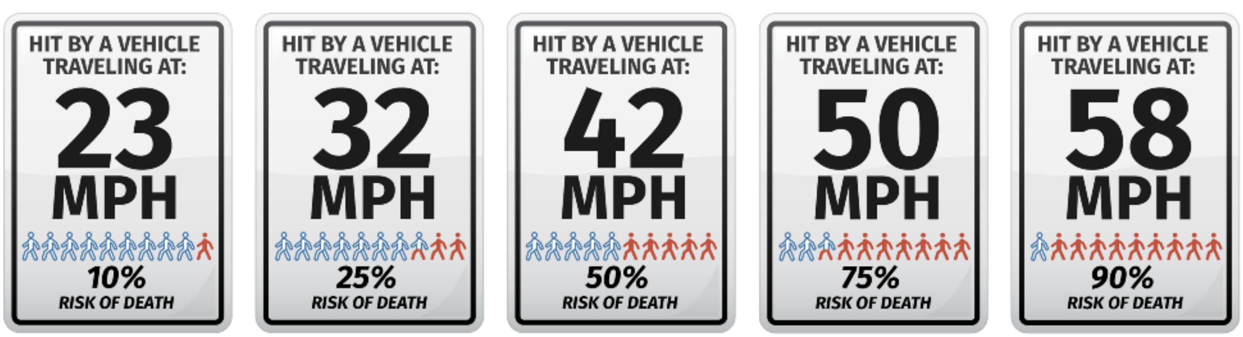
23 FHWA, "Zero Deaths and Safe System," https://highways.dot.gov/safety/zero-deaths.

The Safe System Approach uses a holistic, comprehensive approach to address and mitigate risks inherent to the complex transportation system. This safety approach focuses on both human mistakes and human vulnerability and designs a system with redundancies in place to protect everyone. When crashes do happen, they should be managed so the kinetic energy forces on the human body is kept below tolerable limits for serious harm to occur. Practitioners should incorporate additional layers of protection for vulnerable road users during the conceptual and planning phases of design to reduce the risks of fatalities and serious injuries from occurring. Accepting the principle that humans make mistakes but acknowledging no one should lose their life or be seriously injured because of a crash could change how the transportation system is designed and operated.

Designing safe roads to accommodate human mistakes and injury tolerances can greatly reduce the number and severity of crashes that do occur. Roadway design strongly influences how people use the roadways, including the environment around the roadway system. This includes the surrounding land use, intersections, roads, streets, rail, transit, and other transportation modes for all users.[24]

Designs that encourage safer speeds can also reduce the impact forces, provide additional time for drivers to stop, and improve visibility.[25] Considering speed management strategies during the design process and continually managing speed beyond project implementation can mitigate fatal and serious injury speed-related crashes for all users. Managing and achieving safe speeds requires a multifaceted, equitable approach that leverages road design and other infrastructure interventions, speed limit setting, education, and enforcement.[26]

When setting a speed limit, agencies should consider a range of factors, such as pedestrian and bicyclist activity, crash history, land use context, intersection spacing, driveway density, roadway geometry, roadside conditions, roadway functional classification, traffic volume, and observed speeds. Figure 3 illustrates the effect of impact speed and a pedestrian's risk of death, highlighting the importance of safe speeds. To achieve desired speeds, agencies often implement other speed management strategies, such as self-enforcing roadways, traffic calming, and speed safety cameras,[27] concurrently with setting appropriate speed limits.



Sources: Fatality Analysis Reporting System; Early Estimates of Motor Vehicle Traffic Fatalities and Fatality Rate by Sub-Categories in 2020, DOT HS 813 118, June 2021; AAA Foundation for Traffic Safety, Impact Speed and a Pedestrian's Risk of Severe Injury or Death; National Traffic Speeds Survey III: 2015, DOT HS 812 485, March 2018.

Figure 3. Illustration. The effects of impact speed and a pedestrian's risk of death.

24 FHWA, "Safer Roads," last modified March 14, 2022, https://www.transportation.gov/NRSS/SaferRoads.

25 FHWA, *The Safe System Approach*, FHWA-SA-20-015.

26 FHWA, "Safer Speeds," last modified October 13, 2022, https://www.transportation.gov/NRSS/SaferSpeeds.

27 FHWA, "Appropriate Speed Limits for All Road Users," last modified November 19, 2021, https://safety.fhwa.dot.gov/provencountermeasures/appropriate-speed-limits.cfm.

Incorporating particular design elements during project design can help mitigate human mistakes, account for injury tolerances, encourage safer behaviors, and facilitate safe travel for vulnerable road users. FHWA's Proven Safety Countermeasures[28] are effective strategies agencies can implement to reduce fatalities and serious injuries for all roadway users and can help achieve a Safe System Approach.

Source: Getty Images.

[28] FHWA, "Proven Safety Countermeasures," https://highways.dot.gov/safety/proven-safety-countermeasures.

Chapter 3. Design Speed

DEFINITION

Design speed is used to determine most of the geometric design features of the roadway. It is a practitioner-selected speed. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, modal mix, vulnerability of users, adjacent land use, and functional classification of the highway.[29,30,31] The following highway speed concepts should not be confused with design speed:

- Operating speed: observed speed of traffic operating in free-flow condition unimpeded by other traffic or traffic control devices
- Percentile speed: speed at or below which a specific percentage of traffic travels
- Target speed: intended maximum speed that vehicles should operate given the context of a facility
- Posted speed (speed limit): maximum legal speed for a location as displayed on a regulatory sign[32]

DESIGN SPEED

A selected speed used to determine most of the geometric design features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, modal mix, vulnerability of users, adjacent land use, and functional classification of the highway.

Because of the role that speed plays in fatal crashes, FHWA provides resources on speed management, including setting appropriate speed limits and on reengineering roadways to help self-enforce speed limits.

Design speed is different from other controlling criteria because it is a design control, rather than a specific design element. Because design speed affects so much of a highway's design, it is a fundamental choice a practitioner makes. The adopted criteria allow flexibility by providing ranges of values for design speed, in recognition of the wide range of site-specific conditions, constraints, and contexts that practitioners face. For most cases, the ranges provide adequate flexibility for practitioners to choose an appropriate design speed without the need for a design exception. Additional information on how to apply this flexibility for selecting appropriate design speeds for various roadway types and contexts can be found in *"A Guide for Achieving Flexibility in Highway Design."*[33]

29 AASHTO, Green Book, 7th ed. (2018).

30 FHWA, *Appropriate Speed Limits for All Road Users*, FHWA-SA-21-034 (Washington, DC: 2021).

31 AASHTO, *AASHTO Transportation Glossary* (Washington, DC: AASHTO, 2009).

32 FHWA, *Speed Concepts: Informational Guide*, FHWA-SA-10-001 (Washington, DC: 2009).

33 AASHTO, *A Guide for Achieving Flexibility in Highway Design* (Washington, DC: AASHTO, 2004).

APPLICABILITY

FHWA policy requires a design exception when the design speed criterion is not met on all NHS facility types.[34] However, FHWA generally discourages exceptions to the design speed criterion—particularly on freeways— because exceptions impact other design criteria and elements. Normally, an exception is only needed for a particular criterion, not the overall design speed. If a design exception for design speed appears necessary, practitioners can evaluate the expected performance within the project limits to refine the design and highlight specific locations for mitigation.

SAFETY IMPACT

FHWA's goal is to achieve safe mobility for all road users through the Safe System Approach—a holistic framework for achieving zero traffic deaths. Safe speeds is one of the elements of the Safe System Approach (figure 4). Crashes that occur at higher speeds result in greater impact forces, which lead to more severe injuries and fatalities. This is especially true for vulnerable road users, such as motorcyclists, bicyclists, and pedestrians. A pedestrian hit by a driver traveling at 30 mph has a 45-percent chance of being killed or seriously injured; at 20 mph, that percentage drops to 5 percent.[35] In addition to the decrease in crash energy, lower speeds also provide improved visibility and more effective stopping.

Source: FHWA.

Figure 4. Illustration. Safe speed is an element of the Safe System Approach.

High-Speed Roadways

On high-speed rural roads design values are usually more generous, and managing operating speed is largely a matter of enforcement. Practitioners can use the Interactive Highway Safety Design Model (IHSDM)[36] to determine where operating speeds may exceed the design speed. IHSDM is a collection of software tools that provides evaluations of the safety and operational impacts of geometric design decisions. For rural two-lane roads, IHSDM can identify speed discrepancies, in terms of level of magnitude and length of highway. Large discrepancies do not necessarily indicate a safety problem, and practitioners should analyze each instance on a case-by-case basis. If the discrepancy is especially serious, practitioners can target appropriate countermeasures.

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[34] Robert B. Mooney to Director of Field Services, Division Administrators, Director of Technical Services, Federal Lands Highway Division Engineers, "INFORMATION: Revisions to the Controlling Criteria for Design and Documentation for Design Exceptions," memorandum (Washington, DC: USDOT, May 5, 2016), https://www.fhwa.dot.gov/design/standards/160505.pdf.

[35] Paul Pilkinton, "Reducing the Speed Limit to 20 mph in Urban Areas: Child Deaths and Injuries Would Be Decreased," *BMJ* (April 29, 2000).

[36] FHWA, "Interactive Highway Safety Design Model (IHSDM): Overview," last modified May 24, 2022, https://highways.dot.gov/research/safety/interactive-highway-safety-design-model/interactive-highway-safety-design-model-ihsdm-overview.

Low-Speed Roadways

Speed is an important factor on low-speed roadways where there are vulnerable road users present. Setting appropriate speed limits and implementing speed management strategies can help achieve safe speeds for all road users. Agencies can also modify design elements (e.g., cross-sectional elements, roadway geometry, on-street parking) in such a way that operating at a safe speed becomes the intuitive choice, creating a self-enforcing roadway with traffic calming elements. Similar to discussion above, IHSDM also applies to low-speed rural two-lane roadways.

OPERATIONAL IMPACT

High-Speed Roadways

Traditionally, design speeds were selected to be greater than or equal to the regulatory speed limit. Contemporary designs are beginning to reflect the undesirability of designing to speeds higher than the intended operating speed because drivers inevitably operate faster on facilities designed in this manner.

Low-Speed Roadways

On urban and suburban non-freeways, many agencies have adopted the concept of target speed (i.e., determining the highest operating speed at which vehicles should ideally operate on a roadway given land-use contexts, multimodal activity, and vehicular mobility.) When the target speed and selected design speed are similar, the roadway design elements can help encourage operating speeds near the target speed.

INTERRELATIONSHIPS

The design speed establishes the range of design values for many of the other geometric elements of the highway. The only criteria not controlled by design speed are cross slope, vertical clearance, and design loading structural capacity. Therefore, exceptions to the design speed criterion should be rare. It is more appropriate to evaluate specific geometric elements and treat those as design exceptions when needed, instead of excepting the controlling design speed.

MITIGATION STRATEGIES

Since design speed is rarely excepted, there are no overt strategies to mitigate its impact. Rather, other geometric elements based in design speed should be adjusted. For example, if a roadway is being reconstructed through an existing, tightly constrained right-of-way, the practitioner should not arbitrarily adjust the appropriate design speed simply to make the alignment fit. The practitioner can modify the alignment to fit by excepting the speed-dependent geometric controls, such as horizontal curve radius and stopping sight distance, and applying appropriate mitigation strategies.

Source: Getty Images.

Chapter 4. Lane Width

DEFINITION

Lane width is the lateral roadway distance available to accommodate a single line of motor vehicles. Lane width represents the usable operating space for motor vehicles. It influences the comfort of driving, operating speed and other operational characteristics, and even the potential for crashes.[37]

LANE WIDTH

The lateral roadway distance available to accommodate a single line of vehicles.

APPLICABILITY

FHWA policy does not require a design exception for lane width on non-freeway roadways with a design speed less than 50 mph. FHWA requires a design exception when the lane width criterion is not met on interstate highways and NHS freeways and roadways with a design speed greater than or equal to 50 mph.[38] With respect to widening lanes through horizontal curves, a formal design exception is unnecessary for cases not providing additional lane width, but the decision should be documented in project records.

SAFETY IMPACT

▶ High-Speed Roadways

Narrower lanes on rural two-lane highways increase the risk of run-off-road, head-on, or sideswipe crashes because drivers may have difficulty staying within the travel lane. At volumes as low as 2,000 vehicles per day, the crash risk increases 5 percent for 11-foot lanes, 30 percent for 10-foot lanes, and as much as 50 percent for 9-foot lanes.[39] There are also increases in the crash risk for rural multilane undivided highways, although they are not as pronounced as those on two-lane undivided roadways. On any high-speed roadway, the primary safety issues with reducing lane width are crash types related to roadway departure.

▶ Low-Speed Roadways

On urban and suburban non-freeway roadways, where a Complete Streets design model is recommended, research has shown no substantial differences in safety performance between 10-, 11-, and 12-foot lanes.[40] On urban and suburban roadways, narrower through travel lanes can have substantive advantages by providing space to incorporate features that reduce crashes and enable a Complete Streets design model. Often, the design objective is to distribute limited cross-sectional width to maximize safety for a wide variety of road users. Practitioners may choose narrower lane widths to manage or reduce speed and shorten crossing distances for pedestrians. Practitioners may adjust lane widths to incorporate other cross-sectional elements, such as medians for access control, pedestrian refuge islands, bicycle facilities, on-street parking, transit stops, and landscaping. The adopted ranges for lane width in the urban, low-speed environment normally provide practitioners adequate flexibility to achieve a desirable urban cross section.

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37 AASHTO, Green Book, 7th ed. (2018).

38 Mooney, "Revisions to the Controlling Criteria" (2016).

39 AASHTO, *Highway Safety Manual* (Washington, DC: AASHTO, 2010).

40 Douglas W. Harwood, Daniel J. Cook, Richard C. Coakley, and Chad Polk, *NCHRP Research Report 876: Guidelines for Integrating Safety and Cost-Effectiveness into Resurfacing, Restoration, and Rehabilitation (3R) Projects* (Washington, DC: The National Academies Press, 2021).

OPERATIONAL IMPACT

▶ High-Speed Roadways

When determining highway capacity for high-speed, free-flow roads, adjustments are made to reflect the effect of lane width on free-flow speeds. Lane widths of less than 12 feet reduce travel speeds on high-speed roadways. The reductions are approximately 2 mph for 11-foot lanes and nearly 7 mph for 10-foot lanes.[41]

▶ Low-Speed Roadways

The same operational impacts that unintentionally slow traffic on high-speed roadways can be used to purposefully encourage lower speeds on low-speed roadways. Lane width reduction is a common traffic calming measure that alters driver behavior by making drivers increasingly aware of their surroundings and other users. The interruption to free-flow traffic is not generally a concern in the case of traffic calming since free flow rarely occurs in the urban, low-speed environment in which the effect is desired.

OTHER IMPACTS

In urban or suburban settings, narrower lanes may have a positive effect on vulnerable road users such as bicyclists, pedestrians, and people with disabilities. One example is the decreased exposure and crash risk resulting from reduced crossing time at intersections.

Intentionally narrowing lanes can designate separate operating spaces, such as bicycle lanes or sidewalks. Narrowing can also provide additional space for transit lanes.[42] The combination of lane width and corner radius can affect the safety of vulnerable road users who may be using the adjacent bicycle lane, sidewalk, or shoulder.

INTERRELATIONSHIPS

Practitioners should understand the interrelationships among lane width and other design elements. The risk of roadway departure, head-on, or sideswipe crashes increases on high-speed roadways that have narrow lanes and narrow or absent shoulders. Drivers on rural two-lane highways without shoulders may shift even closer to the centerline as they become less comfortable with noticeable fixed objects on the roadside. Conversely, drivers may shift closer to the edge to distance themselves from oncoming traffic, which can put them at greater risk of driving off the paved portion of the roadway (and driving over potential edge drop-offs).

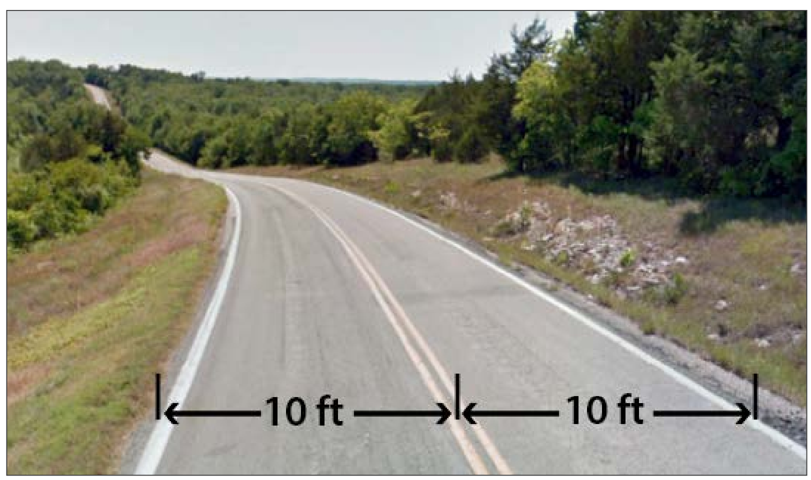

Figure 5. Photo. Narrower lanes on a rural roadway.

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41 Transportation Research Board (TRB), *Highway Capacity Manual 6th Edition: A Guide for Multimodal Mobility Analysis* (Washington, DC: The National Academies Press, 2016).

42 Charles V. Zeeger, Dan Nabors, and Peter Lagerway, *PEDSAFE 2013 Pedestrian Safety Guide and Countermeasure Selection System* (Washington, DC: USDOT, August 2013).

Lane width influences traffic operations and highway capacity on freeways and high-speed (i.e., design speeds of 50 mph and higher) roadways. The interaction of lane width with other geometric elements, primarily shoulder width, also affects operations. Horizontal curve radius is another factor that can influence the safety of lane width reductions on freeways and high-speed roadways. Curvilinear horizontal alignments increase the risk of roadway departure crashes in general. Combined with narrow lane widths, the risk further increases for most high-speed roadways. Trucks and other large vehicles may off-track into adjacent lanes or onto the shoulder.

MITIGATION STRATEGIES

Table 1 summarizes mitigation strategies that may accomplish project objectives when the lane width criterion is not met. Following the table, each strategy is discussed in the same order it appears in the table. More specific information may be found in the Green Book,[43] *Roadside Design Guide*,[44] and the *Manual on Uniform Traffic Control Devices for Streets and Highways*[45] (MUTCD).

Table 1. Summary of mitigation strategies for lane width exceptions.

Objective	Example Mitigation Strategies
Keep vehicles on roadway	Pavement markings Rumble strips and stripes Wider longitudinal lines Enhanced delineation Lighting
Provide for a safe recovery	SafetyEdge[SM] Shoulders Clear zones
Reduce crash severity	Barriers

▸ Keep Vehicles on Roadway

Pavement Markings

Pavement markings are another low-cost mitigation strategy used to enhance drivers' awareness of their surroundings. This awareness can be enhanced by wider edge lines, recessed pavement markings, or raised pavement markers. These applications improve the visibility of the boundary of the lanes and help drivers stay on the road—especially when the pavement is wet or during times when visibility is otherwise poor, such as at nighttime. Pavement markings can indicate an upcoming change in the roadway. Pavement marking condition, retroreflectivity, and durability play important roles in the visibility of the lane boundaries. Raised pavement markers, recessed pavement markings, and durable pavement marking materials may have higher costs than other marking materials, but they may provide advantages with respect to longevity in regions where snow and ice removal operations cause additional wear and tear.

Source: FHWA.

Figure 6. Photo. Raised pavement markers.

[43] AASHTO, Green Book, 7th ed. (2018).

[44] AASHTO, *Roadside Design Guide*, 4th ed. (Washington, DC: 2011).

[45] FHWA, *Manual on Uniform Traffic Control Devices for Streets and Highways*, rev. eds. 1–3 (Washington, DC: 2022).

Rumble Strips and Stripes

Rumble strips and stripes, an FHWA Proven Safety Countermeasure,[46] can warn motorists of an impending lane departure. Longitudinal rumble strips are milled or raised elements on the pavement intended to alert drivers through vibration and sound that the vehicle has left the travel lane. They can be installed on the shoulder, edge line, or at or near the center line of an undivided roadway. Rumble stripes are edge line or center line rumble strips where the pavement marking is placed over the rumble strip. This can increase pavement marking visibility and durability during wet, nighttime conditions and can improve the durability of the marking on roads with snowplowing operations. Where rumble strips cannot be placed due to noise concerns, agencies may consider a design using an oscillating sine wave pattern (also known as mumble strips) that reduces noise outside of the vehicle. Some designs or applications of rumble strips and stripes have negative impacts on the motorcycle and bicycle communities, so agencies should collaborate with State and local groups to address any concerns. Involving stakeholders early in the process may improve the chance for designs to achieve a balance between safety and meeting the needs of all road users.

Source: FHWA.

Figure 7. Photo. Edge line and centerline rumble stripes.

Wider Longitudinal Lines

Center lines, lane lines, and edge lines are the primary longitudinal pavement markings on roadways. They delineate the travel lane for the driver, assist with lane placement to avoid collisions with other vehicles, and provide a preview of changing roadway alignment. Pavement markings located within the driver's focus provide continuous information to help drivers correctly position their vehicles in the roadway. In the case of narrower lanes, agencies may use wider lines to increase conspicuity and enhance their function. As the number of automated vehicles increases on roadways, wider edge lines may also provide better guidance for these vehicles' sensors. Wider edge lines are a Proven Safety Countermeasure.[47]

Enhanced Delineation

The chances of a vehicle staying within narrower lanes are greater if the boundaries of the roadway are well defined. Enhanced delineation treatments can alert drivers of upcoming curves or other changes in the alignment and help drivers stay on the roadway. Examples of enhanced delineation may include retroreflective sign posts or delineator posts, as well as retroreflective strips on roadside barriers. Enhanced delineation is advantageous in dark or adverse weather conditions when pavement markings may not be as effective in keeping vehicles within their lanes.

Source: FHWA.

Figure 8. Photo. Enhanced delineation at night.

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46 FHWA, "Longitudinal Rumble Strips and Stripes on Two-Lane Roads," *Making Our Roads Safer | One Countermeasure at a Time*, FHWA-SA-21-036.

47 FHWA, "Wider Edge Lines," M*aking Our Roads Safer*, FHWA-SA-21-055.

Lighting

Roadway lighting improves the delineation of the roadway at nighttime. Besides illuminating the roadway alignment, lighting also enhances drivers' ability to perceive and react to their surroundings. Lighting is a Proven Safety Countermeasure.[48] Research indicates that continuous lighting on both rural and urban highways (including freeways) has an established safety benefit for motorized vehicles.[49]

Lighting can also provide benefits to pedestrians, bicyclists, and other users as they travel along and across roadways. Agencies can provide adequate visibility of the roadway and its users through the uniform application of lighting that provides full coverage along the roadway or the strategic placement of lighting where it is needed the most.

▶ Provide for a Safe Recovery

SafetyEdge^{SM}

If an errant vehicle travels off a narrow lane, the best outcome is for the driver to safely return the vehicle to the roadway. SafetyEdge^{SM} is a Proven Safety Countermeasure that can aid that return.[50] SafetyEdge^{SM} is a compacted wedge built at the edge of the pavement that enables a vehicle to reenter the roadway without the dangers of tire scrub. The wedge is angled at a relatively gentle 30° and is placed and compacted by way of a special device within the paver. Even with SafetyEdge^{SM} agencies should still cover the edge with material so the pavement remains flush with the adjacent roadside.

Source: FHWA.

Figure 9. Photo. SafetyEdge^{SM}.

Shoulders

Shoulders provide several services, such as refuge for disabled vehicles, emergency functions, and structural support of the traveled way components. They are particularly important adjacent to narrow lanes, however, since they also provide additional lateral space for errant drivers to maneuver their vehicles and recover the roadway. Similarly, they provide space for drivers to take evasive action in the face of an oncoming threat. Finally, a shoulder addition provides lateral distance and a surface on which to install rumble strips, further mitigating the effects of narrow lanes.

Source: FHWA.

Figure 10. Photo. Paved shoulder with rumble stripe.

48 FHWA, *Proven Safety Countermeasures – Lighting*, FHWA-SA-21-050.

49 Rune Elvik and Truls Vaa, *Handbook of Road Safety Measures* (Oxford, UK: Elsevier, 2004).

50 FHWA, *Proven Safety Countermeasures – SafetyEdge^{SM}*, FHWA-SA-21-038.

Clear Zones

An area free of fixed objects and traversable to the extent practicable can minimize harm if a vehicle leaves the roadway.

Depending on the roadway context and site characteristics, implementing this strategy may involve:

- Slope flattening or improved roadside grading to meet the appropriate clear zone criteria
- Removal of trees and other fixed objects to provide a clear area adjacent to the roadway
- Use of breakaway devices for objects located within the clear zone
- Barrier protection or delineation of objects that cannot be removed or relocated

Figure 11. Photo. Clear zone.

Given the wide range of scopes that may be possible to achieve this mitigation strategy, the implementation costs may be low, moderate, or high depending on the approach. More information on clear zone widths, based on speed and volume, can be found in AASHTO's *Roadside Design Guide*.[51]

▸ Reduce Crash Severity

Barriers

Since not all roadside risks can be removed, relocated, or redesigned, installing roadside barriers to shield objects or steep embankments may be necessary. Generally these barriers should only be used when the consequences of crashing with whatever is being shielded are more severe than the consequences of crashing into the barrier itself. Three common types of barriers are cable barrier, metal-beam guardrail, and concrete barrier. Cable barrier is a flexible barrier made from steel cables mounted on weak steel posts. Flexible barriers are more forgiving and have the most deflection. Metal-beam guardrail is a semirigid barrier where a W-beam or box-beam is mounted on steel or timber posts. Metal-beam guardrail deflects less than cable barriers, so it can be located closer to objects where space is limited. Concrete barrier is a rigid barrier that has little-to-no deflection. Barriers can be applied in the median of a divided highway to redirect vehicles when they leave the roadway. Median barriers are a Proven Safety Countermeasure and reduce the risk of cross-median crashes.[52]

[51] AASHTO, *Roadside Design Guide*, 4th ed. (2011).

[52] FHWA, "Median Barriers," *Making Our Roads Safer*, FHWA-SA-21-037.

Chapter 5. Shoulder Width

DEFINITION

Shoulder width is the lateral roadway distance located outside the vehicular lanes primarily provided for the accommodation of stopped vehicles for emergency use and for lateral support of base and surface course.[53]

SHOULDER WIDTH

The lateral roadway distance located outside the vehicular lanes primarily provided for the accommodation of stopped vehicles for emergency use and for lateral support of base and surface course.

The shoulder may also support the following additional functions:

- Recovery opportunity for errant vehicles
- Bicyclist or pedestrian travel
- Lateral clearance to obstacles
- Retention for stormwater spread in curbed sections
- Working space for maintenance, enforcement, or incident management

APPLICABILITY

FHWA policy does not require a design exception for shoulder width on non-freeway roadways with a design speed less than 50 mph. FHWA requires a design exception when the shoulder width criterion is not met on interstate highways and NHS freeways and roadways with a design speed greater than or equal to 50 mph.[54]

SAFETY IMPACT

▸ High-Speed Roadways

On high-speed roadways, shoulders provide the following safety benefits that generally increase with shoulder width:

- Shoulders provide space for emergency storage of disabled vehicles. Particularly on high-speed, high-volume highways, such as urban freeways, the ability to move a disabled vehicle off the travel lanes reduces the risk of rear-end crashes.
- Shoulders provide space for enforcement activities. This is important for the outside (right) shoulder because law enforcement activities are conducted in this location. Shoulder widths of approximately 8 feet or greater are normally required for this function.
- Shoulders are part of the clear zone and provide an area for drivers to maneuver to avoid crashes. This is important on high-speed, high-volume highways or at locations where there is limited stopping sight distance. Shoulder widths of approximately 8 feet or greater are normally required for this function.

53 AASHTO, *AASHTO Transportation Glossary* (2009).

54 Mooney, "Revisions to the Controlling Criteria" (2016).

- Shoulders increase safety by providing a stable, clear recovery area for drivers who have inadvertently left the travel lane. Earthen shoulders should be firm, stable, and maintained to be vertically flush with the adjacent pavement. This enables smooth reentry to the lane without introducing additional instability into the vehicle. Areas with pavement edge drop-offs can be a safety risk. Edge drop-offs occur where gravel or earth material is adjacent to the paved lane or shoulder. This material can settle or erode at the pavement edge, creating a drop-off that can make it difficult for a driver to safely recover after driving off the paved portion of the roadway. The drop-off can contribute to a loss of control as the driver tries to bring the vehicle back onto the roadway, especially if the driver does not reduce speed before attempting to recover. Paved or partially paved shoulders can help assuage this condition.
- Shoulders improve stopping sight distance at horizontal curves by providing an offset to vertical objects, such as barriers and bridge piers.
- In rural areas, shoulders can accommodate bicycle travel. FHWA's *Bikeway Selection Guide*[55] provides information on selecting a preferred shoulder width to accommodate bicyclists based on volumes and posted speeds in the rural context. For the shoulder to be usable, it should be well maintained and periodically swept.

▶ Low-Speed Roadways

On low-speed urban and suburban roadways (non-freeway), curb-and-gutter sections with no shoulder are often used. Shoulders are generally not provided on urban and suburban roadways unless there is an operational need. In some cases, that operational need may be for pedestrian traffic when sidewalks cannot be provided.

OPERATIONAL IMPACT

▶ High-Speed Roadways

Shoulder width has a measurable effect on traffic operations and highway capacity[56] on high-speed, free-flow roadways, such as freeways. Other operational impacts of shoulders include:

- Shoulders provide space for emergency storage of disabled vehicles, which prevents a lane from being closed and the resulting congestion.
- Shoulders may provide space for maintenance activities without closing a travel lane. Shoulder widths of approximately 8 feet or greater are normally required for this function.
- In northern regions, shoulders provide space for snow storage.
- Shoulders provide space for traffic incident management activities and are often used by emergency responders. Even if the response is not being staged on the shoulders at the site, the shoulders may aid responders in traveling to the incident.
- Shoulders are sometimes used on high-speed non-freeways with sloping curbs and enclosed drainage systems to store and convey water during storms, which prevents water from spreading onto the travel lanes.

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55 Bil Schultheiss, Dan Goodman, Lauren Blackburn, Adam Wood, Dan Reed, and Mary Elbech, *Bikeway Selection Guide*, FHWA-SA-18-077 (Washington, DC: USDOT, February 2019).

56 Leverson Boodlal, Eric T. Donnell, Richard J. Porter, Dileep Garimella, Thanh Le, Kevin Croshaw, Scott Himes, Philip Kulis, and Jonathan Wood, *Factors Influencing Operating Speeds and Safety on Rural and Suburban Roads*, FHWA-HRT-15-30 (Washington, DC: USDOT, May 2015).

▸ Low-Speed Roadways

Shoulders are primarily used on high-speed highways. Using a shoulder on urban and suburban non-freeway arterials, where a Complete Streets design model is recommended, may induce higher motor vehicle operating speeds.

INTERRELATIONSHIPS

The interaction of shoulder width with other geometric elements—primarily lane width—affects operations and safety. For very low-volume rural two-lane roads, the increase of shoulder width can reduce crashes.[57] Shoulder width is also related to curve radius, in that it can function as a surrogate for lane widening through sharper curves on rural highways. Widening the shoulders through curves can decrease roadway departures. The wider driving surfaces provide additional lateral space to mitigate the errant trajectories of drivers struggling to steer through the middle of the lane. This phenomenon has a practical limit, however, as too much space can increase operating speeds to undesirable levels.

MITIGATION STRATEGIES

Table 2 summarizes strategies that may be used to accomplish project objectives when the shoulder width criterion is not met. Following the table, each strategy is discussed in the same order it appears in the table. More specific information may be found in the Green Book,[58] *Roadside Design Guide*,[59] and the MUTCD.[60]

Table 2. Summary of mitigation strategies for shoulder width exceptions.

Objective	Example Mitigation Strategies
Keep vehicles on roadway	Pavement markings Rumble strips and stripes Enhanced delineation Wider longitudinal lines Lighting
Provide for a safe recovery	SafetyEdge℠ Clear zones
Reduce crash severity	Barriers
Provide opportunity for enforcement and/or space for slower or disabled vehicles	Speed safety cameras Turnouts
Provide for quick response to incidents or other situations requiring use of shoulder	ITS cameras and surveillance systems

57 Frank Gross, Paul P. Jovanis, Kimberly Eccles, and Ko-Yu Chen, *Safety Evaluation of Lane and Shoulder Width Combinations on Rural, Two-Lane, Undivided Roads*, FHWA-HRT-09-031 (Washington, DC: USDOT, June 2009).

58 AASHTO, Green Book, 7th ed. (2018).

59 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

60 FHWA, MUTCD, rev. eds. 1–3 (2022).

▸ Keep Vehicles on Roadway

Pavement Markings

Pavement markings are a low-cost mitigation strategy used to enhance drivers' awareness of their surroundings. This awareness can be enhanced by wider edge lines, recessed pavement markings, or raised pavement markers. These applications improve the visibility of the boundary of the lanes and help drivers stay on the road—especially when the pavement is wet or during times when visibility is otherwise poor, such as at nighttime. Pavement markings can indicate an upcoming change in the roadway. Pavement marking condition, retroreflectivity, and durability play important roles in the visibility of the lane boundaries. Raised pavement markers, recessed pavement markings, and durable pavement marking materials may have higher costs than other marking materials, but they may provide advantages with respect to longevity in regions where snow and ice removal operations cause additional wear and tear.

Rumble Strips and Stripes

Rumble strips and stripes, an FHWA Proven Safety Countermeasure,[61] can warn motorists of an impending lane departure. Longitudinal rumble strips are milled or raised elements on the pavement intended to alert drivers through vibration and sound that the vehicle has left the travel lane. They can be installed on the shoulder, edge line, or at or near the center line of undivided roadways. Where rumble strips cannot be placed due to noise concerns, agencies may consider a design using an oscillating sine wave pattern (also known as mumble strips) that reduces noise outside of the vehicle. Some designs or applications of rumble strips and stripes have negative impacts on the motorcycle and bicycle communities, so agencies should collaborate with State and local groups to address any concerns. Involving stakeholders early in the process may improve the chance for designs to achieve a balance between safety and meeting the needs of all road users.

Enhanced Delineation

Enhanced delineation treatments can alert drivers of upcoming curves or other changes in the alignment and help drivers stay on the roadway if the shoulder width criterion cannot be met. Examples of enhanced delineation may include retroreflective sign posts or delineator posts, as well as retroreflective strips on roadside barriers. Enhanced delineation is advantageous in dark or adverse weather conditions when pavement markings may not be as effective in keeping vehicles on the roadway.

Wider Longitudinal Lines

Edge lines delineate the outer limits of the travel lane for the driver and provide a preview of the changing roadway alignment. When shoulders are narrow or nonexistent, agencies may use wider edge lines to increase conspicuity and decrease the chances of drivers leaving the lane and encountering the roadside environment. As the number of automated vehicles increases on roadways, wider edge lines may also provide better guidance for these vehicles' sensors. Wider edge lines are a Proven Safety Countermeasure.[62]

Lighting

Roadway lighting improves the delineation of the roadway at nighttime and enhances drivers' ability to perceive and react to their surroundings. Lighting is a Proven Safety Countermeasure.[63] Research indicates that continuous lighting on both rural and urban highways (including freeways) has an established safety benefit for motorized vehicles.[64] Lighting can also provide benefits to pedestrians, bicyclists, and other users as they travel along and across roadways. Agencies can provide adequate visibility of the roadway and its users through the uniform application of lighting that provides full coverage along the roadway or the strategic placement of lighting where it is needed the most.

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61 FHWA, "Longitudinal Rumble Strips and Stripes on Two-Lane Roads," *Making Our Roads Safer*, FHWA-SA-21-036.

62 FHWA, "Wider Edge Lines," *Making Our Roads Safer*, FHWA-SA-21-055.

63 FHWA, *Proven Safety Countermeasures – Lighting*, FHWA-SA-21-050.

64 Rune Elvik and Truls Vaa, *Handbook of Road Safety Measures* (2004).

▶ Provide for a Safe Recovery

SafetyEdge℠

If an errant vehicle travels off the driving lane, the best outcome is for the driver to safely return the vehicle to the roadway. Appropriately sized shoulders generally aid this outcome. When shoulders are narrowed or eliminated, SafetyEdge℠ is a Proven Safety Countermeasure that can aid that return.[65]

SafetyEdge℠ is a compacted wedge built at the edge of the pavement that allows a vehicle to reenter the roadway without the dangers of tire scrub. The wedge is angled at a relatively gentle 30° and is placed and compacted by way of a special device within the paver. Even with SafetyEdge℠, agencies should still cover the edge with material so the pavement remains flush with the adjacent roadside.

Clear Zones

Once a vehicle leaves the roadway it is important to encounter a region free of fixed objects and non-traversable slopes. Depending on the roadway context and site characteristics, implementing this strategy may involve:

- Slope flattening or improved roadside grading to meet the appropriate clear zone criteria
- Removal of trees and other fixed objects to provide a clear area adjacent to the roadway
- Use of breakaway devices for objects located within the clear zone
- Barrier protection or delineation of objects that cannot be removed or relocated

More information on clear zone widths, based on speed and volume, can be found in AASHTO's *Roadside Design Guide*.[66] Since the shoulder is considered part of the clear zone, additional clear roadside width should be established to compensate for narrow shoulders.

▶ Reduce Crash Severity

Barriers

Since not all roadside risks can be removed, relocated, or redesigned, installing roadside barriers to shield objects or steep embankments may be necessary. Generally these barriers should only be used when the consequences of crashing with whatever is being shielded are more severe than the consequences of crashing into the barrier itself. Three common types of barriers are cable barrier, metal-beam guardrail, and concrete barrier. Cable barrier is a flexible barrier made from steel cables mounted on weak steel posts. Flexible barriers are more forgiving and have the most deflection. Metal-beam guardrail is a semirigid barrier where a W-beam or box-beam is mounted on steel or timber posts. Metal-beam guardrail deflects less than cable barriers, so it can be located closer to objects where space is limited. Concrete barrier is a rigid barrier that has little-to-no deflection. Barriers can be applied in the median of a divided highway to redirect vehicles when they leave the roadway. Median barriers are a Proven Safety Countermeasure and reduce the risk of cross-median crashes.[67]

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65 FHWA, *Proven Safety Countermeasures – SafetyEdge℠*, FHWA-SA-21-038.

66 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

67 FHWA, "Median Barriers," *Making Our Roads Safe*r, FHWA-SA-21-037.

▶ Provide Opportunity for Enforcement and/or Place for Slower or Disabled Vehicles

Speed Safety Cameras

Speed safety cameras are devices that employ radio detection and ranging (RaDAR) or light detection and ranging (LiDAR) to determine vehicle speeds on the roadway.The system can capture the license plates of speeding vehicles and use an algorithm to automatically issue citations. Speed safety cameras may be an appropriate strategy to implement on particular roadways if shoulder width criteria cannot be met and therefore little refuge exists for traditional enforcement activities. This is especially important if there is a history of speeding-related crashes. Speed safety cameras are a Proven Safety Countermeasure and can be an effective and reliable technology to manage speeds.[68]

Figure 12. Photo. Speed safety camera.

Turnouts

Turnouts are graded and paved areas next to the through travel lanes that vehicles can enter for several reasons. These include letting queued vehicles overtake a slower-moving vehicle when passing opportunities are limited. Turnouts are also used for enforcement activities, temporary refuge for disabled vehicles, and rural postal carriers to access mailboxes.

▶ Provide for Quick Response to Incidents or Other Situations Requiring Use of Shoulder

Intelligent Transportation System Cameras and Surveillance Systems

Shoulders provide space for disabled vehicles to get out of the main flow of traffic. Agencies may use ITS cameras and surveillance systems in locations with limited shoulders (often on freeways) to monitor traffic flow and watch for incidents or disabled vehicles. This technology allows the agency through its traffic management center to quickly respond and deploy motorist assistance or notify enforcement as needed. Quick response to these occurrences can prevent any secondary incidents or crashes.

Figure 13. Photo. Emergency turnout.

68 FHWA, "Speed Safety Cameras," *Making Our Roads Safer*, FHWA-SA-21-070.

Chapter 6. Horizontal Curve Radius

DEFINITION

Horizontal curves are used to change the direction of the road by providing a transition between two tangent segments of roadway. A horizontal curve is the arc of a circle. The radius of that circle is the distance from the central point to the circumference. The radius of curvature works together with the rate of superelevation and the maximum side friction factor selected for design to provide a threshold of driver comfort that is sufficient to provide a margin of safety against skidding and vehicle rollover.

HORIZONTAL CURVE RADIUS

The distance from the central point to the circumference of a circular curve.

APPLICABILITY

FHWA policy does not require a design exception for horizontal curve radius on non-freeway roadways with a design speed less than 50 mph. FHWA requires a design exception when the horizontal curve radius criterion is not met on interstate highways and NHS freeways and roadways with a design speed greater than or equal to 50 mph.[69]

SAFETY IMPACT

▸ High-Speed Roadways

The safety performance of a high-speed roadway is influenced by the presence and design characteristics of horizontal curvature, including the length of curve and radius. Other factors contributing to safety of horizontal curves include the cross section and the character of the roadside and surface through the curve.

Even when the design criteria are met, the physical forces associated with curved motion make navigating a curve more challenging than driving on a tangent. This is evidenced by the fact that more than a quarter of fatal crashes are associated with a horizontal curve, and more than three quarters of those involve a departure from the roadway.[70]

The horizontal alignment preceding a curve influences approach speeds. Research has shown that for rural two-lane highways, the expected crash frequency increases as the speed differential from the approach tangent to the curve increases.[71] This may occur if the curve is preceded by a long segment of tangent roadway, if the approach is on a significant downgrade, or if the curve is not visible to the driver on the approach. At exit ramps and particularly exit loop ramps, a lack of deceleration length can contribute to drivers running off the road at the first curve after exiting a freeway.

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69 Mooney, "Revisions to the Controlling Criteria" (2016).

70 FHWA, Office of Safety, "Horizontal Curve Safety," last modified: March 14, 2022, https://safety.fhwa.dot.gov/roadway_dept/countermeasures/horicurves/.

71 Kay Fitzpatrick, Lily Elefteriadou, Douglas Harwood, Jon Collins, John McFadden, Ingrid Anderson, Raymond Krammes, Nelson Irizarry, Kelly Parma, Karin Bauer, and Karl Passetti, *Speed Prediction for Two-lane Rural Highways*, FHWA-RD-99-171 (Washington, DC: USDOT, August 2000).

Horizontal curves can present special safety problems for trucks and other large vehicles. Because of their higher center of mass, large vehicles are more susceptible to overturning at curves. Research confirms that such overturning can occur at speeds only slightly greater than the design speed of the curve.[72] In addition, off-tracking of large vehicles onto the adjacent lane or shoulder at horizontal curves can affect the safety of drivers and bicyclists and degrade operations.

▶ Low-Speed Roadways

The risk of lane departure crashes at horizontal curves is significantly influenced by speed. This is why horizontal curves in reduced-speed urban environments generally present fewer safety and operational issues. In these contexts, horizontal curves can have traffic calming impacts and encourage lower operating speeds on roadways, improving the safety for all road users.

OPERATIONAL IMPACT

A horizontal curve that has a radius less than the minimum for the selected design speed may or may not present an operational concern. Such risk depends on the site conditions. Sharp horizontal curves often result in a reduction in operating speeds on rural highways and freeways, and limit passing opportunities on two-lane highways. One approach to characterizing this risk for rural two-lane highways is through use of the design consistency module of IHSDM. The design consistency module predicts the 85th-percentile speed along an alignment as a function of various geometric and operational variables.

INTERRELATIONSHIPS

The minimum radius of curvature, combined with the superelevation rate, maximum side friction factor selected for design, and vehicle speed, affects the risk of lane-departure crashes on high-speed roadways. Theoretically a roadway could be superelevated to the extent that it provides all of the lateral resistance needed to keep a vehicle in its lane of travel. In practice, however, there are limits to these rates. If the cross slope were too steep, slower traffic could be drawn downward and out of the lane toward the inside of the curve. This effect could be exaggerated in icy conditions. Given the practical limits on superelevation, the remainder of lateral force demanded by the vehicle to maintain its lane must either be provided by pavement friction, increasing the radius of curvature, or decreasing speed. This relationship is defined in the horizontal curve model contained in the Green Book. One factor cannot be considered without recognizing the influence of the other factors. Other contributing factors may include the horizontal and vertical alignments preceding the curve and stopping sight distance.

MITIGATION STRATEGIES

Table 3 summarizes strategies that may be used to accomplish project objectives when the horizontal curve radius criterion is not met. Following the table, each strategy is discussed in the same order it appears in the table. More specific information may be found in the Green Book,[73] *Roadside Design Guide*,[74] and the MUTCD.[75]

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72 Douglas Harwood and John M. Mason Jr., "Horizontal Curve Design for Passenger Cars and Trucks," *Transportation Research Record* (Washington, DC: TRB, 1994).

73 AASHTO, Green Book, 7th ed. (2018).

74 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

75 FHWA, MUTCD, rev. eds. 1–3 (2022).

Table 3. Summary of mitigation strategies for horizontal curve radius exceptions.

Objective	Example Mitigation Strategies
Increase awareness of curve and keep vehicles on roadway	Enhanced delineation for horizontal curves Rumble strips and stripes High friction surface treatment (HFST) Roadway widening (lanes and/or shoulders) Speed feedback signs Lighting
Provide for a safe recovery	SafetyEdgeSM Clear zones
Reduce crash severity	Barriers

▸ Increase Awareness of Curve and Keep Vehicles on Roadway

Enhanced Delineation for Horizontal Curves

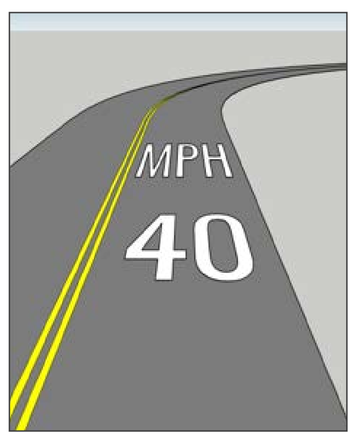
Negotiating a horizontal curve is inherently more challenging than driving along a tangent, but the chances of a vehicle staying on a curved roadway are greater if the limits of the travel lanes are well defined. Enhanced delineation for horizontal curves, an FHWA Proven Safety Countermeasure, outlines a variety of potential strategies that can be implemented in advance of or within curves, in combination, or individually.[76] Examples may include:

- Wider pavement markings
- Raised pavement markers
- In-lane curve warning pavement markings
- Retroreflective strips on sign posts or on roadside barriers
- Delineators
- Chevron signs
- Signs with enhanced conspicuity (e.g., larger signs, fluorescent signs, retroreflective strips on sign posts)
- Dynamic curve warning signs
- Sequential dynamic chevrons

These treatments can alert drivers to upcoming curves and the direction and sharpness of the curve. The MUTCD contains provisions for pavement marking and enhanced curve signing.[77]

Source: FHWA.

Figure 14. Photo. Enhanced curve signing (doubled signs and retroreflective posts).



Source: FHWA.

Figure 15. Illustration. In-lane curve warning pavement marking.

76 FHWA, *Proven Safety Countermeasures – Enhanced Delineation for Horizontal Curves,* FHWA-SA-21-035.

77 FHWA, MUTCD, rev. eds. 1–3 (2022).

Rumble Strips and Stripes

Rumble strips and stripes, an FHWA Proven Safety Countermeasure,[78] can warn motorists of an impending lane departure. Longitudinal rumble strips are milled or raised elements on the pavement intended to alert drivers through vibration and sound that the vehicle has left the travel lane. They can be installed on the shoulder, edge line, or at or near the center line of undivided roadways. Where rumble strips cannot be placed due to noise concerns, agencies may consider a design using an oscillating sine wave pattern (also known as mumble strips) that reduces noise outside of the vehicle. Some designs or applications of rumble strips and stripes have negative impacts on the motorcycle and bicycle communities, so agencies should collaborate with State and local groups to address any concerns. Involving stakeholders early in the process may improve the chance for designs to achieve a balance between safety and meeting the needs of all road users.

High Friction Surface Treatment

HFST is a component of FHWA's Proven Safety Countermeasure, Pavement Friction Management.[79] HFST consists of a layer of durable, anti-abrasion, and polish-resistant aggregate over a thermosetting polymer resin binder that locks the aggregate in place to restore or enhance friction and skid resistance. Calcined bauxite is the aggregate shown to yield the best results and should be used with HFST applications. HFST helps motorists maintain better control in both dry and wet driving conditions and is highly effective for reducing both wet and dry pavement friction-related crashes. FHWA's *High Friction Surface Treatment Site Selection and Installation Guide* provides information on HFST benefits, applications, and successful practices.[80]

Source: FHWA.

Figure 16. Photo. Calcined bauxite aggregate applied to polymer adhesive.

Roadway Widening

Widening the lanes, shoulders, or both through curves can decrease roadway departures. Wider driving surfaces provide additional lateral space to mitigate the errant trajectories of drivers struggling to steer through the middle of the lane. Widening also helps larger vehicles retain their lane of travel by accommodating their wheel paths during off-tracking. Design controls for curve widening are detailed in the Green Book.[81] Although to a somewhat lesser extent than other geometry-based curve countermeasures, widening may be cost-prohibitive as a remedial measure. However, it should be considered, as appropriate, in new designs.

Source: FHWA.

Figure 17. Photo. Lane and shoulder widening through horizontal curve.

78 FHWA, "Longitudinal Rumble Strips and Stripes on Two-Lane Roads," *Making Our Roads Safer*, FHWA-SA-21-036.

79 FHWA, *Proven Safety Countermeasures - Pavement Friction Management*, FHWA-SA-21-052.

80 FHWA, *High Friction Surface Treatment Site Selection and Installation Guide*, FHWA-SA-21-093 (2021).

81 AASHTO, Green Book, 7th ed. (2018).

Speed Feedback Signs

Along with superelevation and side friction, speed is a primary factor when determining horizontal curve radius. Lower speeds, therefore, can assist drivers in safely negotiating sharper curves. Dynamic speed feedback signs are an effective method of managing appropriate operating speeds. These signs are typically RaDAR-activated roadside signs that display a vehicle's current speed in relation to the posted or advisory speed. As a vehicle approaches at a speed higher than the posted or advisory speed, the dynamic portion of the sign alerts drivers, giving them the opportunity to slow down. These devices can be portable or permanent depending on an agency's requirement for a particular location.

Source: FHWA.

Figure 18. Photo. Speed feedback sign.

Lighting

Lighting is an FHWA Proven Safety Countermeasure.[82] Roadway lighting improves the delineation of the roadway and it can be appropriate for highway segments or spot locations that have high nighttime crash proportions. Besides illuminating the roadway alignment, lighting also enhances drivers' ability to perceive and react to their surroundings, including curves. Lighting can also provide benefits to pedestrians, bicyclists, and other users as they travel along and across roadways. Agencies may be reluctant to use lighting as a countermeasure because of initial investment and long-term operational costs, however, lighting can have good crash reduction performance.[83] Newer lighting technologies consume less energy and can mitigate some of the operation costs.

Source: FHWA.

Figure 19. Photo. Highway lighting at curve.

▶ Provide for a Safe Recovery

SafetyEdge℠

If an errant vehicle travels off the driving lane, the best outcome is for the driver to safely return the vehicle to the roadway. SafetyEdge℠ is a Proven Safety Countermeasure that can aid that return.[84] SafetyEdge℠ is a compacted wedge built at the edge of the pavement that allows a vehicle to reenter the roadway without the dangers of tire scrub. The wedge is angled at a relatively gentle 30° and is placed and compacted by way of a special device within the paver. Even with SafetyEdge℠, agencies should still cover the edge with material, so the pavement remains flush with the adjacent roadside.

82 FHWA, *Proven Safety Countermeasures – Lighting*, FHWA-SA-21-050.

83 Rune Elvik and Truls Vaa, *Handbook of Road Safety Measures* (2004).

84 FHWA, *Proven Safety Countermeasures – SafetyEdge℠*, FHWA-SA-21-038.

Clear Zones

Without sufficient superelevation and pavement friction, and operation at an appropriate speed for the conditions, a vehicle cannot successfully negotiate a curve and will continue in a tangential path. It is important for drivers to encounter a region free of fixed objects and non-traversable slopes where data indicate a higher risk for roadway departure fatalities and serious injuries along horizontal curves.

Depending on the roadway context and site characteristics, implementing this strategy may involve:

Source: FHWA.

Figure 20. Photo. Maintaining a clear zone outside a curve.

- Slope flattening or improved roadside grading to meet the appropriate clear zone criteria
- Removal of trees and other fixed objects to provide a clear area adjacent to the roadway
- Use of breakaway devices for objects located within the clear zone
- Barrier protection or delineation of objects that cannot be removed or relocated

More information on clear zone widths, based on speed and volume, can be found in AASHTO's *Roadside Design Guide*.[85] Practitioners may choose to increase these widths through horizontal curves according to adjustment factors given in the same publication.

▶ Reduce Crash Severity

Barriers

On curves with sharp radii, it may be appropriate to shield drivers from fixed objects or steep slopes on the roadside, particularly on the outside of the curve. This is accomplished by roadside devices such as guardrails, cable barriers, or concrete safety barriers. Generally these barriers should only be used when the consequences of crashing with whatever is being shielded are more severe than the consequences of crashing into the barrier itself. Costs may fluctuate depending on the device. Some products have high initial capital costs and low maintenance costs. Other products may initially be more affordable, but may require more costly repairs more often because of the increase in crash frequency and the low resiliency of the system. Additional information on roadside barriers may be found in the *Roadside Design Guide*.[86]

Source: FHWA.

Figure 21. Photo. Longitudinal barrier shielding outside of curve.

85 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

86 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

Chapter 7. Superelevation Rate

DEFINITION

Superelevation, commonly referred to as roadway banking, is the rotation of the pavement through a horizontal curve. Superelevation helps counteract the physical forces on a vehicle produced by tracking the curve, particularly on high-speed highways. The rate of superelevation is the ratio of the difference in pavement elevation—from edge to edge—to the width of the pavement. Superelevation rate is expressed as a percentage. Maximum superelevation rates for design are established by State policy, and they largely depend on climate, terrain, and the volume of heavy vehicles.

SUPERELEVATION RATE

The ratio of the difference in pavement elevation—from edge to edge—to the width of the pavement.

APPLICABILITY

As noted in the Green Book,[87] superelevation is not generally used on low-speed urban and suburban streets. In these situations, the design relies more on side friction to avoid skidding, with less emphasis placed on driver comfort. If the maximum side friction is inadequate for the selected curve radius and design speed, the AASHTO Method 2 distribution of superelevation and side friction may be used on low-speed roadways.[88]

FHWA policy does not require a design exception for superelevation rate on non-freeway roadways with a design speed less than 50 mph. FHWA requires a design exception when the superelevation rate criterion is not met for the proposed horizontal curve radius and design speed on interstate highways and NHS freeways and roadways with a design speed greater than or equal to 50 mph.[89] The AASHTO Method 5 distribution of superelevation and side friction is generally used on high-speed roadways. No design exceptions are required for superelevation transition lengths, or the lack of spiral transitions.[90]

SAFETY IMPACT

▶ High-Speed Roadways

On high-speed roadways, inadequate superelevation for the proposed horizontal curve radius and design speed can cause vehicles to skid as they travel through a curve, which can potentially result in a roadway departure crash. Roadway departure crashes represent the vast majority—more than 80 percent—of all fatal curve crashes.[91] Trucks and other large vehicles with high centers of mass are more likely to roll over at curves with inadequate superelevation. The roadway grade also impacts vehicle dynamics when traversing a curve. For example, inadequate superelevation of a curve at the bottom of a steep grade may not accommodate vehicles that have accelerated to an excessive speed while traversing the downgrade.

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87 AASHTO, Green Book, 7th ed. (2018).

88 AASHTO, Green Book, 7th ed. (2018), 1–5.

89 Mooney, "Revisions to the Controlling Criteria" (2016).

90 AASHTO, Green Book, 7th ed. (2018), 1–5.

91 NHTSA, Fatality Analysis Reporting System (FARS): 2006-2019 Final File and 2020 Annual Report File.

▶ Low-Speed Roadways

Superelevation is generally not used on low-speed urban and suburban roadways, where design relies more on side friction to avoid skidding with less emphasis on driver comfort. The generally lower speeds in the urban environment compensate for the lack of superelevation. Therefore, crash frequency is less influenced by superelevation in this setting than it would be for higher speed rural highways or freeways.[92]

OPERATIONAL IMPACT

As with horizontal curve radius, superelevation influences a driver's speed behavior on high-speed highways. Improperly superelevated cross sections decrease drivers' ability to comfortably navigate horizontal curves, prompting drivers to reduce their speed, which may negatively affect highway capacity.

INTERRELATIONSHIPS

Superelevation works together with horizontal curve radius and side friction to develop highways that can be driven in comfort, and without likelihood of skidding, by most drivers. While not a controlling criterion in and of itself, shoulder cross slope is affected by superelevation. If the shoulder is not superelevated at all, or rotated at a different rate than the roadway, then the breakover between the two may affect traversability. When this is the case, the algebraic difference between the cross slope of the roadway and that of the shoulder should not exceed 8 percent.[93] Rounding of the cross-sectional break between the lane and shoulder may alleviate some of the effects of a pronounced breakover.

Vertical grade is also related to superelevation. On grades steeper than 5 percent, the braking forces (downgrade) and the tractive forces (upgrade) increase friction demand through curves. Some adjustment to superelevation should be considered in these cases.[94] Conversely, where very mild grades are used for significant lengths of highway, practitioners should assure that superelevation transition cross slope and grade do not combine to form an isolated undrained area of pavement.

MITIGATION STRATEGIES

Table 4 summarizes strategies that may be used to accomplish project objectives when the superelevation rate criterion corresponding to the proposed horizontal curve radius and design speed is not met. Following the table, each strategy is discussed in the same order it appears in the table. More specific information may be found in the Green Book,[95] *Roadside Design Guide*,[96] and the MUTCD.[97]

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92 Douglas W. Harwood, Jessica M. Hutton, Chris Fees, Karin M. Bauer, Alan Glen, Heidi Ouren, Quincy Engineering, and HQE Inc., *NCHRP Report 783: Evaluation of the 13 Controlling Criteria for Geometric Design* (Washington, DC: The National Academies Press, 2014).

93 AASHTO, Green Book, 7th ed. (2018).

94 AASHTO, Green Book, 7th ed. (2018).

95 AASHTO, Green Book, 7th ed. (2018).

96 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

97 FHWA, MUTCD, rev. eds. 1–3 (2022).

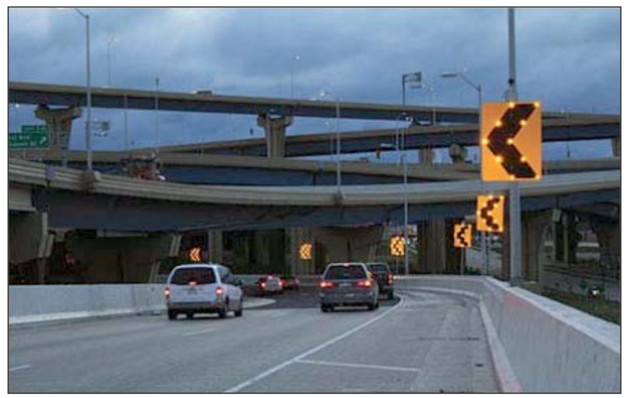
Table 4. Summary of mitigation strategies for superelevation rate exceptions.

Objective	Example Mitigation Strategies
Increase awareness of curve and keep vehicles on roadway	Enhanced delineation for horizontal curves Rumble strips and stripes High-friction surface treatment Roadway widening (lanes and/or shoulders) Dynamic curve warning system Speed feedback signs
Provide for a safe recovery	SafetyEdge[SM] Clear zones
Reduce crash severity	Barriers

Increase Awareness of Curve and Keep Vehicles on Roadway

Enhanced Delineation for Horizontal Curves

Even though superelevation provides a physical reaction, and delineation requires a behavioral adjustment, the chances of a vehicle staying on a curved roadway are greater if the limits of those lanes are well defined. Enhanced delineation for horizontal curves, an FHWA Proven Safety Countermeasure, outlines a variety of potential strategies that can be implemented in advance of or within curves, in combination, or individually.[98] Examples may include:



Source: FHWA.

Figure 22. Photo. Sequential dynamic curve warning system.

- Wider pavement markings
- Raised pavement markers
- In-lane curve warning pavement markings
- Retroreflective strips on sign posts or on roadside barriers
- Delineators
- Chevron signs
- Signs with enhanced conspicuity (e.g., larger signs, fluorescent signs, retroreflective strips on sign posts)
- Dynamic curve warning signs
- Sequential dynamic chevrons

These treatments can alert drivers to upcoming curves and the direction and sharpness of the curve. The MUTCD contains provisions for pavement marking and enhanced curve signing.[99]

98 FHWA, *Proven Safety Countermeasures – Enhanced Delineation for Horizontal Curves*, FHWA-SA-21-035.

99 FHWA, MUTCD, rev. eds. 1–3 (2022).

Rumble Strips and Stripes

Rumble strips and stripes, an FHWA Proven Safety Countermeasure,[100] can warn drivers of an impending lane departure. Longitudinal rumble strips are milled or raised elements on the pavement intended to alert drivers through vibration and sound that the vehicle has left the travel lane. They can be installed on the shoulder, edge line, or at or near the center line of an undivided roadways. Where rumble strips cannot be placed due to noise concerns, agencies may consider a design using an oscillating sine wave pattern (also known as mumble strips) that reduces noise outside of the vehicle. Some designs or applications of rumble strips and stripes have negative impacts on the motorcycle and bicycle communities, so agencies should collaborate with State and local groups to address any concerns. Involving stakeholders early in the process may improve the chance for designs to achieve a balance between safety and meeting the needs of all road users.

High Friction Surface Treatment

The primary factors that keep vehicles on the roadway through curves are superelevation and pavement friction. In the absence of adequate superelevation, increasing friction can reduce roadway departures. HFST is a component of FHWA's Proven Safety Countermeasure, Pavement Friction Management.[101] HFST consists of a layer of durable, anti-abrasion, and polish-resistant aggregate over a thermosetting polymer resin binder that locks the aggregate in place to restore or enhance friction and skid resistance. Calcined bauxite is the aggregate shown to yield the best results and should be used with HFST applications. HFST helps motorists maintain better control in both dry and wet driving conditions and is highly effective for reducing both wet and dry pavement friction-related crashes. FHWA's *High Friction Surface Treatment Site Selection and Installation Guide* provides information on HFST benefits, applications, and successful practices.[102]

Roadway Widening

Widening the lanes, shoulders, or both through curves can decrease roadway departures. Wider driving surfaces provide additional lateral space to mitigate the errant trajectories of drivers struggling to steer through the middle of the lane. Widening also helps larger vehicles retain their lane of travel by accommodating their wheel paths during off-tracking. Design controls for curve widening are detailed in the Green Book.[103] Although to a somewhat lesser extent than other geometry-based curve countermeasures, widening can be cost-prohibitive as a remedial measure. However, it should be included, as appropriate, in new designs.

Dynamic Curve Warning System

The superelevation needed is closely tied to the radius of curvature, maximum side friction factor, and vehicle speed. Lower speeds can assist drivers in safely negotiating curves with less dependency on superelevation. Dynamic curve warning systems are an effective method of managing appropriate operating speeds. These signs have beacons activated by either RaDAR or pavement loop detection, and flash to vehicles approaching at speeds higher than the advisory speeds. The beacons are intended to draw the drivers' attention to a static speed warning sign for the curve.

Speed Feedback Signs

The superelevation needed is closely tied to the radius of curvature, maximum side friction factor, and vehicle speed. Lower speeds can assist drivers in safely negotiating curves with less dependency on superelevation. Dynamic speed feedback signs are an effective method of managing appropriate operating speeds. These signs are typically activated by RaDAR and display a vehicle's current speed in relation to the posted or advisory speed. As a vehicle approaches at a speed higher than the advisory speed, the dynamic portion of the sign alerts drivers, giving them the opportunity to slow down. These devices can be portable or permanent depending on an agency's requirement for a particular location.

[100] FHWA, "Longitudinal Rumble Strips and Stripes on Two-Lane Roads," *Making Our Roads Safer*, FHWA-SA-21-036.

[101] FHWA, *Proven Safety Countermeasures - Pavement Friction Management*, FHWA-SA-21-052.

[102] FHWA, *High Friction Surface Treatment Site Selection and Installation Guide*, FHWA-SA-21-093 (2021).

[103] AASHTO, Green Book, 7th ed. (2018).

Provide for a Safe Recovery

SafetyEdge[SM]

If an errant vehicle travels off the driving lane, the best outcome is for the driver to safely return the vehicle to the roadway. Appropriately sized shoulders generally aid this outcome. When shoulders are narrowed or eliminated, SafetyEdge[SM] is a Proven Safety Countermeasure that can aid that return.[104] SafetyEdge[SM] is a compacted wedge built at the edge of the pavement that allows a vehicle to reenter the roadway without the dangers of tire scrub. The wedge is angled at a relatively gentle 30° and is placed and compacted by way of a special device within the paver. Even with SafetyEdge[SM], agencies should still cover the edge with material so the pavement remains flush with the adjacent roadside.

Clear Zones

Superelevation rates that do not correspond to the horizontal curve radius and design speed can lead to roadway departures. When a vehicle does depart the roadway, it is important for drivers to encounter a region free of fixed objects and non-traversable slopes. Depending on the roadway context and site characteristics, implementing clear zones may involve:

- Slope flattening or improved roadside grading to meet the appropriate clear zone criteria
- Removal of trees and other fixed objects to provide a clear area adjacent to the roadway
- Use of breakaway devices for objects located within the clear zone
- Barrier protection or delineation of objects that cannot be removed or relocated

More information on clear zone widths, based on speed and volume, can be found in the *Roadside Design Guide*. Practitioners may choose to increase these widths through horizontal curves according to adjustment factors given in the *Roadside Design Guide*.[105]

Reduce Crash Severity

Barriers

On curves that do not meet design criteria for superelevation, it may be appropriate to shield drivers from fixed objects or steep slopes on the roadside. This is accomplished by roadside devices such as guardrails, cable barriers, or concrete barriers. Generally these barriers should only be used when the consequences of crashing with whatever is being shielded are more severe than the consequences of crashing into the barrier itself. Costs may fluctuate depending on the device. Some products have high initial capital costs and low maintenance costs. Other products may initially be more affordable, but may require more costly repairs more often because of the increase in crash frequency and the low resiliency of the system. Additional information on shielding roadsides may be found in the *Roadside Design Guide*.[106]

104 FHWA, *Proven Safety Countermeasures – SafetyEdge[SM]*, FHWA-SA-21-038.

105 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

106 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

Source: Getty Images.

Chapter 8. Stopping Sight Distance

DEFINITION

Stopping sight distance is the length of roadway available to a driver to perceive, react, and bring a vehicle traveling at or below design speed to a controlled stop in advance of an obstacle.

Stopping sight distances are derived for various design speeds based on assumptions for:

- Driver reaction time
- Braking ability of most vehicles under wet pavement conditions
- Friction provided by most pavement surfaces, assuming good tires

STOPPING SIGHT DISTANCE

The length of roadway available to a driver to perceive, react, and bring a vehicle traveling at or below design speed to a controlled stop in advance of an obstacle.

APPLICABILITY

FHWA policy does not require a design exception for stopping sight distance on non-freeway roadways with a design speed less than 50 mph. FHWA requires a design exception when the stopping sight distance criterion is not met on interstate highways and NHS freeways and roadways with a design speed greater than or equal to 50 mph.[107] The stopping sight distance controlling criterion applies to horizontal alignments and vertical alignments except for sag vertical curves.[108]

SAFETY IMPACT

High-Speed Roadways

The adopted criterion for stopping sight distance applies to the entire length of a roadway. Limited stopping sight distance on rural two-lane highways is unlikely to lead to crashes, unless the portion of roadway hidden from the driver's view by the sight distance limitation includes a roadway feature, such as an intersection, a driveway, or a horizontal curve, that may require drivers to take steering or braking action.[109] Extrapolating this concept from rural two-lane highways to rural multilane highways may also be appropriate.[110]

Frequent lane use by slow-moving traffic, such as tractors, bicyclists, and horse-drawn carriages, are also a factor when considering the safety impact of limited stopping sight distance.

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107 Mooney, "Revisions to the Controlling Criteria" (2016).

108 AASHTO, Green Book, 7th ed. (2018).

109 *NCHRP Report 783* (2014).

110 *NCHRP Research Report* 876 (2021).

▶ Low-Speed Roadways

Stopping sight distance has less effect on the safety of low-speed roadways, unless an approaching intersection or driveway is hidden from the driver by the stopping sight distance limitation.[111] Where specific crash patterns or risks are due to limited stopping sight distance or where an approaching curve, intersection, or driveway is hidden by the stopping sight distance limitation, mitigation strategies should be considered. Mitigation should also be considered for inadequate stopping sight distances in advance of facilities meant for nonmotorized users (e.g., crosswalks, mid-block crossings, transit stops).

OPERATIONAL IMPACT

Drivers on high-speed highways are less comfortable on roadway segments with inadequate stopping sight distance, such as segments with short vertical curves and sharp horizontal curves. This reduced comfort can often lead to lower operating speeds. The impact of these reduced speeds on vehicular capacity is unclear, since these conditions most frequently occur on lower volume rural highways.

INTERRELATIONSHIPS

Stopping sight distance is influenced by several controlling criteria. Design speed is a primary factor in determining stopping sight distance because the distance required to bring a vehicle to a full controlled stop largely depends on the vehicle's speed before braking.

Stopping sight distance is also influenced by vertical and horizontal alignment. Parabolic curves are used to effect gradual changes between tangent grades on a roadway profile. Crest vertical curves naturally limit stopping sight distance; therefore, the design criterion specify minimum curve requirements based on the algebraic difference in grade and the design speed of the roadway. Stopping sight distance matters for sag vertical curves only in the sense that the geometry could result in headlight beams not illuminating the concern in the roadway ahead. Crashes related to stopping sight distance are largely a result of roadway geometry obscured by crest vertical curves.[112] On horizontal curves, physical obstructions such as bridge piers, barrier, walls, backslopes, and vegetation can limit stopping sight distance.

The combination of vertical alignment and vertical clearance may be related to stopping sight distance. For example, an overpass bridge—or other structural support over the roadway—can limit a driver's view of downstream obstacles in the road. This is particularly the case in sag curves.

MITIGATION STRATEGIES

Table 5 summarizes strategies that may be used to accomplish project objectives when the stopping sight distance criterion is not met. Following the table, each strategy is discussed in the same order it appears in the table. More specific information may be found in the Green Book,[113] *Roadside Design Guide*,[114] and the MUTCD.[115]

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111 *NCHRP Report 783* (2014).

112 *NCHRP Report 783* (2014).

113 AASHTO, Green Book, 7th ed. (2018).

114 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

115 FHWA, MUTCD, rev. eds. 1–3 (2022).

Table 5. Summary of mitigation strategies for stopping sight distance exceptions.

Objective	Example Mitigation Strategies
Enhance driver awareness approaching intersections	Signing Transverse rumble strips Intersection conflict warning systems
Manage conflict points	Access management Dedicated left- and right-turn lanes at intersections
Improve ability to avoid crash	High-friction surface treatment Shoulder widening Lighting
Reduce operating speeds	Speed feedback signs

▶ Enhance Driver Awareness Approaching Intersections

Signing

Warning signs call attention to unexpected conditions on the roadway that drivers might not readily perceive. Crest vertical curves frequently contribute to this lack of perception, and inadequate stopping sight distance can increase the risk of crash injury. For this reason, signs indicating conditions beyond the drivers' vision can be installed to warn drivers of situations that may otherwise catch them unaware and unable to react in time. MUTCD contains provisions for warning signs.[116]

Figure 23. Photo. Enhanced intersection ahead warning sign.

Transverse Rumble Strips

Rumble strips are effective at influencing driver behavior by providing real-time feedback using an audible warning and a vibration within the vehicle. They are typically longitudinally applied to help keep drivers on the roadway, but agencies may also transversely install them to warn drivers of a changing roadway condition ahead. This is especially important for stop-controlled intersections beyond a sharp horizontal curve, crest vertical curve, or other situations with limited stopping sight distance.

Figure 24. Photo. Transverse rumble strip warning of intersection beyond crest vertical curve.

[116] FHWA, *Manual on Uniform Traffic Control Devices*, rev. eds. 1–3 (2022).

Intersection Conflict Warning System

Reduced stopping sight distances could lead to drivers' inability to avoid sudden conflicts at intersections. Intersection conflict warning system is a dynamic signing system, designed to reduce crash frequency by warning drivers approaching an intersection of the presence of crossroad traffic entering. The system consists of static signing bearing the legend ENTERING TRAFFIC. The sign can be supplemented with a plaque reading WHEN FLASHING, or similar. These signs have beacons that are activated when crossroad traffic is sensed, and flash to warn mainline vehicles approaching the intersection.

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Figure 25. Photo. Intersection conflict warning system.

▸ Manage Conflict Points

Access Management

Access management involves minimizing or managing the number of access points, and therefore conflict points, along a corridor. The benefits of access management include increased travel efficiency and decreased crash levels.[117] Where stopping sight distance is limited and a driveway is hidden from mainline motorists, consolidating access points at a location with better stopping sight distance can be an effective mitigation measure. Reducing the number of access points along a roadway also reduces the potential conflicts. Corridor access management is an FHWA Proven Safety Countermeasure.[118]

Dedicated Left- and Right-Turn Lanes at Intersections

In settings with high traffic volumes and limited visibility of traffic queues or vulnerable road users, practitioners can consider separating movements at the intersection to provide for dedicated turn lanes to improve intersection operations. In rural settings, providing dedicated right- or left- turn lanes can enable drivers to exit the through traffic lane while they make their turning maneuver. Moving queued traffic out of the through traffic lanes can also lower the crash risk for drivers who suddenly encounter the intersection after traversing an area of limited stopping sight distance. Providing offset of left- and right-turn lanes to increase visibility can provide added safety benefits, and is preferable in many situations, particularly at locations with higher speeds, or where free-flow or permissive movements are possible. Dedicated left- and right-turn lanes at intersections are an FHWA Proven Safety Countermeasure.[119]

© 2022 Google® Street View™.

Figure 26. Photo. Dedicated left-turn lane on rural two-lane roadway.

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117 FHWA, "What is Access Management?," last modified June 3, 2021, https://ops.fhwa.dot.gov/access_mgmt/what_is_accsmgmt.htm.

118 FHWA, *Proven Safety Countermeasures – Corridor Access Management*, FHWA-SA-21-040.

119 FHWA, "Dedicated Left- and Right-Turn Lanes at Intersections," *Making Our Roads Safer*, FHWA-SA-21-041.

▶ Improve Ability to Avoid Crash

High Friction Surface Treatment

HFST is a component of FHWA's Proven Safety Countermeasure, Pavement Friction Management.[120] HFST is a durable calcined bauxite aggregate bonded to the concrete or asphalt roadway surface by a polymer agent. HFST is used to increase surface friction and skid resistance to keep drivers on the roadway. HFST helps decrease roadway departure crashes through horizontal curves, but it can also provide drivers an opportunity to stop more quickly on tangent segments and prior to intersections. This is especially important in situations where the condition is unexpected (as is the case with inadequate stopping sight distance) or on a steep downgrade.

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Figure 27. Photo. High friction surface treatment on tangent section in advance of signal on steep downgrade.

Shoulder Widening

Where there is limited sight distance to vehicles or other objects on the roadway ahead, a fundamental strategy is to provide shoulders that will improve a driver's ability to avoid a crash. Wide shoulders can give drivers a better chance to safely avoid a crash and to remain on the roadway. If the driver leaves the roadway, providing additional clear recovery areas on the roadside can reduce the probability of a severe run-off-the-road crash. Inside shoulders on divided highways with median barriers can be widened to improve stopping sight distance by reestablishing sight lines.[121]
If widening is infeasible, this mitigation can be effectively accomplished by swapping the inside and outside shoulder widths through the vicinity of the curve.[122]

© Missouri DOT.

Figure 28. Photo. Widened and paved shoulder improvements.

Lighting

Lighting is an FHWA Proven Safety Countermeasure.[123] Roadway lighting may be appropriate for spot locations with limited stopping sight distance that have high nighttime crash proportions. Besides illuminating the roadway alignment, lighting also enhances drivers' ability to perceive and react to their surroundings. Lighting can also provide benefits to pedestrians, bicyclists, and other users as they travel along and across roadways. Agencies may be reluctant to use lighting as a countermeasure because of initial investment and long-term operational costs, however lighting can have good crash reduction performance.[124] Newer lighting technologies consume less energy and can mitigate some of the operation costs.

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120 FHWA, *Proven Safety Countermeasures - Pavement Friction Management*, FHWA-SA-21-052.

121 AASHTO, Green Book, 7th ed. (2018), 3–118.

122 Texas Department of Transportation, *Roadway Design Manual* (Austin, Texas: Texas Department of Transportation, 2022).

123 FHWA, *Proven Safety Countermeasures – Lighting*, FHWA-SA-21-050.

124 Rune Elvik and Truls Vaa, *Handbook of Road Safety Measures* (2004).

▸ Reduce Operating Speeds

Speed Feedback Signs

Dynamic speed feedback signs may be an effective method of managing appropriate operating speeds in an area that has reduced stopping sight distance. These signs are typically activated by RaDAR and display a vehicle's current speed in relation to the posted or advisory speed. As a vehicle approaches at a speed higher than the advisory speed, the dynamic portion of the sign alerts drivers, giving them the opportunity to slow down. These devices can be portable or permanent depending on an agency's requirement for a particular location.

Source: Getty Images.

Chapter 9. Maximum Grade

DEFINITION

Grade is the rate of ascent or descent of a roadway expressed as a percentage or as the change in elevation per unit of horizontal length.[125,126] Maximum grade is the highest rate at which vehicles can operate without an appreciable loss in speed below that normally maintained on level roadways. The effect of grades on truck speeds is much more pronounced than on speeds of passenger cars.[127] Selecting maximum grade is influenced by the natural terrain, desired operating speed of the roadway, and anticipated vehicle mix.

MAXIMUM GRADE

Maximum grade is the highest rate at which vehicles can operate without an appreciable loss in speed below that normally maintained on level roadways.

APPLICABILITY

FHWA policy does not require a design exception for maximum grade on non-freeway roadways with a design speed less than 50 mph. FHWA requires a design exception when the criterion for maximum grade is not met on interstate highways and NHS freeways and roadways with a design speed greater than or equal to 50 mph.[128]

SAFETY IMPACT

▶ High-Speed Roadways

Speed differential on high-speed highways with steep grades can contribute to safety issues. On high-speed highways, a primary safety concern is the potential for drivers of heavy trucks to lose control as they descend steep grades. Another potential safety concern is when a horizontal curve lies at the bottom of a steep grade. This combination of alignments increases the risk of rollover and roadway departure crashes.[129] Snowy and icy conditions can complicate the ability to stop on steeper downgrades or reach the crest of steeper upgrades.

▶ Low-Speed Roadways

Maximum grade does not generally impact safety for vehicular traffic on low-speed urban and suburban streets. When these roadways are also used by pedestrians, bicyclists, and transit riders, excessive grades can make travel more difficult and less accessible for individuals with disabilities.

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125 AASHTO, *AASHTO Transportation Glossary* (2009).

126 AASHTO, Green Book, 7th ed. (2018).

127 AASHTO, Green Book, 7th ed. (2018), 3–122.

128 Mooney, "Revisions to the Controlling Criteria" (2016).

129 AASHTO, Green Book, 7th ed. (2018), 3–36.

OPERATIONAL IMPACT

Steep grades on streets used by pedestrians and bicyclists can negatively impact operations. Bicyclists decelerate going uphill, so if they share a lane with motor vehicles, all traffic will decelerate. If there is insufficient space for a bicycle lane on both sides of the roadway, providing a bicycle lane on the uphill side can improve operations for bicyclists and motor vehicles. Steep grades also make travel for pedestrians more difficult, and less accessible for individuals with disabilities. In addition, since the cross slope in pedestrian crosswalks matches the grade of the roadway, the maximum grade may be controlled by cross slope limitations under accessibility standards.

Speed differential on high-speed highways with steep grades can contribute to operational issues. Trucks and other heavy vehicles lose speed on steep, ascending grades and may be unable to reach full highway speed until they have reached the crest. Vehicles behind the heavy trucks are slowed, which degrades operations at the least, contributes to rear-end conflicts, and, in some cases, results in risky passing maneuvers. Truck drivers may also choose to descend grades at slower speeds to maintain better control of their vehicles. Operations may be degraded for faster-moving vehicles from behind, creating an increased risk of rear-end crashes and risky passing maneuvers.

The critical length of grade should be evaluated to determine the maximum length of an upgrade on which a loaded truck can operate without an unreasonable reduction in speed. If satisfactory operations are to be maintained on grades longer than critical, adding extra lanes should be considered.[130] On rural two-lane highways, one tool for assessing the impact of grade on operations is IHSDM's design consistency module. This module produces a speed profile for continuous alignment by direction of travel.

INTERRELATIONSHIPS

Maximum grade controls are determined based on the design speed and terrain. In general, the lower the design speed and the more pronounced the terrain, the steeper the grade allowed. Stopping sight distance on steep downgrades with sight obstructions may need to be increased for heavy truck traffic.[131]

MITIGATION STRATEGIES

Table 6 summarizes strategies that may be used to accomplish project objectives when the maximum grade criterion is not met. Following the table, each strategy is discussed in the same order it appears in the table. More specific information may be found in the Green Book,[132] *Roadside Design Guide*,[133] and the MUTCD.[134]

Table 6. Summary of mitigation strategies for maximum grade exceptions.

Objective	Example Mitigation Strategies
Provide advanced warning	Signing
Improve safety and operations for vehicles navigating steep grades	Climbing lane Downgrade lane High-friction surface treatment Speed feedback signs Variable speed limits
Reduce crash severity	Runaway truck ramps

130 AASHTO, Green Book, 7th ed. (2018), 3–131.

131 AASHTO, Green Book, 7th ed. (2018), 3–6, 3–7.

132 AASHTO, Green Book, 7th ed. (2018).

133 AASHTO, *Roadside Design* Guide, 4th ed. (2011).

134 FHWA, MUTCD, rev. eds. 1–3 (2022).

▶ Provide Advanced Warning

Signing

Signs can be used to warn drivers in advance of steep grades. The MUTCD provides provisions on the size of warning signs for various highway types.[135] Flashing beacons may also be installed on grade warning signs to provide emphasis, and speed advisories based on vehicle weight may be posted. Advance warning signs are most effective as part of a comprehensive approach consisting of several mitigation strategies.

Figure 29. Photo. Grade warning sign with supplemental flashing beacons.

▶ Improve Safety and Operations for Vehicles Navigating Steep Grades

Climbing Lane

Often used in mountainous or rolling terrain, a climbing lane is a strategy for improving safety and operations on steep grades. Trucks and other slow-moving vehicles use a climbing lane, which allows other motorists to continue at free-flow speeds. This enhances safety by lowering driver frustration and reducing the temptation to make risky passing maneuvers.

Figure 30. Photo. Climbing lane on steep upgrade.

Downgrade Lane

Adding a lane on the downgrade side of the facility may be beneficial in some situations. Introducing a downgrade lane in instances where there are large trucks or other slower-moving vehicles may maintain efficient traffic flow while reducing the risk of a crash from faster-moving vehicles approaching from behind. The *Highway Capacity Manual* (HCM) contains procedures for determining the practicality of such facilities.[136]

Figure 31. Photo. Truck descent lane (far right) on steep downgrade.

135 FHWA, MUTCD, rev. eds. 1–3 (2022).

136 National Academies of Sciences, Engineering, and Medicine, *Highway Capacity Manual 7th Edition* (2022), 3–136.

High Friction Surface Treatment

HFST is a component of FHWA's Proven Safety Countermeasure, Pavement Friction Management.[137] HFST is a durable calcined bauxite aggregate bonded to the concrete or asphalt roadway surface by a polymer agent. HFST is used to increase surface friction and skid resistance to keep drivers on the roadway. HFST is used mostly to decrease roadway departure crashes through horizontal curves, but it can also provide drivers an opportunity to stop more quickly or have higher levels of control on changes in horizontal alignment. This is particularly important on steep downgrades.

Figure 32. Photo. High friction surface treatment on steep downgrade.

Speed Feedback Signs

Lower speeds can assist drivers in safely negotiating steep grades. Dynamic speed feedback signs are an effective method of managing appropriate operating speeds. These signs are typically activated by RaDAR and display a vehicle's current speed in relation to the posted or advisory speed. As a vehicle approaches at a speed higher than the posted or advisory speed, the dynamic portion of the sign alerts drivers, giving them the opportunity to slow down.

Variable Speed Limits

Variable speed limits are an FHWA Proven Safety Countermeasure.[138] Variable speed limits use prevailing information on the roadway, such as traffic speed, volumes, weather, and road surface conditions, to determine appropriate speeds and display them to drivers. Variable speed limits may be an effective strategy for roadways with steep grades to help drivers determine an appropriate operating speed for the conditions. Variable speed limits can be implemented as a regulatory or an advisory system.

▶ Reduce Crash Severity

Runaway Truck Ramps

For large freight and commercial vehicles, steep downhill grades may sometimes pose a risk of equipment failure, causing the driver to lose control of the vehicle. One mitigation for this risk is to provide escape ramps where drivers can maneuver their vehicles, and where the vehicle can come to a safe stop if a driver has lost control.

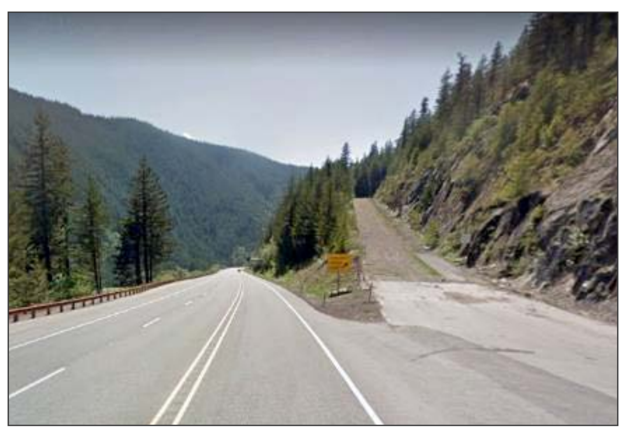


Figure 33. Photo. Runaway truck ramp.

[137] FHWA, *Proven Safety Countermeasures - Pavement Friction Management*, FHWA-SA-21-052.

[138] FHWA, "Variable Speed Limits," *Making Our Roads Safer*, FHWA-SA-21-054.

Chapter 10. Cross Slope

DEFINITION

Cross slope is the rate of change in elevation of the roadway surface measured perpendicular to the direction of travel. Pavement cross slope is an important cross-sectional design element to ensure proper drainage of water away from the roadway. The Green Book recommends cross slope rates for paved roadways, with appropriate adjustments for multilane pavements and areas that experience intense rainfall.[139]

CROSS SLOPE

Cross slope is the rate of change in elevation of the roadway surface measured perpendicular to the direction of travel.

APPLICABILITY

FHWA policy does not require a design exception for cross slope on non-freeway roadways with a design speed less than 50 mph. FHWA requires a design exception when the cross slope criterion is not met on interstate highways and NHS freeways and roadways with a design speed greater than or equal to 50 mph.[140]

SAFETY IMPACT

High-Speed Roadways

Providing proper drainage requires adequate pavement cross slope to reduce hydroplaning risk and mitigate loss of driver visibility from road spray. The risk of hydroplaning—when vehicle tires break their grip on the pavement and instead ride on a film of water—renders the driver temporarily unable to steer or brake.

Low-Speed Roadways

Pavement cross slope is important to drainage, and improper drainage could contribute to potential vehicle loss of control under some circumstances, including in the low-speed environment.[141]

OPERATIONAL IMPACT

High-Speed Roadways

The cross slope laterally drains water from the roadway and, combined with the roadway grade, helps minimize ponding of water on the pavement. On roadways with curbed cross sections, the cross slope moves water to a narrower channel adjacent to the curb away from the travel lanes where it can be removed. Keeping water from ponding on the roadway is important for traffic operation and pavement longevity.

139 AASHTO, Green Book, 7th ed. (2018).

140 Mooney, "Revisions to the Controlling Criteria" (2016).

141 *NCHRP Report 783* (2004).

The Green Book recommends a normal cross slope of 1.5–2 percent for paved roadways. Cross slopes in this range are barely perceptible in terms of vehicle steering. However, cross slopes steeper than 2 percent are noticeable and may require a conscious effort in steering.

▶ Low-Speed Roadways

In areas with pedestrian generators (e.g., schools, retail, manufacturing) but no sidewalks, paved roadway shoulders may provide the stable surface needed for nonmotorized traffic.[142,143] In this case, the shoulder cross slope should not exceed 2 percent to ensure accessibility for people with disabilities.[144,145]

INTERRELATIONSHIPS

The cross slope criterion applies to tangent alignments and is often referred to as the normal cross slope. The normal cross slope may be rotated and steepened throughout a curve with superelevation. Whereas superelevation is controlled by the physical forces involved with moving around a curve, cross slope is largely a function of pavement drainage. When pavements are rotated to reverse the cross slope direction, a portion of the pavement will have no cross slope. These instances are routine and necessary in design, and a design exception for cross slope is not required. However, pavement drainage should be carefully checked in these areas to minimize the risk of hydroplaning. Where pedestrians or bicyclists use the roadway, such as intersection crosswalks, the cross slope of the roadway may affect the accessibility of the nonmotorized path.

MITIGATION STRATEGIES

Table 7 summarizes strategies that may be used to accomplish project objectives when the cross slope criterion is not met. Following the table, each strategy is discussed in the same order it appears in the table. More specific information may be found in the Green Book,[146] *Roadside Design Guide*,[147] and the MUTCD.[148]

Table 7. Summary of mitigation strategies for cross slope exceptions.

Objective	Example Mitigation Strategies
Promote positive drainage	Cross slope improvements Drainage improvements Transversely grooved pavements
Improve pavement surface friction	High-friction surface treatment
Reduce operating speeds during adverse weather conditions	Signing Variable speed limits

142 FHWA, *Safety Benefits of Walkways, Sidewalks, and Paved Shoulders*, FHWA-SA-10-021 (Washington, DC: USDOT, 2013), https://safety.fhwa.dot.gov/ped_bike/tools_solve/walkways_trifold/walkways_trifold.pdf.

143 FHWA, *Guidance Memorandum on Consideration and Implementation of Proven Safety Countermeasures* (Washington, DC: USDOT, 2020), https://safety.fhwa.dot.gov/legislationandpolicy/policy/memo071008/.

144 AASHTO, *Guide for the Development of Bicycle Facilities* (Washington, DC: AASHTO, 2012).

145 United States Access Board, *Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way*, 36 CFR, Part 1190 (Washington, DC: July 26, 2011).

146 AASHTO, Green Book, 7th ed. (2018).

147 AASHTO, *Roadside Design Guide*, 4th ed. (2011).

148 FHWA, MUTCD, rev. eds. 1–3 (2022).

▸ Promote Positive Drainage

Cross Slope Improvements

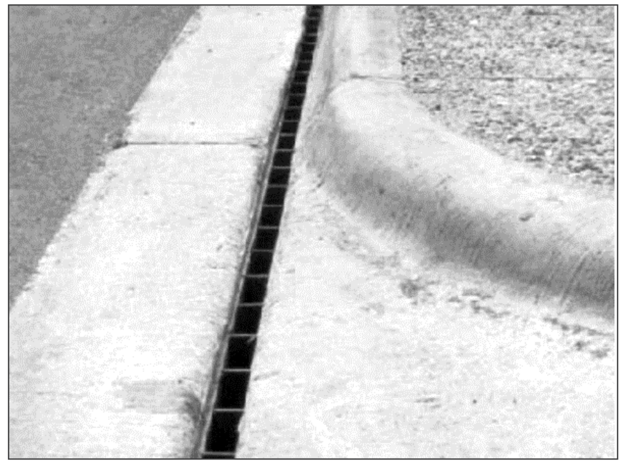
The objective of this strategy is to modify the existing pavement to achieve the minimum cross slope needed to provide adequate drainage of the pavement. Existing cross slope should be checked prior to resurfacing. Milling should be included as needed to restore the cross slope to an acceptable rate.

Drainage Improvements

Adequate infrastructure to capture stormwater more efficiently helps mitigate drainage issues caused by cross slope design. Most commonly this takes the form of additional inlets or longitudinal edge drains, such as slotted edge drains with or without curbs, and do not appreciably affect traffic operations.[149]

Transversely Grooved Pavements

Milling or tining small parallel grooves into the pavement surface can be another low-cost method for effectively promoting drainage on roadways with flatter cross slopes. The grooves channel water away from the pavement-tire interface so that surface water film never forms. This phenomenon reduces hydroplaning and the splash spray associated with wet pavements. The grooves also increase the pavement's macro-texture, which improves traction.[150] Longitudinal grooving has been associated with adverse steering inputs into motorcycle operation, but has seldom been reported for transversely grooved surfaces. Laboratory tests have not detected unusual steering influences resulting from any grooving geometrics.[151,152] Because of the tire noise generated, practitioners should avoid using transversely grooved pavement in residential areas where houses are nearby.



Source: FHWA.

Figure 34. Photo. Slotted edge drain near driveway.

Source: FHWA.

Figure 35. Photo. Transverse grooving on concrete pavement.

149 S.A. Brown, J.D. Schall, J.L. Morris, C.L. Doherty, S.M. Stein, and J.C. Warner, "Urban Drainage Design Manual," *Hydraulic Engineering Circular 22, Third Edition: Urban Drainage Design Manual*, FHWA-NHI-10-009 (August 2013).

150 International Grooving and Grinding Association (IGGA), *Longitudinal vs. Transverse Grooving* (West Coxsackie, New York: 2020).

151 David K. Merritt, Craig A. Lyon, and Bhagwant N. Persaud, *Evaluation of Pavement Safety Performance: Skid-Resistant Pavements*, FHWA-HRT-14-065 (Washington, DC: USDOT, 2015).

152 J.E. Martinez, "Effects of Pavement Grooving on Friction, Braking, and Vehicle Control," *Transportation Research Record*, no. 633 (Washington, DC: TRB, 1977).

▶ Improve Pavement Surface Friction

High Friction Surface Treatment

HFST is a component of FHWA's Proven Safety Countermeasure, Pavement Friction Management.[153] HFST is a durable calcined bauxite aggregate bonded to the concrete or asphalt roadway surface by a polymer agent. HFST is used to increase surface friction and skid resistance to keep drivers on the roadway. Given the angularity of the aggregate and the open gradation of the application, it is effective under wet conditions and can mitigate risks posed by a thin water film on the pavement surface. Wet weather crash reduction may be the greatest benefit of HFST.[154] FHWA's *High Friction Surface Treatment Site Selection and Installation Guide* provides information on HFST benefits, applications, and successful practices.[155]

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Figure 36. Photo. High friction surface treatment to reduce wet weather crashes.

▶ Reduce Operating Speeds for Adverse Weather Conditions

Signing

The primary concern for locations with insufficient cross slope is inadequate drainage and ponding of water on the travel lanes. The Slippery When Wet (W8-5) sign may be used to warn drivers of pavements with insufficient cross slope that can become slicker than sections with standard cross slope. The MUTCD provides provisions on the size of warning signs for various highway types but notes that larger signs may be used when appropriate.[156]

Source: FHWA.

Figure 37. Illustration. Slippery when wet sign.

Variable Speed Limits

Variable speed limits are an FHWA Proven Safety Countermeasure.[157] Variable speed limits use prevailing information on the roadway, such as traffic speed, volumes, weather, and road surface conditions, to determine appropriate speeds and display them to drivers. Variable speed limits may be an effective strategy for roadways that do not meet the cross slope criterion to help drivers determine an appropriate operating speed during adverse weather conditions. Variable speed limits can be implemented as a regulatory or an advisory system.

153 FHWA, *Proven Safety Countermeasures - Pavement Friction Management,* FHWA-SA-21-052.

154 FHWA, "Frequently Asked Questions – High Friction Surface Treatments (HFST) – 2017," FHWA-SA-18-004 (Washington, DC: 2017).

155 FHWA, *High Friction Surface Treatment Site Selection and Installation Guide*, FHWA-SA-21-093 (2021).

156 FHWA, MUTCD, rev. eds. 1–3 (2022).

157 FHWA, "Variable Speed Limits," *Making Our Roads Safer*, FHWA-SA-21-054.

Chapter 11. Vertical Clearance

DEFINITION

Vertical clearance is the unobstructed height measured from the roadway surface to the lowest element of an overhead structure. The vertical clearance criterion varies with the functional classification and context of the roadway. These clearances apply to the entire roadway width, including auxiliary lanes and shoulders, and to ramps and collector-distributor roadways.

VERTICAL CLEARANCE

Vertical clearance is the unobstructed height measured from the roadway surface to the lowest element of an overhead structure.

APPLICABILITY

FHWA policy does not require a design exception for vertical clearance on non-freeway roadways with a design speed less than 50 mph. FHWA requires a design exception when the vertical clearance criterion is not met on interstate highways and NHS freeways and roadways with a design speed greater than or equal to 50 mph.[158]

The Strategic Highway Network (STRAHNET) is a subset of the NHS. STRAHNET can be important to U.S. strategic defense policy by providing defense access, continuity, and emergency capabilities for defense services.[159] For all facilities on the Department of Defense's STRAHNET, 23 U.S.C. 101(b)(3)[160] emphasizes the need to provide safe and efficient connections for military vehicles accessing NHS intermodal freight terminals. Interstate projects that do not achieve the minimum vertical clearance contained in AASHTO's *A Policy on Design Standards: Interstate System*[161] should be coordinated with the Military's Surface Deployment and Distribution Command Transportation Engineering Agency.[162]

SAFETY IMPACT

The safety impacts of deficiencies in vertical clearance include the potential for collision with the overhead structure. This can pose a risk to occupants of the impacting vehicle, others on the roadway, and users of the structure at the time of collision. Traffic following the impacting vehicle could be at risk of rear-end collision, given the vehicle's sudden deceleration. There is also a risk of crashes and damage from debris generated by the impact.

158 Mooney, "Revisions to the Controlling Criteria" (2016).

159 U.S. Department of Energy, "Strategic Highway Network (STRAHNET)," https://www.directives.doe.gov/terms_definitions/strategic-highway-network-strahnet.

160 Code of Federal Regulations (CFR), 23 U.S.C. §101(b)(3).

161 AASHTO, Green Book, 6th ed. (2016).

162 Dwight A. Horne to Division Administrators, Federal Lands Highway Division Engineers, "ACTION: Coordination of Vertical Clearance Design Exceptions on the Interstate System," memorandum (Washington, DC: USDOT, April 15, 2009), https://www.fhwa.dot.gov/design/090415.cfm.

OPERATIONAL IMPACT

Impacts to low bridges can result in closure of the bridge for lengthy periods and costly repairs. Insufficient vertical clearance can also impact freight management and military movements, in that it limits handling and routing of over-height loads.

MITIGATION STRATEGIES

Table 8 summarizes strategies that may be used to accomplish project objectives when the vertical clearance criterion is not met. Following the table, each strategy is discussed in the same order it appears in the table. More specific information may be found in the Green Book,[163] *Roadside Design Guide*,[164] and the MUTCD.[165]

Table 8. Summary of mitigation strategies for vertical clearance exceptions.

Objective	Example Mitigation Strategies
Provide advance warning	Signing Over-height vehicle warning system
Prevent impacts with low structures	Alternate routes Restricted vehicles

Provide Advance Warning

Signing

Warning signs are used to warn drivers of unexpected roadway conditions. Low clearance signs (W12-2 and W12-2a) warn of clearances less than 12 inches above the statutory maximum vehicle height. The sign may be installed in advance of the structure (W12-2) or on the structure itself (W12-2a). Where the clearance is less than the legal maximum vehicle height, the sign should be installed in an advance location that allows a driver ample room to turn around and detour around the condition. The MUTCD provides provisions on the size of warning signs for various highway types but notes that larger signs may be used when appropriate.[166]

© 2022 Google® Street View™.

Figure 38. Photo. Low clearance sign on structure.

[163] AASHTO, Green Book, 7th ed. (2018).

[164] AASHTO, *Roadside Design Guide*, 4th ed. (2011).

[165] FHWA, MUTCD, rev. eds. 1–3 (2022).

[166] FHWA, MUTCD, rev. eds. 1–3 (2022).

Over-Height Vehicle Warning System

Bridge strikes by over-height vehicles are often caused by ignorance of existing clearances, or by part of a regulation-height vehicle being inadvertently higher. For instance, drivers may be unaware that the bed of their dump truck could be partially deployed. Over-height vehicle warning systems can alert drivers to the risk of low clearance bridges and give them ample opportunity to seek alternate routes. These systems use infrared sensors to detect critical vehicle heights ahead of the low structure, and then activate a flashing beacon attached to a static sign. This provides a warning to drivers.

▶ Prevent Impacts with Low Structures

Alternate Routes

In areas with vertical height restrictions, providing alternate routes for over-height vehicles can be a mitigation strategy. This allows drivers to take a route where height restrictions do not exist to altogether avoid conflict with structures. Alternate routes should be clearly marked to alert users of their existence, and trailblazing signs along their lengths should be used to guide unfamiliar travelers. Practitioners should consider the inconvenience to drivers when implementing this strategy.

Source: FHWA.

Figure 39. Illustration. Truck route sign.

Restricted Vehicles

Restricting large vehicles on corridors with height deficiencies is another way to allow vehicles to avoid conflicts with structures. Any restrictions involving the National Network with respect to the operation of commercial motor vehicles meeting the applicable size and weight standards must comply with FHWA regulations.[167]

Source: FHWA.

Figure 40. Illustration. No trucks sign.

[167] 23 CFR Part 658.

Source: Getty Images

Chapter 12. Design Loading Structural Capacity

DEFINITION

Design loading structural capacity is a structure's ability to support the design loading and remain operationally serviceable. This criterion pertains to a structure's design as opposed to its load rating.[168] The design loading itself should conform to *AASHTO's Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures - Reference Manual*.[169] Design loading structural capacity will not be covered in this resource because it is not strictly an element of geometric design.

DESIGN LOADING STRUCTURAL CAPACITY

A structure's ability to support the design loading and remain operationally serviceable.

APPLICABILITY

FHWA policy requires a design exception for design loading structural capacity on all NHS facility types.[170] Since this criterion is key to achieving and maintaining consistently safe bridges, design exceptions pertaining to design loading structural capacity should be rare.

168 U.S. National Archives, "Revision of Thirteen Controlling Criteria for Design; Notice and Request for Comment," *Federal Register*, document no. 2015-25526 (Washington, DC: October 7, 2015).

169 FHWA, *Load and Resistance Factor Design (LRFD) For Highway Bridge July 2015 Superstructures - Reference Manual*, FHWA-NHI-15-047 (2015).

170 Mooney, "Revisions to the Controlling Criteria" (2016).

Source: Getty Images.

Chapter 13. Risk Management

Regardless of size or complexity, all transportation projects contain risks. Decreasing the likelihood of negative impacts resulting from risk and uncertainty involves a methodical process that agencies can enforce to meet project goals and objectives. Employing risk management strategies within a transportation agency's everyday practice may mitigate legal liabilities, identify faulty procedures, encourage flexible design, and maximize dollars to allocate wherever needed.

RISK MANAGEMENT

Risk management is the process of identifying, analyzing, prioritizing, planning, executing, and continually monitoring project uncertainty. Risks have the potential to impact a variety of events, such as cost, time, scope, and quality. Risks from design decisions may have the potential to impact the safe and efficient operation of the finished roadway. Figure 41 shows FHWA's risk management process.[171]

Source: FHWA.

Figure 41. Diagram. Federal Highway Administration's risk management process.

▸ Managing Risks with Design Exception Decisions

Design exceptions can create a perception of legal vulnerability among practitioners, but risk management practices may decrease this perception and encourage design flexibility. The two most common design exception risks are tort liability risk (i.e., lawsuits arising from crashes allegedly associated with design) and engineering risk (i.e., design solutions not performing as expected in terms of safety, serviceability, and operations). Practitioners should be aware that choosing design solutions that conform to standards while ignoring other factors, such as substantive safety for all users, environmental, historical, and economic concerns, may carry risk as well. Context sensitive design and performance-based design encourage practitioners to solve unique problems the design standard may not address. When considering design options, practitioners need to balance these factors within the given context and use their professional judgement to develop a creative solution with the least amount of risk.[172]

[171] Daniel Fodera, "Handling Risk: FHWA Integrated Approach," *Public Roads* 84, no. 4, FHWA-HRT-21-002 (2021).

[172] NCHRP, *Legal Research Digest 57: Tort Liability Defense Practices for Design Flexibility* (Washington, DC: TRB, 2012).

As shown in figure 41, the risk management process begins early in the initial planning and scoping phase and continues toward the monitoring phase.[173] The transportation agency can work with all stakeholders to identify the project's goals, context, and desired outcomes. Early engagement with stakeholders helps establish their needs and informs later project decisions. Practitioners can then begin to develop project alternatives and develop conceptual designs that align with performance-based goals.

Design exceptions are often required for site-specific situations when the minimum design criteria conflict with achieving a context sensitive design that aligns with the project's goal. Practitioners can conduct a risk assessment to identify all potential risks stemming from the design exception. Acceptable risk means the design exception benefit outweighs the potential risks the design exception may possess.

This risk-based approach can occur when evaluating and assessing all project alternatives before a preliminary design is selected. During this approach, practitioners identify all risk factors associated with each design alternative and evaluate them to select the solution that best meets project goals and objectives. Risk factors may include community and environmental concerns, operational performance, safety performance, geometric conditions that do not meet the minimum criteria, historic and scenic locations, and total project cost. The risk-based approach can help practitioners verify if the design meets the project's goals and objectives. It informs project decision-making through a methodical process that balances multiple factors.

Once a design is selected, practitioners can reduce risks by identifying potential mitigation strategies to implement within the project. For example, this may include implementing rumble strips, installing a guardrail, or providing clear zone along the roadside. Agencies can evaluate the design after implementation to determine whether the design and the mitigation strategies were effective. This demonstrates a commitment to mitigate safety concerns if the selected design required a design exception or unique solution.[174] All risk analyses and design decisions should be documented throughout the project development process. Leaders who have authority to approve design exceptions should have a working knowledge of risk management approaches to accomplish project goals and objectives. Leaders can allocate risks appropriately within the respective project levels to those who can best manage the risks within their technical expertise. This practice can strengthen the validity of the design exception itself, and also provides efficiency and clarity across the project spectrum.

▸ Proactive Risk Management Strategies

Failure to adhere to agency practices, procedures, and standards may open the door to future litigation. As explained in NCHRP's *Legal Research Digest 83*, during the litigation process, lawyers examine agency policy and practices for discrepancies. Agencies can be proactive by implementing the following risk management strategies.[175]

Current Policy and Agency Practice

Policy language in agency manuals should reflect the current practices being applied in the design process. Agencies can routinely schedule reviews of manuals to check for liability discrepancies in the policy language. Engineers, lawyers, and other agency personnel who routinely reference the manuals can be involved in the review process. Inaccurate, confusing, or outdated language should then be revised as needed to reflect current practices.

173 Daniel Fodera, "Handling Risk: FHWA Integrated Approach" (2021).

174 NCHRP, *Legal Research Digest 57: Tort Liability Defense Practices for Design Flexibility* (2012).

175 NCHRP, *Legal Research Digest 83: Guidelines for Drafting Liability Neutral Transportation Engineering Documents and Communication Strategies* (Washington, DC: TRB, 2020).

Records Management

State and Federal agencies are required by law to establish and maintain records.[176] Agencies can establish record retention policies to ensure design documentation is archived and accessible. This process may help safeguard agencies against claims that may arise in the future.

176 NCHRP, *Legal Research Digest 52: Record Keeping Requirements for State Departments of Transportation* (Washington, DC: TRB, 2009).

Chapter 14. Design Decision Documentation, Approvals, and Post-construction Evaluation

Effective transportation design, using context-based and performance-based design principles and key concepts described in chapter 2, starts in the early stages of project planning and continues throughout project development.

Transportation agencies can consider the following recommendations for effective transportation design:

- Involve a multidisciplinary group of stakeholders throughout the process.
- Establish clear project goals and objectives, including overall vision, desired role of the facility, context classification, and primary users.
- Confirm these goals and objectives at all stages of the project development process and update them as needed.
- Develop a plan or methodology for identifying, assessing, and evaluating alternatives and the risks they may have. This may also include identifying performance measures, data needs, and necessary analytical tools.
- Apply the plan or methodology at key decision stages.
- Document all assessments, evaluations, and project team decisions throughout the process.

Documenting all design decisions provides a historical record of the project that can inform future projects on that particular road, or projects on other roadways. Documenting design decisions can also help support decisions about maintenance and operations activities on that roadway.

DESIGN DECISION DOCUMENTATION

It is best practice for State DOTs to document all decisions during project planning and design. These practices vary among States, but many State DOTs have developed standard forms or templates for staff to use. The Massachusetts Department of Transportation (MassDOT) developed a design justification workbook to identify and document criteria for each controlling design element.[177]

This document becomes a living document that starts early in the planning stage and is updated throughout project development. The document is then archived with the project files and serves as a history of the project, including the purpose and need, project characteristics and goals, alternatives considered, evaluation methods and results, and the final design decisions.

Design exceptions are a legitimate exercise of combining contextual roadway characteristics, data analysis, scope, and professional judgement to develop a design solution that best meets the goals and objectives of the project. Practitioners use their skills, experience, and engineering judgement to flexibly solve transportation problems. Combining this with complete, sound documentation can give agencies a toolkit to address issues that may arise.

[177] MassDOT, "MassDOT Design Justification Reports," https://www.mass.gov/info-details/massdot-design-justification-reports.

Design exception documentation enhances the decision-making process by providing detailed explanations for designs that deviate from the standards. Justifications for each alternative balance project goals and desired outcomes. Practitioners can document the safety, operational, environmental, historical, and cost factors considered when developing the proposed design.

It is important to document not only why a particular design was selected, but also why a different design was not selected.

When FHWA's controlling criteria are not met on an NHS project, a design exception must be prepared, regardless of project funding.[178] Documenting design exceptions must be based on an evaluation of the context of the facility, needs of all users, safety, operational performance, human and environmental impacts, and project costs.[179] It is important to document not only why a particular design was selected, but also why a different design was not selected. The level of analysis should be proportional to the complexity and associated risks of the project.

Design exception documentation should describe all the following:

- Specific design criteria that will not be met
- Existing roadway characteristics
- Alternatives considered
- Comparison of the safety and operational performance of the roadway and other impacts, such as right-of-way, community, environmental, cost, and usability by all modes of transportation
- Proposed mitigation measures
- Compatibility with adjacent sections of roadway

Exceptions to design speed and design loading structural capacity should be rare and should include additional documentation. Design speed exceptions should also describe the length of the proposed section with a lower design speed compared to the overall length of the project, and the measures that practitioners will use in transitioning to adjacent sections with a different design speed. Documentation for exceptions to design loading structural capacity should include verification of safe load-carrying capacity (load rating) for all State unrestricted loads or routine permit loads and, in the case of bridges and tunnels on the interstate system, all Federal legal loads.[180]

APPROVALS

FHWA must approve design exceptions for controlling criteria.[181] Some States have stewardship and oversight agreements with FHWA through which the State DOT assumes the responsibility to evaluate and approve design exceptions on behalf of FHWA. Many States have additional approval processes relating to designs that deviate from criteria established in the State's policies and manuals. Practitioners should refer to their agency's documentation for specific information on approval requirements.

178 23 CFR Part 625.3.

179 23 CFR Part 625.3.

180 FHWA, "Guidance on NHS Design Standards and Design Exceptions," updated March 6, 2019, https://www.fhwa.dot.gov/design/standards/qa.cfm.

181 23 CFR Part 625.3.

POST-CONSTRUCTION PERFORMANCE EVALUATIONS

It is good practice for agencies to conduct follow-up evaluations relating to project designs to determine whether project objectives have been met. These evaluations can inform future design decisions and mitigation strategies.

Post-construction performance evaluations serve several purposes:

- Allow agencies, interested stakeholders, and the public to better understand the benefits of projects that have been implemented
- Observe how people are using the facility
- Help identify lessons learned for future similar projects
- Help identify positive or negative impacts of design decisions and mitigation strategies

Post-construction performance evaluations compare the post-construction conditions of projects to pre-construction conditions. They assess overall roadway changes and how well project goals were addressed. Transportation agencies often conduct these evaluations as part of funding or grant conditions.

Pre- and post-construction comparison evaluations typically include the following elements:

- Data collection: Data are collected before and after construction of the project. In some cases, the types of data collected for post-construction analysis are unable to be collected under pre-construction conditions.
- Analysis methodologies and results: The same methodologies and analysis should be used for the pre-construction and post-construction evaluations to allow direct comparisons.
- Performance goals and measures: Evaluating the goals and measures established for the project is important. There is also an opportunity to identify other goals and measures that could have been considered or that may be considered for future construction projects.

APPENDIX A. NOTEWORTHY PRACTICES

Source: Getty Images

NOTEWORTHY PRACTICE

Oregon Department of Transportation—A New Multimodal and Flexible Planning and Design Approach

▸ Background

Designing multimodal transportation facilities in urban areas is complex. Project teams develop a project to meet the needs of the transportation system, and integrate design, operations, and safety for a variety of roadway users. Although past design trends have emphasized adhering to strict roadway design standards, design approaches now encourage flexibility and emphasize the need to identify project goals and performance measures that align with the intended project outcomes.

The Oregon Department of Transportation (ODOT) developed the *Blueprint for Urban Design*[182] as an approach to implementing urban multimodal projects that achieve project-intended outcomes and meet user's needs. The *Blueprint for Urban Design* provides statewide urban design guidance based on a performance-based design framework. The *Blueprint for Urban Design* emphasizes the need to identify appropriate design dimensions and multimodal treatments based on the urban land use contexts and functional classifications. This approach also highlights the need to collaborate with a multidisciplinary project team, from early planning to final design stages. Engagement from the multidisciplinary team throughout the project development process can help verify that early project decisions are implemented in the final project solutions.

AT A GLANCE

Objectives/goals

- Provide flexible design guidance and criteria for each urban context classification integrating all modes
- Establish a process for multimodal decision-making framework and urban design concurrence documentation

Characteristics

- Define characteristics and conditions for each urban context
- Provide relative need for modal integration based on each urban context
- Work collaboratively in a multidisciplinary team throughout all project development stages

Results/outcomes

- Design roadways that meet the needs of the community
- Integrate modal needs based on existing and future adjacent land uses (urban contexts)
- Provide appropriate documentation capturing decisions

[182] ODOT, *Blueprint for Urban Design*, volume 1 of 2 (2020), https://www.oregon.gov/odot/Engineering/Documents_RoadwayEng/Blueprint-for-Urban-Design_v1.pdf.

▸ Solution/Approach

In 2016, ODOT embarked on an urban design initiative. ODOT's goal was to align its design policies and practices with changing national urban design guidance, including a compilation of NCHRP reports, FHWA reports, National Association of City Transportation Officials guides, and other State DOT manuals. The initiative led ODOT to develop the *Blueprint for Urban Design* as a bridge between current and future ODOT manuals.

Internal and External Stakeholder Input

Before developing the *Blueprint for Urban Design*, ODOT conducted outreach to internal and external stakeholders. Internal stakeholders included various departments within ODOT. External stakeholders included those who do not work for ODOT as staff or contractors. ODOT identified the following key themes during outreach:

- Current standards and design and planning processes lack flexibility
- Additional design guidelines are needed for the variety of land use contexts, not just for urban and rural areas
- Inconsistent experience with design exception process, and a desire for more clarity regarding obtaining approval
- Current planning and design decision practices typically prioritize freight and automobile needs
- Innovative practices are difficult to implement through ODOT's planning and design process

Identifying Urban Contexts

ODOT identified six land use context classifications to describe the variety of urban areas and unincorporated communities in Oregon. The six ODOT urban contexts, shown in table 9, can be evaluated through a combination of a field visit, internet-based aerial and street view imagery, map analysis, local jurisdiction consultation, and land use plan review. ODOT identified rural communities as an ODOT urban context to address the need of slowing vehicular traffic moving through the town to accommodate the mix of users. Similar to an urban environment, reducing the operating speed in rural communities with contextual designs related to sidewalks, bicycles, and curbside uses should be considered.

The urban context of a roadway and its transportation characteristics provide information about the types of users to expect along the roadway, the regional and local travel demand of the roadway, and the challenges and opportunities for each roadway user. Chapter 2 of *Blueprint for Urban Design* provides information on how to identify the urban context and highlights key characteristics of each context. Table 9 presents the framework to determine the urban context along State roadways. The measures in table 9 provide more detailed assessments of the existing or planned conditions along the roadway.

Table 9. Oregon Department of Transportation's framework to determine urban context.

Land Use Context	Setbacks (distance from building to property line)	Building Orientation (front door access from sidewalks along pedestrian path)	Land Use (existing or future mix of land uses)	Building Coverage (percent of area adjacent to right-of-way with buildings as opposed to parking, landscape, or other uses)	Parking (location of parking in relation to buildings along right-of-way)	Block Size (average size of blocks adjacent to right-of-way)
Traditional downtown/ CBD	Shallow/none	Yes	Mixed (residential, commercial, park/ recreation)	High	On-street/ garage/ shared in back	Small, consistent block structure
Urban mix commercial corridor	Shallow	Some	Commercial fronting, residential behind or above	Medium	Mostly off-street/single row in front/ back/on side	Small to medium blocks
Commercial corridor	Medium to large	Sparse	Commercial, institutional, industrial	Low	Off-street/in front	Large blocks, not well defined
Residential corridor	Shallow	Some	Residential	Medium	Varies	Small to medium blocks
Suburban fringe	Varies	Varies	Varied, interspersed development	Low	Varies	Large blocks, not well defined
Rural community	Shallow/none	Some	Mixed (residential, commercial, institutional, park/ recreation)	Medium	Single row in front/in back/on side	Small to medium blocks

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CBD = commercial business district.

Designing for Multimodal Users

The ODOT urban contexts help planners and engineers understand the types of users and the intensity of use to expect within each urban context. When determining the roadway typical section to be used, practitioners can use the urban context to better understand anticipated users and identify appropriate consideration for each user. Table 10 shows a representation of the relative need of each user to drive planning and design decisions in the different urban contexts.

Table 10. Oregon Department of Transportation's general modal consideration in different urban contexts.

Land Use Context	Motorist	Freight	Transit	Bicyclist	Pedestrian
Traditional downtown/CBD	Low	Low	High	High	High
Urban mix	Medium	Low	High	High	High
Commercial corridor	High	High	High	Medium	Medium
Residential corridor	Medium	Medium	Low	Medium	Medium
Suburban fringe	High	High	Varies	Low	Low
Rural community	Medium	Medium	Varies	High	High

Note: High = highest level facility should be considered and prioritized over other modal treatments. Medium = design elements should be considered; trade-offs may exist based on desired outcomes and user needs. Low = incorporate design elements as space permits.[183]

Cross Section Realms and Considerations

Table 11 provides an overview of the various cross section realms to enable an understanding of the functions the realms may serve in urban areas. Figure 42 shows an overview of the various cross section realms. The elements and dimensions of the realms will vary depending on the urban context, anticipated users, and desired project outcomes.

Table 11. Overview of cross section realms.

Street Realm	Location	Function
Land use realm	Immediately adjacent to the roadway right-of-way	▪ Typically privately owned, the land use realm contributes to the urban context of the place ▪ This space can also serve a variety of other functions in some cases, including pedestrian space, and amenities such as bicycle parking, utilities, landscaping, and parking ▪ Awnings or building appurtenances, signs, and other activities that require use of the public right-of-way or overhang into the pedestrian realm must be permitted by ODOT or the local agency (if sidewalk is locally owned)
Pedestrian realm	Includes the sidewalk and the buffer or furniture zone	▪ Serves pedestrians and access to land uses ▪ Buffer/furniture zone often used as a place for utilities, lighting, signs, street trees, and other furnishings ▪ May also serve as public space for art, sidewalk seating, or other types of public uses if sidewalk is locally owned
Transition realm	The area immediately adjacent to the curb or sidewalk edge (e.g., parking, loading, transit stops); may also include non-pedestrian areas behind the curb (e.g., curb-separated bicycle lanes)	▪ Bicycle movement or parking, pedestrians, planters, transit stops, parking, loading/unloading, pick-up/drop-off ▪ May serve multiple functions in same block or location; may vary by time of day ▪ May also include street trees and/or other green streets treatments

183 ODOT, *Blueprint for Urban Design*, volume 1 (2020).

Table 11. Overview of cross section realms. (continued)

Street Realm	Location	Function
Travelway realm	The center of the right-of-way used for movement, typically including travel lanes, median, and/or turn lanes	▪ Primarily functions to serve various types of vehicle movement (including motor vehicles, buses, light rail vehicles, streetcars, bicycles, motorcycles, freight, etc.) ▪ Can provide or manage vehicular access through turn lanes, medians, and other treatments ▪ Median can function as a place for vegetation, green streets stormwater treatments, and as a pedestrian refuge

Figure 42. Illustration. Example of cross section realms.

The *Blueprint for Urban Design* provides statewide design recommendations for design elements within each realm for each context. The multidisciplinary project team evaluates the recommendations to identify the most appropriate cross section for the desired project outcomes and user needs. A holistic evaluation of the cross section that considers the design elements within each realm can help project teams verify the overall roadway cross section aligns with desired project outcomes and user needs.

Multimodal Decision-Making Framework

Chapter 4 of the *Blueprint for Urban Design* focuses on a performance-based approach to project development and delivery that supports decision-making from planning to design. Identifying the desired project outcomes and understanding the urban context and primary roadway users can help practitioners determine appropriate performance measures to evaluate trade-offs of design decisions. Completing these steps early in the project can inform the planning phase and refine the range of alternatives for practitioners to consider. Reviewing and confirming project goals throughout planning, design, and construction validates that the alternative a practitioner chose reflects the original project goals and serves the intended users.

Chapter 4 of the *Blueprint for Urban Design* identifies how ODOT will integrate design concurrence documentation into the decision-making framework. The new urban design concurrence documentation enables project teams to more efficiently and effectively document decisions and project outcomes. The documentation can extend into the final design stages and the maintenance and monitoring stages to verify the original goals are still being met.

Although each project requires a tailored approach, the following elements provide a suggested outline for incorporating performance-based design into ODOT's project flow:

- Initiate or maintain collaboration with a multidisciplinary project team.
- Establish or review project goals, desired outcomes, performance measures, and documentation approach.
- Review past studies and plans to understand the urban context and modal expectations. If there are no prior studies, then the project should identify the urban context and modal expectations.
- Verify the preliminary design meets original project goals and desired outcomes.
- Confirm that detailed design decisions still meet project goals and outcomes.
- Document decisions at each stage of the project and confirm the final design meets project goals and outcomes. Any changes from prior decisions will be evaluated against the original intent of the project, and a multidisciplinary project team would provide justification for evaluation.

▶ Lessons Learned

Providing ranges in the dimensions for the respective design elements for each context classification provided additional flexibility. This flexibility resulted in greater engagement among ODOT headquarter and region staff to discuss design decisions and identify appropriate cross section dimensions. With the *Blueprint for Urban Design*, project teams are more focused on flexibility. ODOT project teams shared that they feel empowered to optimize specific project needs rather than constrained by rigid standards.

The performance-based design approach and the urban design concurrence documentation process have increased the level of detailed documentation and the evaluation of trade-offs to support design decisions. The evaluation process and compilation of the urban design concurrence documentation set the foundation for an efficient design phase for the project. Project teams noted that documenting what the project is not doing is often just as important as documenting what the project is going to do.

ODOT continues to streamline this process. It has acknowledged that additional collaboration among planning and design staff requires effort from the project team, which can add to the overall time line. As the multidisciplinary project teams gain more experience with the approach and level of collaboration, identifying project solutions and design decisions will become more efficient and embedded in agency practice.

▶ Outcomes

Key takeaways of the overall change in how ODOT plans and designs its roads include:

- Integrates planning and design for each urban context in addition to existing roadway classification and highway designations
- Highlights opportunities for design flexibility with a range of cross sections in each urban context
- Incorporates a performance-based planning and design approach to evaluate trade-offs and document design decisions
- Encourages practitioners to start at the highest level of protection for vulnerable users
- Outlines the new ODOT design concurrence documentation
- ODOT has incorporated the *Blueprint for Urban Design* content within its 2023 *Highway Design Manual*.[184]

[184] ODOT, *Highway Design Manual* (2023), https://www.oregon.gov/odot/Engineering/Documents_RoadwayEng/HDM-0000-Full.pdf.

NOTEWORTHY PRACTICE

Washington State Department of Transportation's Practical Design Approach

Background

In 2015, the Washington State Department of Transportation (WSDOT) transitioned to practical design in lieu of a more standards-based design approach. WSDOT now leverages data, analysis tools, and methodologies to make informed design decisions for its multimodal transportation system.

WSDOT used a prescriptive design process of applying standards and design elements based on the project type. WSDOT recognized that using design deviations and design exceptions often have a negative connotation that implies there was a problem when not meeting a standard. WSDOT determined its process needed to provide more design flexibility to meet the context of the location, and that the process did not give the best return on investment.

WSDOT wanted to shift to a practice of doing the right thing for the situation. WSDOT realized relying too heavily on the standards-based approach came with risks when a design exception needed to be defended in court. It was difficult for WSDOT to defend design decisions without a decision-making framework to justify needs, performance, and other metrics that had led to a nonstandard element on a project. WSDOT determined that leveraging data and new performance tools to help make design decisions would lead to better overall performance on WSDOT's roadway system.

AT A GLANCE

Objectives/goals

- Improve design decision process
- Leverage data, tools, and methodologies

Characteristics

- Practical design framework
- Cultural shift away from standards-based design
- Context considerations and modal priority

Results/outcomes

- Informed and effective project designs
- Empowered designers
- Thorough analysis and documentation

> **Project solutions are not one-size-fits-all. It is more about doing the right thing for the situation.**
>
> **WSDOT**

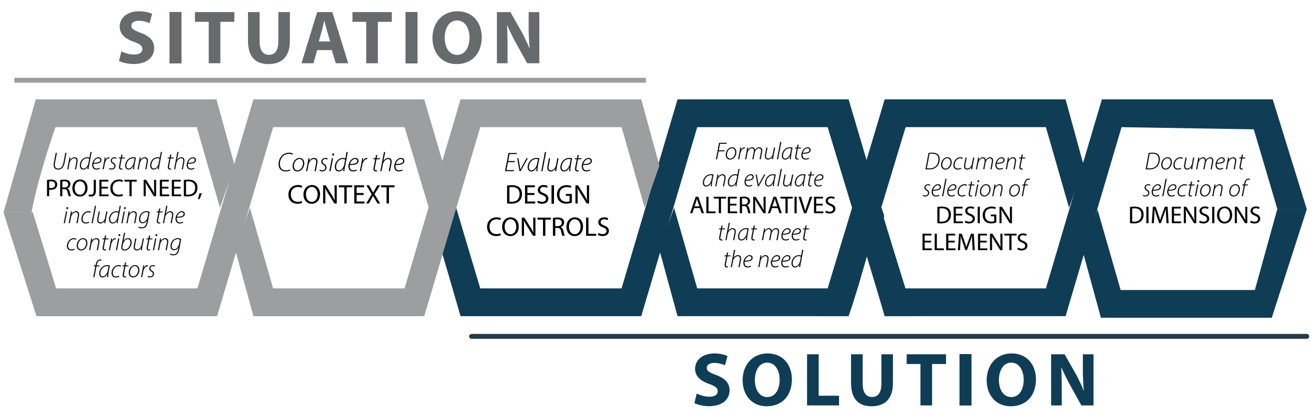

Figure 43. Illustration. Washington State Department of Transportation's practical design process.

Solution/Approach

WSDOT developed documentation tools and a practical design approach to record decisions and analyses. Figure 43 shows WSDOT's practical design process. The figure illustrates how assessing the project situation overlaps with developing the solution when determining the design controls.

With the transition to practical design, WSDOT wanted its designers to evaluate the baseline and contextual needs of every project. WSDOT developed tools to help designers through the practical design process. For example, designers use the *Context and Modal Accommodation Report*[185] (CMAR) and the *Basis of Design*[186] (BOD) to record their decisions during the design process. This design documentation answers the question, Why did you do that?

During practical design, designers must understand current and future context. Context characteristics provide insight relating to roadway function, users, and performance. WSDOT divides context into two categories:

- Land use (rural, suburban, urban, and urban core)
- Transportation (roadway type, bicycle route type, pedestrian route type, freight route type, transit use considerations, Complete Streets, and main street designations)

WSDOT staff uses the CMAR template to record land use and transportation characteristics during the scoping or predesign phase. The questions in CMAR require knowledge of local agency plans and zoning. Therefore, CMAR is best completed by planners during scoping. CMAR provides a framework for designers to determine modal priority for the project. CMAR information is then rolled into the BOD form. The BOD starts at the beginning of a project. It organizes information around the practical design procedural steps and includes the following information:

- Community engagement details
- General project information

185 WSDOT, *Context and Modal Accommodation Report Learner's Guide*, https://wsdot.wa.gov/publications/fulltext/design/ASDE/ContextandModalAccommodationReportGuide.pdf.

186 WSDOT, *Basis of Design*, https://wsdot.wa.gov/publications/fulltext/design/ASDE/BasisDesignForm.docx.

- Project need and performance identification
- Context determination
- Design control selection
- Alternative formulation and evaluation
- Design elements changed

WSDOT selected the design analysis terminology because it more closely represented WSDOT's approach of analyzing the situation and doing the right thing.

Through the practical design process, WSDOT promoted the importance of design decisions and documentation to shift the negative perception that a standard was not being met. WSDOT uses the terminology "consider," "document," "justify," and "design analysis" in its manuals. These terms have the following unique meanings and represent a scaled level of documenting a design decision:

- **Consider** means to think carefully about a decision, and the level of documentation is at the discretion of the engineer.
- **Document** means to place a short note in the design documentation package that explains the decision.
- **Justify** means to prepare a design decision memo for the design documentation package that identifies the reason for the decision using a comparison of the advantages and disadvantages.
- **Design analysis** is the highest level of documenting a decision. It is required where a dimension chosen for a design element is outside the range of values provided for that element in the design manual.

▶ Lessons Learned

Designers did not immediately embrace the transition to practical design. It took time for WSDOT to shift a culture that had been accustomed to standards-based design. WSDOT developed a clear framework for applying practical design. It offers resources, tools, and methodologies for designers to be successful. WSDOT also provides training on design documentation and the project development process, and provides specific training on design analysis.

Recognizing the transportation network is multimodal, WSDOT established modal priority as one of its design controls. WSDOT is still finding better ways to analyze and evaluate multimodal decisions. Designers struggle with balancing the needs of different modes and assessing trade-offs.

In 2019, WSDOT assessed the BOD because WSDOT had been getting complaints about the BOD's usefulness. WSDOT discovered the BOD was useful, but had been required at the wrong time. Prior to the lean review, WSDOT had been requiring the BOD at 100-percent design completion. The lean process determined the BOD should be completed at the 10–20-percent design phase. As a result, WSDOT initiated a new predesign process, which provides up-front funds for design teams to take the design to about 10–20 percent and complete the BOD. The design teams are not given any additional funds for the remainder of the design until the BOD has been approved. This has greatly changed the validity of the BOD for WSDOT and has improved its usefulness, because project needs are researched and addressed early in the project design process when there is an ability to impact the scope of the project.

▸ Outcomes

With practical design, WSDOT is implementing and investing in project designs that consider baseline needs, context, modal prioritization, and equity in transportation. Designers are embracing the process and feel empowered because they help determine the course of a project (e.g., what solution is best and what elements to apply).

WSDOT designers are understanding why it is important to document their design decisions. The design documentation package consists of project development and design approvals and supporting documents from the design process. It explains the design process that was followed, design decisions, and design criteria. Moving away from strict standards-based design and providing data-driven analysis and documentation has put WSDOT in a better place when faced with litigation.

> "We tell our engineers we want them to make the right decisions. We cannot restrict our teams in their thinking if there is something new that comes along that can work to tackle a problem. If it ends up being a variation to our policy, that's OK. We just need to document it properly."
>
> **WSDOT**

NOTEWORTHY PRACTICE

Massachusetts Department of Transportation Complete Streets

Background

Over the past 20 years, MassDOT has made cultural and systemic changes to address pedestrian, bicyclist, and transit user needs. MassDOT's commitment to Complete Streets has transformed how designers think about the facilities they are designing and how they address the mobility and safety needs of bicyclists, pedestrians, and transit users.

In 2012, MassDOT established a mode shift goal of promoting intermodal access by seeking to triple the distance traveled by pedestrians, bicyclists, and transit users by 2030. In 2013, the MassDOT Secretary of Transportation signed the *Healthy Transportation Policy Directive*.[187]

The purpose of the statewide directive is to ensure all MassDOT projects are designed and implemented to provide MassDOT facilities with equal, safe, and comfortable healthy transportation options. However, the *Healthy Transportation Policy Directive* does not specifically state what MassDOT must do from an engineering perspective other than accommodate pedestrian, bicycle, and transit facilities in the design process.

In 2014, MassDOT issued *Engineering Directive E-14-006*[188] to clarify the design criteria that are applied to MassDOT Highway Division projects, including State design criteria for pedestrian and bicycle accommodation. When MassDOT published its bicycle lane design guidance in 2015, some of the information in the guide was not reflected in *Engineering Directive E-14-006*. Thus, *Engineering Directive E-14-006* needed to be updated. The agency also wanted to move away from the term "design exceptions" and introduce a new approach called "design justifications," which would enhance the design decision process for MassDOT.

AT A GLANCE

Objectives/goals

- Provide all projects and modes with safe, comfortable, and healthy transportation options
- Improve process for design decision justification and documentation
- Increase short trips by walking, bicycling, or using transit

Characteristics

- Complete Streets State design criteria
- Stakeholder engagement and relationships
- Cultural changes and policy improvements

Results/outcomes

- Safer infrastructure for all road users
- Enhanced and streamlined practices for analysis, decision-making, and documentation
- Stronger relationships with stakeholders and advocates

187 MassDOT, *Healthy Transportation Policy Directive*, Policy P-13-0001 (September 9, 2013), https://www.mass.gov/doc/healthy-transportation-policy-directive/download.

188 MassDOT, *Engineering Directive*, Number E-14-006 (December 19, 2014), https://www.mass.gov/doc/design-criteria-for-massdot-highway-division-projects-e-14-006/download.

▶ Solution/Approach

MassDOT's objectives were to establish engineering criteria that aligned with the needs and goals of the *Healthy Transportation Policy Directive* while also creating a streamlined design justification and documentation process. The agency had a multifaceted approach to accomplish its vision of providing safe, comfortable, and convenient transportation options for all people.

In 2020, MassDOT released *Engineering Directive E-20-001*[189] to reflect recent changes to FHWA's controlling criteria. MassDOT also established and defined new criteria for its multimodal facilities and created a design justification workbook for all projects to more efficiently document design decisions and any necessary design exceptions or variances from the minimum criteria. *Engineering Directive E-20-001* was a milestone for MassDOT.

In addition to FHWA's 10 controlling criteria, MassDOT implemented four criteria of its own: provision of pedestrian facilities, bicycle facilities, and transit improvements, and ramp length at interchanges. Pedestrian, bicycle, and transit provisions are referred to as MassDOT's Complete Streets criteria. If a project does not meet the minimum Complete Streets criteria, approval is required by the MassDOT Secretary of Transportation.

Source: MassDOT, "Bicycle and Pedestrian Update – 2021."

Figure 44. Photo. Two-way bicycle lane.

Source: MassDOT, "Bicycle and Pedestrian Update – 2021."

Figure 45. Photo. Multimodal Complete Streets.

189 MassDOT, *Engineering Directive*, Number E-20-001 (January 2, 2020), https://www.mass.gov/doc/controlling-criteria-and-design-justification-process-for-massdot-highway-division-projects-e/download.

The following is a summary of definitions and requirements for each facility type provided in MassDOT's *Engineering Directive E-20-001*.[190]

- Pedestrian facilities may include sidewalks, shared-use paths, or side paths. Other than shared-use paths and side paths, pedestrian facilities are exclusive of any width intended for bicycle travel. Pedestrian facilities must be provided on both sides of the roadway if specific criteria apply.
- Bicycle facilities may include shared-use paths, side paths, separated bicycle lanes, buffered bicycle lanes, bicycle lanes, or paved outside shoulders. Bicycle facilities must provide service for each direction of vehicular travel for all roadways where bicycles are legally allowed, except roadways classified as local. The bicycle facility must be a shared-use path, side path, separated bicycle lane, or buffered bicycle lane if specific criteria apply. Bicycle facilities may provide service in a single direction of travel (unidirectional) or two directions of travel (bidirectional).
- Transit provisions are required at transit routes and stops operated by the Regional Transit Authority, the Massachusetts Bay Transportation Authority, or any public or State agency. This includes any fixed-route bus, shuttles, streetcar, or trolley services. All transit stops, regardless of owner or operator, with 100 or more boardings per day must have a shelter or bench in place. Crosswalks for pedestrian access must be provided between both sides of a roadway within 250 feet of transit stops. Transit priority treatments must be provided along transit routes with headways of 15 minutes or less.

Source: MassDOT, "Bicycle and Pedestrian Update – 2021."

Figure 46. Photo. Bus transit shelter located within near distance to accessible crosswalks.

Engineering Directive E-20-001 also provided a uniform method for documenting design decisions. MassDOT developed its own spreadsheet workbook for design justifications. The workbook provides a uniform method for designers to identify and document their decision-making process for each controlling design element in every project.[191] The workbook enables a step-by-step approach using checkboxes, drop-down menus, and text boxes to type in numeric values and justification details. The workbook contains tabs for MassDOT's four controlling criteria for pedestrian, bicycle, transit, and ramp length, and all 10 of FHWA's controlling criteria. The workbook identifies the minimum criteria for a facility, and if the proposed solution does not meet that minimum the designer will write a justification to document and ensure the solution meets the intended purpose and need. Designers can also justify project alternatives to minimize or eliminate associated impacts, which allows designers to look at each project equally. An example of the workbook is shown in figure 47.

190 MassDOT, *Engineering Directive*, Number E-20-001 (January 2, 2020).

191 Commonwealth of Massachusetts, "MassDOT Design Justification Reports," https://www.mass.gov/info-details/massdot-design-justification-reports.

Subcriterion: Type

Type of Bicycle Accommodation: SEPARATED BICYCLE LANE (1-WAY)
Posted or statutory speed of facility: 40 MPH
Facility volume (vehicles per day): 8500
Number of travel lanes (in each direction): 1 *(If this varies, use the higher number.)*

☑ The roadway is classified as a corridor with a High Potential for Everyday Biking in the Bike Plan.

Justify the proposed value.

(Attach additional sheets as necessary.)

Subcriterion: Width

(Width excludes any buffer areas.)

Minimum: 5.0 FT Existing: FT Proposed: 5.0 FT

(If the width varies, provide a minimum.)

Source used for minimum: MassDOT Controlling Criteria

Justify the proposed value.

(Attach additional sheets as necessary.)

Source: MassDOT.

Figure 47. Illustration. Example of the design justification workbook for separated bicycle lane facilities.

Stakeholders outside of MassDOT including advocacy and special interest groups wanted to be involved in reviews to offer their concerns and potential solutions on projects. MassDOT recognized that successfully implementing its vision and goals required a partnership with these stakeholders. Stakeholders now take part in MassDOT's monthly design exception review committee meetings. This allows transparency and open communication, giving stakeholders a forum to share information and offer additional perspectives to support the project development process. The meetings also give stakeholders a better understanding of all the factors MassDOT balances during the decision-making process.

To enhance its project development process, MassDOT holds scoping meetings early in the design process to discuss design decisions. The multidisciplinary team reviews the scope of work, proposed cross sections, and project alternatives. If the design solution costs more than what the budget allows, but is at a priority location, MassDOT uses a process to identify additional funding to ensure it applies the most desirable solution that balances safety, operations, and community needs.

MassDOT also created a geographic information system (GIS) tool to analyze the low, medium, and high potential for walking and bicycling. Maps in the GIS tool take into account a variety of factors, such as equity, population, communities, hospitals, and schools within the area.[192]

"The design of a Complete Street should be context sensitive and incorporate improvements or treatments that fit the need and with the character of a community."

MassDOT Complete Streets Program

▶ Lessons Learned

While implementing multimodal design solutions, MassDOT aims to accommodate and satisfy stakeholders throughout the project development process. Sometimes compromise is necessary, and MassDOT may not always be able to implement desired elements in the project because of certain constraints. Design flexibility is key. The overall goal of each project is to ensure the design solution is safe, convenient, and accessible for all users.

Source: MassDOT, "Bicycle and Pedestrian Update – 2021."

Figure 48. Photo. Complete Streets design.

MassDOT knows that some projects with multimodal aspects may require more extensive surveying and design work. To make this process more efficient, MassDOT identifies the multimodal design criteria elements early in the project development process and includes input from stakeholders. This helps projects stay on schedule and within the budget. The design justification workbook also helps designers throughout the beginning stages of projects as the designers identify and justify their design decisions.

▶ Outcomes

Throughout the last 20 years, MassDOT has evolved its engineering directives to reflect its multimodal policy directives. MassDOT established its own Complete Streets controlling criteria for pedestrian, bicycle, and transit facilities, and streamlined its design decision and justification process. MassDOT is continually striving to improve its engineering practices and policies to encourage performance-based design and context-based design.

The following benefits have resulted from these efforts:

- Designers are more focused on pedestrian, bicyclist, and transit user needs throughout the project development process and have more flexibility to incorporate design options that reflect the surrounding environment.
- The design justification workbook and GIS tools have enhanced and streamlined analysis, decision-making, and documentation practices.
- MassDOT's relationships with stakeholders and advocacy groups are stronger because of increased involvement, communication, and transparency.

Incorporating MassDOT's Complete Streets criteria into project implementation has increased safety and mobility for all road users.

Overall, incorporating MassDOT's Complete Streets criteria into project implementation has increased safety and mobility for all road users.

192 MassDOT, "Potential for Walking Trips," https://geo-massdot.opendata.arcgis.com/datasets/MassDOT::potential-for-walkable-trips/about.

NOTEWORTHY PRACTICE

Transitioning to a Multimodal Corridor

FRANKFORT, KENTUCKY

Background

The Second Street corridor on U.S. Route 60 (U.S. 60) in downtown Frankfort, Kentucky, was revitalized with improved multimodal facilities and slower traffic. Drainage and sewer infrastructure was also improved, which provides an environmental benefit for the Kentucky River.

This multi-agency effort involved the City of Frankfort, KYTC, FHWA, utility partners, and contractors. The project was made possible through USDOT's Transportation Investment Generating Economic Recovery Grant program.

The City of Frankfort and its partners realized the need for this project through a study of the existing conditions of the sidewalks, roadway, and combined sanitary and stormwater sewer system. The following key circumstances led to this improvement project:

- The functional and context classification of the Second Street corridor has changed over time. It used to be an arterial, carrying more through traffic. However, broader transportation improvements in the Frankfort area have reduced traffic volumes on this section of U.S. 60. It now serves as more of a local downtown street for the community.
- There were sidewalk issues specific to vulnerable road users, such as elementary school students, the older population, and persons with disabilities. For example, the only route to downtown accessible to pedestrians with disabilities involved crossing the Kentucky River twice. Bicycle facilities were also discontinuous and not well marked.
- The steep topography included a 5–6-percent downgrade for roughly half a mile, which resulted in speeds higher than the posted speed limit. A horizontal curve at the base of the steep downgrade also led into a school zone.
- The combined sanitary and stormwater system needed to be separated to reduce sewage overflows into the Kentucky River during heavy rainfall, a key environmental concern.

AT A GLANCE

Objectives/goals

- Improve multimodal facilities and connections
- Reduce traffic speeds
- Improve drainage and reduce sewer overflows into the Kentucky River

Characteristics

- Downtown, urban core classification
- Accessibility barriers for people with disabilities
- Historic infrastructure
- Challenging topography

Results/outcomes

- Design flexibility and collaboration are keys to success
- Importance of design documentation records

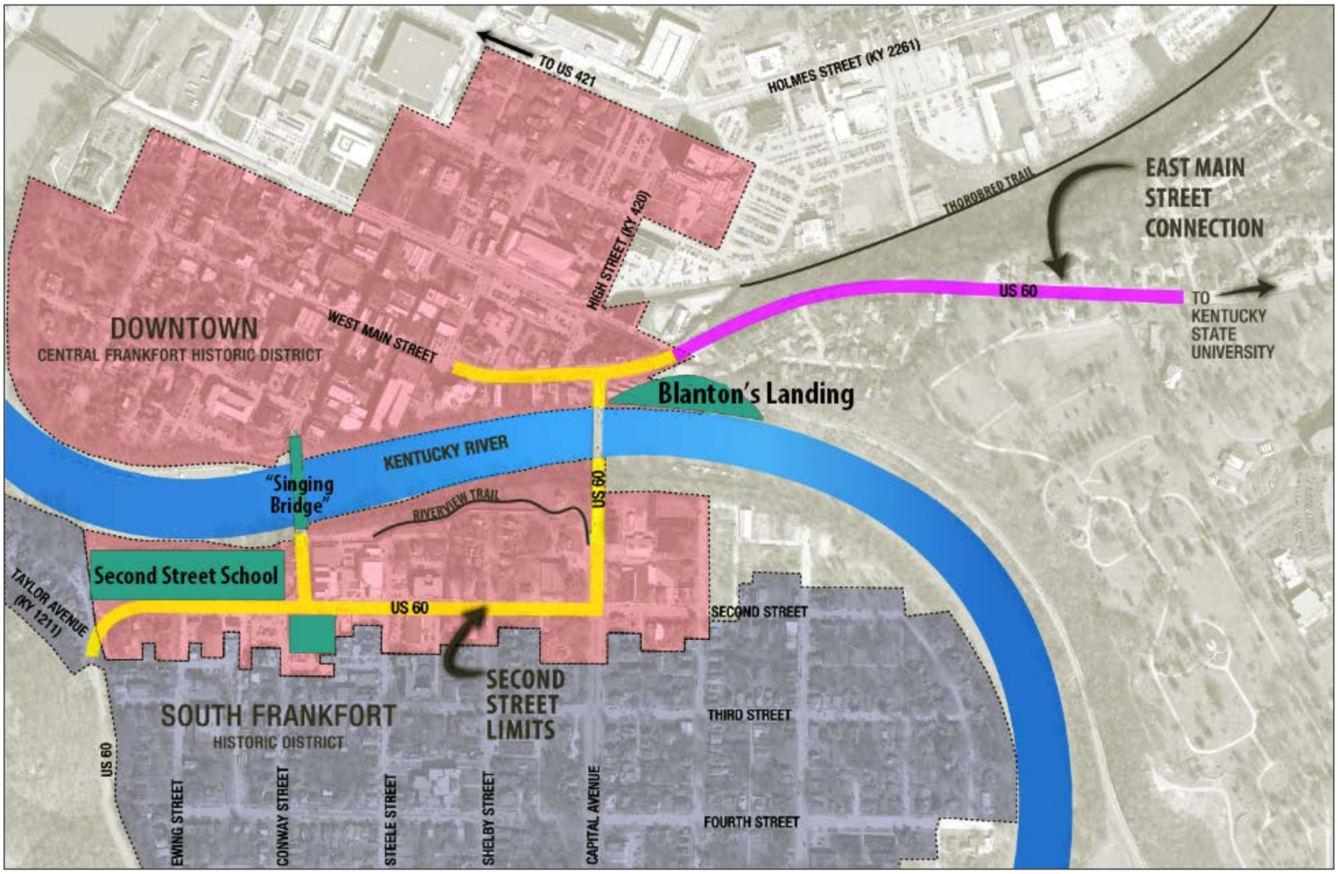

Figure 49. Map. The project limit range for the corridor improvement.

▶ Solution/Approach

This project, entitled Second Street (US 60) Corridor Complete Street and Road Diet, solves multiple issues that stem from centuries-old construction and steep topography. The project creates a multimodal corridor aligned with the City of Frankfort and Franklin County's *Pedestrian and Bicycle Master Plan*.[193]

Figure 50. Photo. Example of steep topography and lack of accessible sidewalks.

193 WalkBike Frankfort, *City of Frankfort & Franklin County Pedestrian & Bicycle Master Plan* (2016), https://www.frankfort.ky.gov/DocumentCenter/View/1120/Walk-Bike-2016.

Figure 51. Illustration. Conceptual design of the Second Street and Bridge Street intersection.

Multimodal Solutions and Connectivity

The project team designed improvements to enhance mobility and improve accessibility for all road users, per the public's request for multimodal facilities.

These improvements include:

- Redesigning the sidewalks so that pedestrians do not have to use steps to access transit or other destinations. This includes providing a two-tiered sidewalk (southwest side) and a sloped walkthrough around the existing steps (northeast side).
- Installing leading pedestrian intervals at traffic signals.
- Reducing the length of pedestrian crosswalks by reconfiguring turn lanes and extending the sidewalk streetscape to improve safety.
- Widening the sidewalks to a minimum of 6 feet to improve accommodations for pedestrians.
- Providing bicycle accommodations, such as designated bike lanes.

Figure 52. Photo. Before condition, showing barriers to accessibility.

A. Improved sidewalk and curb ramps.

B. Improved pavement markings.

Figure 53. Photo. After condition, showing improved sidewalks, curb ramps, and pavement markings.

Figure 54. Photo. Before condition, showing the crosswalk at the Second Street and Bridge Street intersection.

Figure 55. Photo. After condition, showing reduced crosswalk length and improved sidewalk accessibility at the Second Street and Bridge Street intersection crosswalk.

Traffic Calming and Speed Management

Multimodal design features provide visual cues to motorists to reduce their speed. The project team also added a mountable median with flexible delineator posts along the horizontal curve at the base of the steep downgrade to calm traffic and encourage slower speeds. The team assessed the existing roadway width and reallocated the space for improved pedestrian and bicycle accommodations.

© Strand Associates, Inc.

Figure 56. Photo. Mountable median with a traffic calming effect along the horizontal curve at the base of the steep downgrade.

Drainage System and Historic Infrastructure Improvements

The team corrected issues associated with the old infrastructure, such as the combined sanitary and stormwater system. The team navigated around the stone retaining walls to remove the existing sanitary sewer and connect the new storm sewer to storm overflow so the storm drainage can go directly into the Kentucky River.

Flexibility in Design

The team used flexibility in design and performance-based practical design to address planning and design elements. Downtown Frankfort's terrain, infrastructure, and limited right-of-way provided challenges for the design team. The historic infrastructure includes design and stone retaining walls from the late 1800s. The infrastructure is an important historic feature in the city.

Although design exceptions were not required, because the design speed is 30 mph, design variances from State standards were needed to achieve the project's goals. The team used design variances to work within limited right-of-way and minimize the impact on historic resources. Increased signage and pavement markings give visual cues to drivers for the horizontal curve, superelevation, and stopping sight distance of the roadway. The mountable median also provides traffic calming along the horizontal curve.

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Figure 57. Photo. Retaining walls affect sight distance, but moving them would create disruption to the built environment and require investment because of the homes, businesses, and trees behind the walls.

Table 12. Design variances for the project.

Controlling Criteria	Existing Condition	AASHTO Guidance	Proposed Condition
Horizontal curve radius	200 feet	231 feet	200 feet
Maximum superelevation rate	8 percent	6 percent	8 percent
Stopping sight distance	150 feet	200 feet	155 feet
Maximum grade	10 percent	9 percent	10 percent
Border area-urban (similar to clear zone, considered as other criteria)	4.5-foot minimum	8-foot minimum	4.5-foot minimum

© KYTC Item No. 5-565 Design Executive Summary.

Note: If the controlling criteria are less than AASHTO's recommended guidance and the recommended design speed is <50 mph, variances are needed.

▶ Lessons Learned

The project team learned the following key lessons during the project:

- **Collaboration among stakeholders.** Planning, designing, and constructing the improvement to this corridor involved a 4-year plan incorporating a committee with representatives from the City of Frankfort, KYTC, FHWA, utility partners, and contractors. The committee made a large effort to collaborate, which was paramount to getting the project off the ground and constructed.
- **Design documentation and records management.** One challenge and lesson learned was specific to utility construction and the lack of previous documentation or recorded knowledge of the historic infrastructure. The project team thoroughly documented its design variances that impacted the limited right-of-way and navigated around the historic retaining wall. The reasoning behind those decisions will support the detailed records for future efforts on the corridor. Although it is not uncommon for historic records to be incomplete, or even nonexistent, this is an example of how thorough design documentation can inform future project plans and budgets.

▶ Outcomes

The environmental, design, and right-of-way phases were all completed in less than 4 years, with the project completed in October 2022. To meet the schedule, the project team of Federal, State, and city personnel proactively collaborated. The team saw itself as problem solvers, rather than barriers to implementation. The team's commitment to collaboration and regular, open communication resulted in successful planning, design, and implementation. The City of Frankfort recognizes the importance of evaluating the effectiveness of design decisions. The city is planning to observe operating speeds coming into the corridor after it completes construction to assess the traffic calming countermeasures it had implemented and to consider additional improvements.

- Multimodal solutions to provide access for all users
- Traffic calming and speed management
- Drainage system enhancements
- Historic infrastructure preservation

NOTEWORTHY PRACTICE

U.S. Route 31 Roadway and Pedestrian Improvements

GRAND TRAVERSE COUNTY, MICHIGAN

Background

The Michigan Department of Transportation (MDOT) used design exceptions and a context sensitive approach on U.S. Route 31 (US-31) to balance roadway issues and the needs of users in the area. Located in Grand Traverse County, just east of Traverse City, this stretch of US-31 is a multilane signalized urban arterial on a national truck route. It is situated in a commercial and recreational hub known as the Miracle Mile. The Miracle Mile is dotted with hotels, businesses, and State and township park properties.

When MDOT initially scoped the project, the primary purpose was to replace the degraded pavement throughout the corridor. However, as the project progressed into the planning and design phase, the project team noted footpaths in the grass alongside the roadway indicating heavy pedestrian use. This stretch of US-31 contained some intermittent pedestrian facilities but did not provide the needed connectivity along the route between the commercial and recreational hubs. Because of this observation, the team revised the project scope to also improve pedestrian facilities within the corridor.

Carrying approximately 36,000 vehicles per day, US-31 has four 11-foot through lanes with a center turn lane and curb and gutter. The posted speed limit is 45 mph. The project had limited existing right-of-way and was surrounded by high-value commercial real estate and public parks. Adding sidewalks to the scope posed challenges to the project team, including right-of-way acquisitions, adjacent park land disturbances, and cost and schedule implications.

AT A GLANCE

Objectives/goals

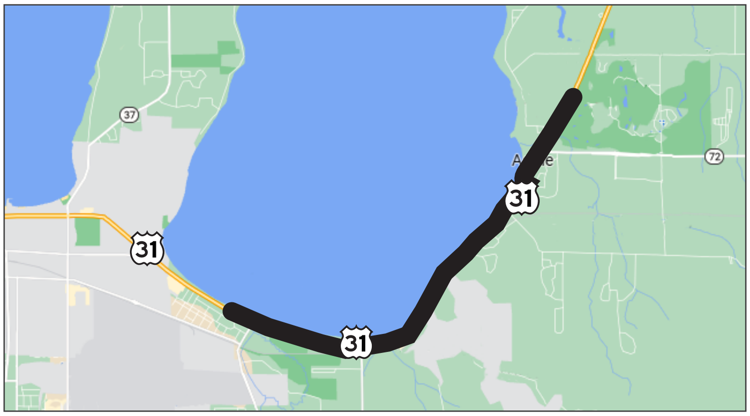
- Replace deteriorating pavement
- Improve pedestrian facilities and connectivity

Characteristics

- Multilane arterial within constrained commercial and recreational area
- Extensive outreach
- Collaboration with stakeholders

Results/outcomes

- Reduced crashes
- Improved pedestrian facilities for community
- Updated policies on design flexibility and context sensitive design



© 2023 Google® Maps™, modified by FHWA.

Figure 58. Map. U.S. Route 31 improvement boundaries.

▶ Solution/Approach

The team assessed the project's design criteria to identify potential alternatives that would reduce the overall footprint of the project's proposed typical section. MDOT's design criteria recommended widening the existing lanes from 11 feet to 12 feet. Adding sidewalks along each side of the road would expand the project's footprint. The team evaluated the existing roadway's performance and determined there would not be appreciable changes in traffic volumes, posted speed limit, alignment, or vehicle use over the design life of the project. MDOT also examined the crashes within the project limits over a 4-year period, from 2009 to 2013. A summary of the crash types is provided in table 13.

Table 13. Pre-project crash type summary from 2009 to 2013.

Crash Type	Number of Crashes
Rear-end	93
Angle impact	32
Miscellaneous	20
Head-on*	11
Fixed object*	8
Animal	3

© MDOT.
*Crash types commonly associated with roadway departures.

The team focused on the crash types associated with the inability to maintain a vehicle's desired path of travel. After reviewing the sideswipe, head-on, and fixed-object crashes, the team could not directly link any of them to a driver's failure to maintain a vehicle path. Instead, the crashes were attributed to weather or to driver error during intentionally initiated vehicle maneuvers, such as lane changes. The team's analysis did not identify any particular crash pattern, and it did not find evidence the existing 11-foot lane widths had contributed to crashes within the project limits.

The team determined that maintaining the existing 11-foot lanes and completing a design exception for the lane width were important in constructing the pedestrian facilities. In addition to improving sidewalk connectivity for the community, maintaining the existing lane widths would have the following benefits:

- Minimize the need for right-of-way acquisition
- Reduce the overall impacts to utilities within the corridor
- Eliminate any impacts to protected park property

The East Bay Charter Township and the Michigan Department of Natural Resources (MDNR) also saw the value of incorporating pedestrian facilities into the project. The support from East Bay Charter Township and MDNR aided in the team's coordination in the Section 4(f) protected lands process.[194] The stakeholders agreed the community would benefit from new sidewalks and improved connectivity for pedestrians.

MDOT developed a project website and partnered with local businesses in the project corridor. The contractor hosted daily coffee hours in a local hotel lobby where the team interacted with the public and answered questions about the project.

194 FHWA, "Section 4(f) at a Glance," https://www.environment.fhwa.dot.gov/legislation/section4f/4fAtGlance.aspx#:~:text=What%20are%20Section%204(f,National%20Register%20of%20Historic%20Places.

MDOT leveraged State funding resources to execute easement agreements as part of the project. With these agreements, the contractor was able to access and temporarily disturb property during the project's construction. It also allowed MDOT to construct sidewalk facilities outside of the existing right-of-way.

The team also identified other improvements to enhance safety within the corridor, including consolidating access points or driveways, installing centerline rumble stripes, and providing enhanced lighting.

▶ Lesson Learned

"Scope the job you want. Do what is right for the road and the community."

MDOT team member

Many transportation agencies, including MDOT, had not formally incorporated context sensitive design into the planning and design processes at the time this project was developed. The MDOT team could see the value in maintaining the existing 11-foot lanes and improving the pedestrian facilities. The team developed documentation to support the design exception request for the lane width. MDOT focused on increased project coordination and communication. The team coordinated with East Bay Charter Township, MDNR, FHWA, community stakeholders, and business owners. The team also held discussions with MDOT's chief operating officer to explain the design decision and enhance MDOT executive staff's understanding of the team's context sensitive approach.

▶ Outcomes

MDOT's final project met the needs of the roadway and the community. By taking a context sensitive approach and thoughtfully using the design exception process, the team was able to incorporate the pedestrian facilities into the project corridor.

MDOT completed a post-project crash study and found a 30-percent reduction in total crashes and a 67-percent reduction in fatal and incapacitating injury crashes when compared to the pre-project analysis. A pedestrian count study revealed people were using the new sidewalks to either cross at the existing overhead pedestrian bridge or at one of the two existing signalized intersections.

Figure 59. Photo. U.S. Route 31 roadway and sidewalk pedestrian improvements.

A. Before conditions. B. After conditions with paved sidewalks.

Figure 60. Photos. Before and after the project improvements.

This project's success helped lead to MDOT's updated design variance process and demonstrated the positive impacts that design exceptions can have in some situations. MDOT now has a program dedicated to applying context sensitive solutions on projects across the State. This project is a testament to design flexibility and leveraging the design exception process to benefit the project and community.

MDOT completed a post-project crash study and found there was a 30-percent reduction in total crashes and a 67-percent reduction in fatal and incapacitating injury crashes when compared to the pre-project analysis.

"In the end we came through this process and were able to achieve the right scope of work [including] sidewalks, replacing curb and gutter, and doing the right thing for the road [while maintaining] the 11-foot lanes, which made it all possible. We got the best of both worlds."

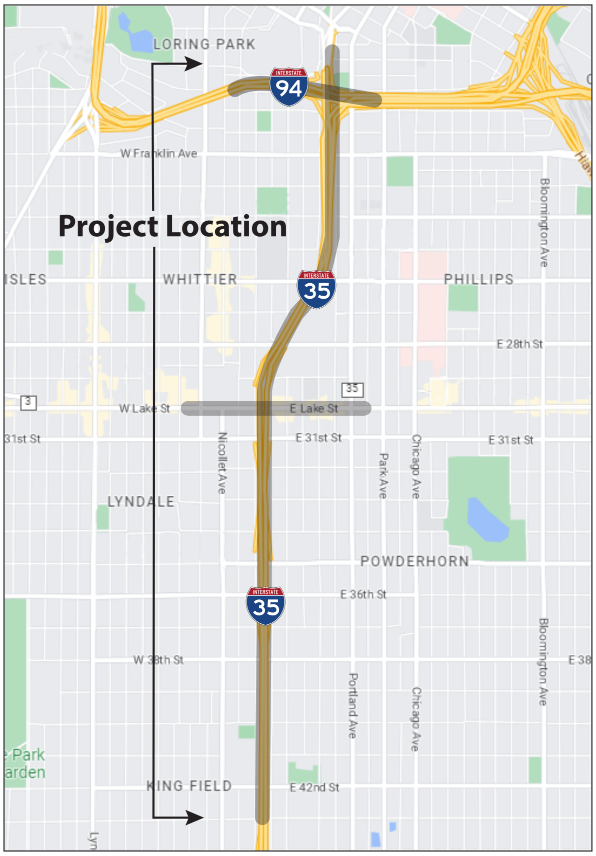
MDOT team member

NOTEWORTHY PRACTICE

Interstate 35W at Lake Street In-Line Transit Station and Extension of High-Occupancy Toll Lanes

Background

Using design flexibility principles, the Minnesota Department of Transportation (MnDOT) implemented TSMO strategies along portions of Interstate 35W (I-35W) and Interstate 94 (I-94), south of the City of Minneapolis. The project extended the existing high-occupancy toll (HOT) lane infrastructure. The project also increased the multimodal access, connectivity, and safety of an in-line two-story transit station on I-35W at Lake Street. Figure 61 shows the project location.



©

MnDOT.

Figure 61. Map. Project location.

AT A GLANCE

Objectives/goals

- Extend HOT lanes through corridor
- Improve safety of transit station
- Increase multimodal access and connectivity in the region

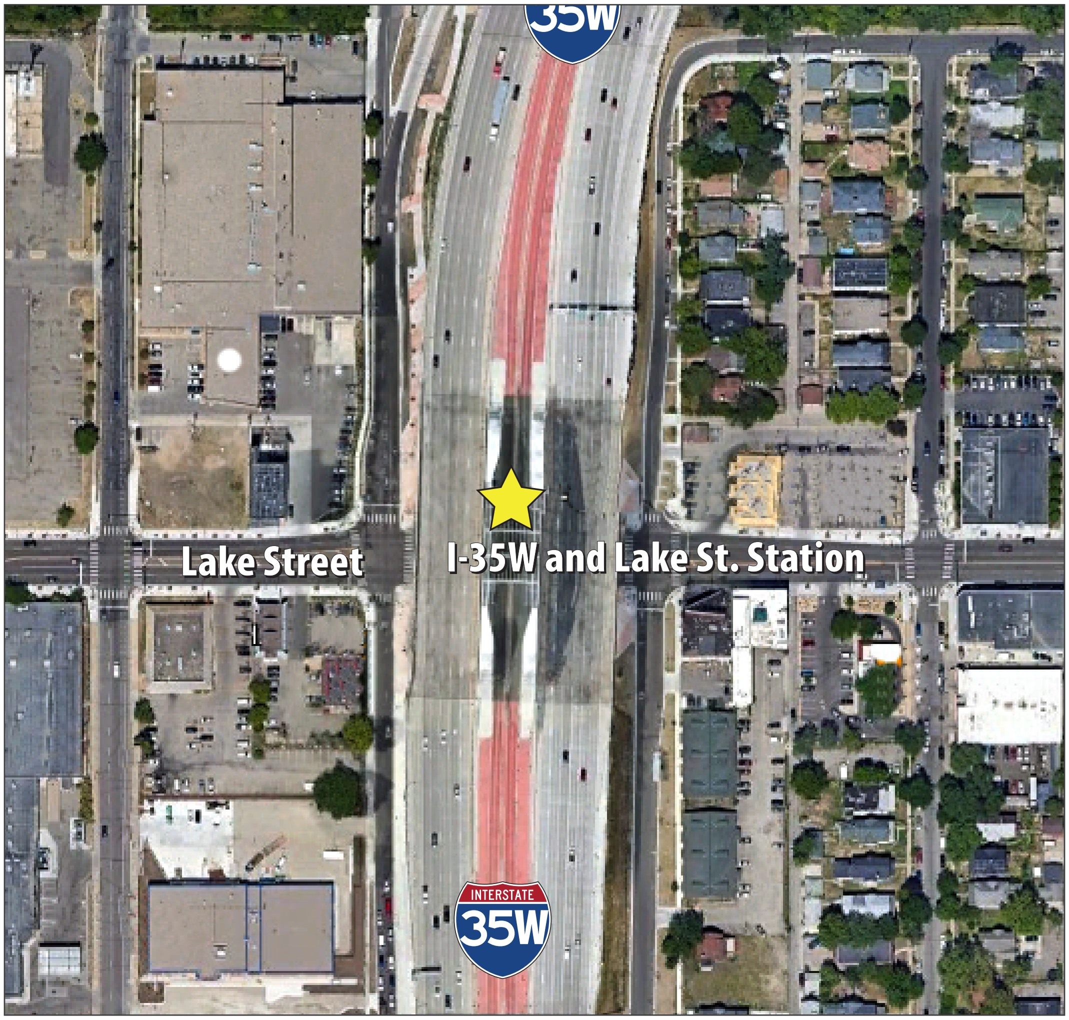
Characteristics

- Expansion of roadway footprint not feasible
- TSMO strategies/HOT lane
- Connections to other travel modes

Results/outcomes

- Improved I-35W corridor operations and reliability by reducing conflict points/weaving
- Improved safety for buses entering/leaving transit station
- Safer multimodal access and connectivity to in-line transit station and context sensitive design

Figures 62-A and 62-B show the new in-line transit station located at Lake Street.



A. Aerial view of the new Lake Street train station.

B. Street view of the new Lake Street train station.

Figure 62. Photos. New Lake Street train station.

During planning and design, MnDOT had to work within the physical constraints of the area to achieve the project objectives. The corridor plan called for the extension of the HOT lane, but limited width was available along the corridor, especially under existing bridges. The existing bus stop at Lake Street was located on the right-hand side of the travel lanes. Buses travelling in the HOT lane adjacent to the median had to weave across five lanes to enter the bus stop. Other vehicles sometimes followed the buses into the station, which posed safety issues. Because of this design, buses only dropped off passengers but did not pick them up.

▸ Solution/Approach

The MnDOT project team held regular meetings with stakeholders to discuss plans and concerns. The team conducted studies to assess transit station locations and design options. MnDOT completed an origin-destination study and operational and weave analyses to assess traffic patterns along the corridor. The project team also conducted risk assessments to examine alternatives. MnDOT carefully analyzed crashes along the corridor to ensure its design decisions would not adversely affect safety.

MnDOT investigated transit station locations and designs. The results indicated Lake Street was the preferred location because it offered the best connectivity to local bus routes on Lake Street, and to the Midtown Greenway—a 5.5-mile shared-use bicycling and walking path. The transit station would also be located adjacent to the median to eliminate buses weaving across lanes of traffic. MnDOT chose a split platform design for the transit station to allow buses to enter, stop at the station, and reenter I-35W. If a car followed a bus into the station, the car could pass through the station and reenter I-35W.

The HOT lane extensions would have to address lane and shoulder width issues. The provisions for a standard typical section on I-35W for the proposed project would require reconstructing the bridges at 42nd Street, 38th Street, 36th Street, and 35th Street, as well as further expansion of I-35W. The estimated cost of providing the new bridges was up to $15 million. Reconstructing I-35W would also impact the local parallel routes, as well as additional right-of-way requirements and environmental concerns. MnDOT would also have to modify lighting systems, traffic management systems, and signing along the corridor. These factors led MnDOT to pursue design exceptions to achieve the project goals. The design speed of the facility is 60 mph. Table 14 summarizes the design exceptions needed to extend the HOT lane and build the in-line transit station.

Table 14. Summary of design exceptions.

Design Element	Existing Condition	Proposed Condition	Standard
Lane Width	11-foot minimum	11-foot minimum	12 feet
Shoulder Width	4 feet (right) 6 feet (left)	4–10 feet minimum (right) 4.5 feet (left)	10 feet
Bridge Shoulder Width	3 feet 4 inches (right) 2 feet 6 inches (left)	10 feet (right) 4.5 feet (left)	10 feet

Overall, MnDOT either maintained or improved existing conditions. The project included widening the width of right shoulder to 10 feet throughout the corridor; the 4-foot shoulder width was only proposed under bridges. MnDOT's crash analyses did not indicate that existing narrow lane width or shoulder widths had been contributing to crashes. Most crashes were indicative of congested conditions, not lane or roadway departure crashes.

MnDOT actively monitors and restricts HOT lane use to mitigate potential drainage issues that could occur on the 4.5-foot left shoulder during heavy rainfall.

Using concepts of design flexibility, TSMO, and multimodal connectivity, MnDOT successfully addressed real-world design issues while achieving the vision for the corridor.

▶ Lessons Learned

The MnDOT team encountered two challenges: 1) the physical space available to accommodate the expansion of HOT lanes and the in-line transit station and 2) the concerns of the local community impacted by the project. To make room for HOT lanes and the transit station, the MnDOT team obtained design exceptions for lane width. To address community concerns about the proposed transit station's location and noise, the team moved the I-35W corridor further west along the segment between 35th Street and Lake Street. I-35W between 35th Street and Lake Street needed to fit between a historic district on the east side of I-35W and a church, which was eligible for the historic register, on the west side of I-35W. Using narrowed lanes, using narrowed inside shoulders, and adjusting the alignment of I-35W made this a possibility. Sound walls are also present along portions of I-35W between 35th Street and Lake Street where the transit station is located.

▶ Outcomes

The project team successfully overcame the physical design and community challenges. The resulting project provided:

- Improved I-35W mobility by extending the HOT lane to downtown Minneapolis
- Improved I-35W mobility by creating the southbound HOT lane from downtown Minneapolis to 46th Street
- Improved safety for buses entering and leaving the transit station
- Increased connectivity to the transit station, and other multimodal transportation options in the area
- Improved bicycle and pedestrian access throughout project limits
- Improved access to the Lake Street business district and neighborhood with a high concentration of medical facilities

NOTEWORTHY PRACTICE

A Context-Based Design Decision to Improve Safety and Operations at a Tourist Destination

HORSESHOE BEND, ARIZONA

Background

Horseshoe Bend is a point of interest in Glen Canyon National Recreation Area in northern Arizona. This landmark offers visitors hiking, kayaking, and beautiful views across the Colorado River (see figure 63). Located near U.S. Route 89 (U.S. 89) just south of the City of Page, 2 million people visit Horseshoe Bend each year.[195] It has become a tourist destination, bringing cars, motorcycles, shuttle buses, and recreational vehicles.

© Arizona Department of Transportation (ADOT).

Figure 63. Photo. Horseshoe Bend, Arizona.

AT A GLANCE

Objectives/goals

- Reduce potential pedestrian/vehicle conflicts
- Prevent parking on shoulder
- Improve traffic flow

Characteristics

- Rural tourist destination
- High traffic influx
- Variety of vehicles and users

Results/outcomes

- Improved traffic operations/less congestion
- Reduced parking on shoulder
- Reduced risk of pedestrian-involved crashes

Visitors to Horseshoe Bend use a parking lot in close proximity to U.S. 89 and hike to the viewpoint about 1 mile from the parking lot. This unpaved parking lot, shown in figure 64-A, did not have the capacity to accommodate the growing crowds. As a result, visitors often parked on the shoulders of U.S. 89, as shown in figure 65, and walked across and along the highway to get to the viewpoint. There were no crosswalks.

195 Arizona Office of Tourism, "A Guide to Visiting Horseshoe Bend the Right Way," https://www.visitarizona.com/like-a-local/a-guide-to-visiting-horseshoe-bend-the-right-way/#:~:text=Horseshoe%20Bend%20attracts%202%20million,more%20meaningfully%20with%20the%20destination.

A. Before the project, the parking lot was a small, unpaved lot.

B. After view of the parking lot.

Figure 64. Photos. Before-and-after views of the Horseshoe Bend parking lot and corridor.

In 2018, the State of Arizona, City of Page, National Park Service, and Coconino County held a safety summit. The safety summit uncovered a need to improve safety and traffic flow along the U.S. 89 corridor at Horseshoe Bend.

The discussions at the summit revealed the following:

Figure 65. Photo. Cars parked along the shoulder at Horseshoe Bend.

- Visitor numbers in 2018 had doubled from 2016. Because of the increased numbers, visitor parking had become an issue. Local agencies had started working on parking lot improvements.
- Vehicles parked along the U.S. 89 shoulders were narrowing the corridor for motorists coming to or passing through this area.
- Visitors who parked on the shoulders often walked along and across the highway to get to the trailhead, causing pedestrian safety risks and increased safety concerns.
- The local sheriff's office had to regularly direct traffic at the parking lot entrance to help mitigate congestion and improve traffic operations.
- Incident management, traffic response, and emergency needs were also a priority considering the extreme heat in Arizona and the high levels of congestion and pedestrians. Because of increased traffic and the narrowed corridor, getting emergency vehicles to the area was a challenge.
- Attempts by ADOT to place pylons along the shoulder to prohibit parking were unsuccessful. Vehicles instead opted to park farther up or down the road from the parking lot entrance.

▶ Solution/Approach

ADOT partnered with the City of Page, Coconino County, and the National Park Service to develop solutions to address pedestrians, parking, and traffic congestion. Local agencies had already begun working on improving and expanding the parking lot. During the summit, participants identified access, shoulder parking, and pedestrian traffic along U.S. 89 as safety topics.

To address the issues uncovered in the safety summit, ADOT looked at existing conditions of the corridor surrounding Horseshoe Bend. ADOT also considered the history of the corridor as well as alternatives that might remedy or improve conditions. Although a southbound right-turn lane existed at the parking lot entrance, no dedicated northbound left-turn lane existed at this location. As a result, northbound traffic trying to enter the overlook's parking area would often back up traffic along northbound U.S. 89. To address the project's objectives to improve safety and operations along the U.S. 89 corridor, a dedicated left-turn lane was added to U.S. 89 northbound. This allowed left-turn movements into the new and expanded parking lot constructed at the scenic overlook. The left-turn lane was implemented to mitigate potential crashes from occurring at the intersection of U.S. 89 and the parking lot, and to improve access and traffic flow.

Dedicated left- and right-turn lanes are a Proven Safety Countermeasure that can improve safety and operations at an intersection.[196] Left- and right-turn lanes physically separate turning traffic that is slowing or stopped from adjacent through traffic at intersection approaches. They also provide storage of vehicles that are stopped and waiting for the opportunity to complete a turn.

U.S. 89 had to be widened to accommodate the construction of the left-turn lane. Existing shoulders along U.S. 89 at this location were 5 feet wide. Because AASHTO's Green Book recommends an 8-foot shoulder width for this roadway, a design exception would be required to maintain the 5-foot shoulder width within the project limits.[197] Although an 8-foot shoulder would have fit in the corridor, ADOT intended to maintain the existing 5-foot shoulder to discourage visitors from using it for parking. ADOT's analysis of the existing shoulder width conditions indicated that the existing shoulder width was not contributing to safety, operational, or maintenance performance concerns within the project limits.

ADOT prepared the required performance documentation that supported the shoulder design as part of the overall project improvements within this corridor. The ADOT team completed the 5-foot shoulder with a combination of 2 feet of asphalt and 3 feet of stabilized shoulder. Keeping the paved shoulder at 2 feet visually discouraged visitors from parking along U.S. 89. By adding 3 feet of stabilized shoulder, the shoulder was still able to function as necessary for the roadway.

Table 15. Arizona Department of Transportation's design exception for the U.S. 89 northbound shoulder width.

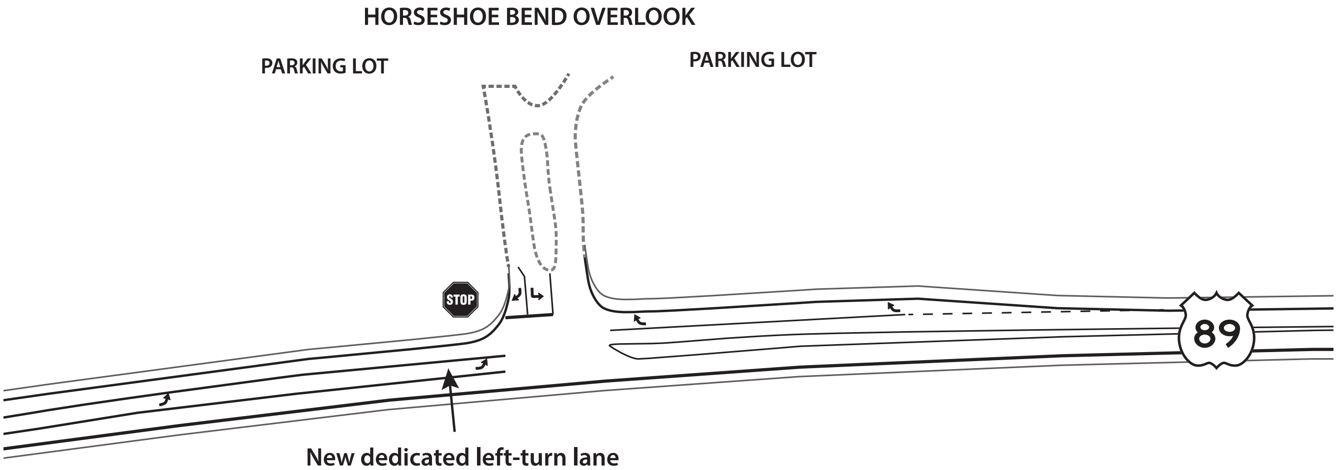
U.S. 89 Location	AASHTO Guidance	Existing Shoulder	Proposed Shoulder
Northbound shoulder	8 feet	5 feet	5 feet (2 feet paved + 3 feet stabilized)

The design of the shoulder, new left-turn lane, and larger parking lot improves access to the parking area, discourages visitors from parking on the shoulders, and reduces the risk of crashes involving pedestrians along U.S. 89 at this location. The combination of these context-based solutions provides safety and operational improvements that met the project's objectives.

196 FHWA, "Dedicated Left- and Right-Turn Lanes at Intersections," *Making Our Roads Safer*, FHWA-SA-21-041.

197 AASHTO, Green Book, 7th ed. (2018).

A number of Proven Safety Countermeasures[198] were also included to address issues on the Horseshoe Bend U.S. 89 corridor. A new left-turn lane and improved signing and pavement markings were added at the project location. Signs were installed approaching the access drive and tubular markers were installed along the edge line to discourage visitors from parking on the shoulder, though this countermeasure can also serve as a solution to roadway departure crashes.



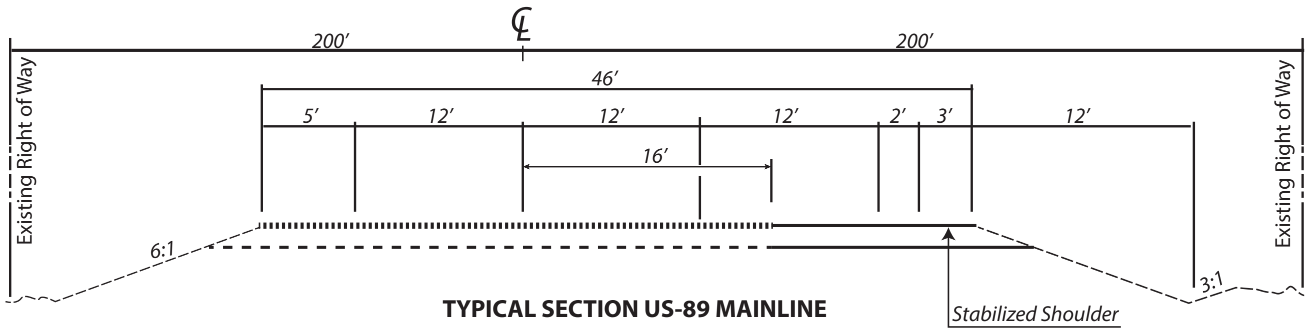
Source: ADOT, modified by FHWA.

Figure 66. Diagram. Plans for improvements along U.S. Route 89.

Lessons Learned

This project faced challenges with schedules, budgets, and coordination among many stakeholders. The project was developed under an accelerated time frame because of the expiration of available funding at the end of the fiscal year. With the number of studies that needed to be completed, the team operated within tight deadlines to complete them and make decisions. Coordination was accelerated with the City of Page and Coconino County, which controls the parking lot, and the National Park Service, which controls the overlook. ADOT also needed to coordinate with FHWA, as U.S. 89 is on the NHS.

198 FHWA, "Proven Safety Countermeasures," https://highways.dot.gov/safety/proven-safety-countermeasures.



Source: ADOT, modified by FHWA.

Figure 67. Diagram. Plans for 5-foot shoulder, partially paved.

© ADOT.

A. Dedicated left-turn lane into parking lot.

© ADOT.

B. Narrowed 5-foot shoulder comprised of 2 feet of paved shoulder and 3 feet of stabilized shoulder.

Figure 68. Photos. Final countermeasures applied to U.S. Route 89 corridor near Horseshoe Bend.

▶ Outcomes

ADOT completed the design updates at the end of 2020, and completed construction in 2021. As a result of this project, ADOT has seen a reduction in visitor parking along the shoulders and a reduction in pedestrian use and crossings along the corridor. The increased parking lot capacity and improved entrance design have provided better access to visitors, and parking has been reduced along U.S. 89. Due to safety countermeasures, design exceptions, and collaboration among stakeholders, the team was able to find creative solutions to mitigate safety and congestion concerns, ultimately creating a safer and better experience for visitors to Horseshoe Bend.

Source: Getty Images.

U.S. Department of Transportation
Federal Highway Administration

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Office of Safety website
https://highways.dot.gov/safety

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