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coated or plated with metal (HTS 7408.29.10). See List II (Decision on Petitions to Grant Waiver of the Competitive Need Limitation). Additionally, the President revoked existing CNL waivers for three products: (1) Certain plywood sheets (HTS 4412.31.40) from Indonesia; (2) certain copper, stranded wire (HTS 7413.00.10) from Turkey; and (3) certain copper cables and plaited bands (HTS 7413.00.50) from Turkey. See List III (Revocations of Competitive Need Limitation Waivers).

The President also redesignated certain articles from GSP-eligible countries that had previously exceeded the CNLs, but had fallen below the CNL for total annual trade in 2014. The President redesignated as GSP-eligible: (1) Oilcake and other solid residues, resulting from the extraction of vegetable fats or oils, of sunflower seeds (HTS 2306.30.00) from Ukraine; (2) rare gases, other than argon (HTS 2804.29.00) from Ukraine; (3) insulated ignition wiring sets and other wiring sets of a kind used in vehicles, aircraft or ships (HTS 8544.30.00) from Indonesia; and (4) parts of railway/tramway locomotives/rolling stock, axles (HTS 8607.19.03) from Ukraine. See List IV (Products Receiving GSP Redesignation).

The President granted *de minimis* waivers to 98 articles that exceeded the 50-percent import-share CNL, but for which the aggregate value of all U.S. imports of that article was below the 2014 *de minimis* level of $22 million. See List V (Products Receiving De Minimis Waivers). The articles for which *de minimis* waivers were granted will continue to be eligible for duty-free treatment under GSP when imported from the associated countries.

William D. Jackson,

Deputy Assistant U.S. Trade Representative for the Generalized System of Preferences and Chair of the GSP Subcommittee of the Trade Policy Staff Committee Office of the U.S. Trade Representative.

[FR Doc. 2015–25548 Filed 10–6–15; 8:45 am]

BILLING CODE 3290–F6–P

DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

[FHWA Docket No. FHWA–2015–0020]

Revision of Thirteen Controlling Criteria for Design; Notice and Request for Comment

AGENCY: Federal Highway Administration (FHWA), DOT.

ACTION: Notice; request for comment.

SUMMARY: The geometric design standards for projects on the National Highway System (NHS) are incorporated by reference in FHWA regulations. These design standards are comprehensive in nature, covering a multitude of design characteristics, while allowing flexibility in application. Exceptions may be approved on a project basis for designs that do not conform to the minimum or limiting criteria set forth in the standards, policies, and standard specifications.

The FHWA is updating its policy regarding controlling criteria for design. The current policy identifies 13 controlling criteria for design and requires formal design exceptions when any of the 13 controlling criteria are not met. The FHWA intends to further streamline the controlling criteria, and the application of these criteria, based on the results of recent research that evaluated the safety and operational effects of the 13 controlling criteria. The FHWA also intends to clarify when design exceptions are required and the documentation that is expected to support such requests. This notice solicits comments on the proposed revisions to the 13 controlling criteria for the design of projects on the NHS that require a design exception when adopted design criteria are not met, in accordance with FHWA regulations.

DATES: Comments must be received on or before December 7, 2015. Late comments will be considered to the extent practicable.

ADDRESSES: Mail or hand deliver comments to the U.S. Department of Transportation, Dockets Management Facility, Room W12–140, 1200 New Jersey Avenue SE., Washington, DC 20590, or fax comments to (202) 493–2251. Alternatively, comments may be submitted to the Federal eRulemaking portal at *http://www.regulations.gov*. All comments must include the docket number that appears in the heading of this document. All comments received will be available for examination and copying at the above address from 9 a.m. to 5 p.m., e.t., Monday through Friday, except Federal holidays. Those desiring notification of receipt of comments must include a self-addressed, stamped postcard or you may print the acknowledgment page that appears after submitting comments electronically. Anyone is able to search the electronic form of all comments in any one of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an association, business, or labor union). Anyone may review DOT's complete Privacy Act Statement in the **Federal Register** published on April 11, 2000 (Volume 65, Number 70, Pages 19477–78).

FOR FURTHER INFORMATION CONTACT: For questions about the program discussed herein, contact Elizabeth Hilton, Geometric Design Engineer, FHWA Office of Program Administration, (512) 536–5970 or via email at *elizabeth.hilton@dot.gov*. For legal questions, please contact Robert Black, Office of the Chief Counsel, (202) 366–1359, or via email at *Robert.Black@dot.gov*. Office hours are from 8:00 a.m. to 4:30 p.m., e.t., Monday through Friday, except Federal holidays.

SUPPLEMENTARY INFORMATION:

Electronic Access and Filing

You may submit or retrieve comments online through the Federal eRulemaking portal at: *http://www.regulations.gov*. The Web site is available 24 hours each day, 365 days each year. Please follow the instructions. Electronic submission and retrieval help and guidelines are available under the help section of the Web site. An electronic copy of this document may also be downloaded from the Office of the Federal Register's home page at: *http://www.archives.gov* and the Government Printing Office's Web page at: *http://www.access.gpo.gov/nara*.

Purpose of This Notice

The FHWA is requesting comment on proposed revisions to the 13 controlling criteria for the design of projects on the NHS that require a design exception when not met, in accordance with 23 CFR 625.3(f). Design exceptions are an administrative tool used to document an engineer's evaluation of possible solutions to a specific design issue, including the operational and safety performance of each option, impacts to the human and natural environment, and other factors, and demonstrating the reasons a particular solution that does not meet applicable design standards was selected. Many States have their own process for reviewing design deviations when State or Federal design criteria are not met. When used in this Notice, the term 'design exception' refers to documentation prepared for projects on the NHS when a controlling criterion is not met, and that must be approved by the FHWA or on behalf of FHWA if a State Transportation Agency (STA) has assumed this responsibility through a Stewardship and Oversight agreement. Stewardship and Oversight agreements set forth the agreement between FHWA and each STA on the roles and responsibilities of FHWA and the STA with respect to Title 23 project approvals and related responsibilities and oversight activities. The FHWA also intends to clarify when design exceptions are required and the documentation that is expected to support such requests.

Comments received through this Notice will be considered by FHWA when revising the controlling criteria for the design of projects on the NHS, as well as design exception documentation and application.

Background

As codified in 23 CFR 625.3 and 625.4, the geometric design standards for projects on the NHS are A Policy on Geometric Design of Highways and Streets (2001) and A Policy on Design Standards Interstate System (2005), published by the American Association of State Highway and Transportation Officials (AASHTO). Rulemaking is underway to adopt the current (2011) edition of A Policy on Geometric Design of Highways and Streets. These design standards are comprehensive in nature, covering a multitude of design characteristics, while allowing flexibility in application. As codified in 23 CFR 625.3(f), and in accordance with the delegated authority provided by FHWA Order M1100.1A, exceptions may be approved on a project basis for designs that do not conform to the minimum or limiting criteria set forth in the standards, policies, and standard specifications adopted in 23 CFR part 625.

The FHWA issued a policy memorandum on April 15, 1985, available on the docket for this notice, and on FHWA's Web site at *http://www.fhwa.dot.gov/design/standards/850415.cfm*, which identified 13 criteria contained in A Policy on Geometric Design of Highways and Streets and designated them as controlling criteria. The policy required formal design exceptions when any of the 13 controlling criteria were not met.

The FHWA proposes to streamline the 13 controlling criteria to refine the focus on criteria with the greatest impact on road safety and operation. This streamlined application of the controlling criteria is consistent with the industry's move toward a modified design approach, often referred to as performance based practical design (PBPD), and will reduce the instances when a design exception must be prepared when applicable design standards are not met for projects on the NHS. The controlling design criteria set forth in 1985 are: Design speed, lane width, shoulder width, bridge width, horizontal alignment, superelevation, vertical alignment, grade, stopping sight distance, cross slope, vertical clearance, horizontal clearance, and structural capacity. The term 'horizontal clearance' was initially interpreted as the 'clear zone' described in the AASHTO Roadside Design Guide (*http://www.fhwa.dot.gov/design/standards/850415.cfm*), but in the early 1990s was clarified to mean 'lateral offset to obstruction' as described in the AASHTO geometric design policies (*http://www.fhwa.dot.gov/design/standards/930525.cfm*). Recent research, culminating in publications of the most recent Highway Capacity Manual (2010, Transportation Research Board) and the Highway Safety Manual (2010, AASHTO), developed much greater knowledge of the traffic operational and safety effects of the controlling criteria than was available when they were established. The NCHRP Report 783 ''Evaluation of the 13 Controlling Criteria for Geometric Design'' (2014) specifically examined the safety and operational effects of the existing controlling criteria.

The PBPD is an approach to decisionmaking that encourages engineered solutions rather than relying on minimum, maximum, or limiting values found in design criteria. The PBPD is grounded in an analytic framework that enables transportation agencies to utilize existing design flexibility and analytical tools in a way that maximizes benefits while minimizing costs. The PBPD does not disregard engineering guidance or standards. Rather, flexibility in design typically requires more information and a higher level of analysis when defining and deciding on the most appropriate design value for a particular location. Consistent with FHWA's efforts regarding PBPD and to ensure that design exceptions are only required for criteria with significant safety or operational effects, FHWA intends to streamline the controlling criteria based on the findings of recent research. Since 1985, the controlling criteria have been applied to all projects, regardless of roadway type or context. The NCHRP Report 783 found that the 13 controlling criteria had minimal influence on the safety or operations on urban streets. On rural roadways, freeways, and high-speed urban/suburban roadways, a stronger connection to safety and operations was found for some of the criteria than for others.

Proposed Revisions to Controlling Criteria

Based on the findings of NCHRP Report 783 and FHWA's own assessment and experience, FHWA proposes to eliminate the following controlling criteria:

- Bridge Width.
- Vertical Alignment.
- Lateral Offset to Obstruction.

To improve clarity, FHWA proposes to rename the following existing controlling criteria:

- Horizontal Alignment to be renamed Horizontal Curve Radius.
- Grade to be renamed Maximum Grade.
- Structural Capacity to be renamed Design Loading Structural Capacity.

The resulting controlling criteria for design are proposed as follows:

- Design Speed.
- Lane Width.
- Shoulder Width.
- Horizontal Curve Radius.
- Superelevation.
- Stopping Sight Distance.
- Maximum Grade.
- Cross Slope.
- Vertical Clearance.
- Design Loading Structural Capacity.

The FHWA also proposes a revision to the application of the controlling criteria. Most controlling criteria would apply only to high-speed [design speed ≥50 mph (80 km/h)] roadways. Only design loading structural capacity and design speed would continue to be applied to all NHS facility types. Research indicates that the current controlling criteria are less influential on the traffic operational and safety performance of low-speed urban and suburban arterials than other features such as intersection design and access management strategies. Therefore, consistent with FHWA's risk-based approach to stewardship and oversight, FHWA intends to focus application of the controlling criteria on high-speed NHS roadways [design speed ≥ 50 mph (80 km/h)]. On low-speed NHS roadways [design speed <50 mph (80 km/h)], design exceptions are proposed to only be required by FHWA for deviations from the design speed or design loading structural capacity criteria. Exceptions to the controlling criteria must be carefully evaluated and approved by FHWA or on behalf of FHWA if an STA has assumed the responsibility through a Stewardship and Oversight agreement.

While all of the criteria contained in the adopted standards are important design considerations, they do not all affect the safety and operations of a roadway to the same degree, and therefore should not require the same level of administrative control. Based on the findings of recent research and FHWA's assessment and experience, a brief discussion on each of the proposed changes to the controlling criteria is provided below.

Controlling Criteria FHWA Proposes To Eliminate

1. Bridge width is proposed to be removed from the list of controlling criteria because research found little relationship between bridge width and crash frequency on rural, two-lane highways and surmised the same would be true for other roadway types. Lane and shoulder width criteria apply to roadways and bridges, so any deficiency in bridge width will require design exception documentation if the lane or shoulder width criteria is not met under this proposal. Design criteria allow lesser shoulder width, and therefore lesser bridge widths, on long bridges [overall length over 200 feet (60 m)]. If the minimum lane or shoulder widths are not provided on a long bridge, the deviation would be documented as a lane or shoulder width design exception under the proposed revisions to controlling criteria.

2. Vertical alignment is proposed to be removed from the list of controlling criteria. Three of the existing criteria relate to vertical alignment. Crest vertical curve design is covered under the stopping sight distance criterion. Grade is explicitly covered as a separate criterion, leaving only sag vertical curve length to be covered under the vertical alignment criterion. While research has confirmed the interrelationship between vehicle headlight illuminations, sag vertical curves, and sight distance to features in the roadway, no relationship has extended to the effect of these combined elements on crashes. Furthermore, except when a horizontal curve or overhead structure is also present, sag vertical curve length is not critical under daytime conditions when the driver can see beyond the sag vertical curve, or at night, when vehicle taillights and headlights make another vehicle on the road ahead visible in or beyond a sag vertical curve.

3. Lateral offset to obstruction is proposed to be removed from the list of controlling criteria because on rural roadways, the controlling criterion for shoulder width ensures that there will be at least 18 inches of lateral offset to roadside objects. Lateral offset is most relevant to urban and suburban roadways to ensure that mirrors or other appurtenances of heavy vehicles do not strike roadway objects and so that passengers in parked cars are able to open their doors. While these are important considerations, they do not rise to the same level of effect as other controlling criteria proposed to be retained.

Controlling Criteria FHWA Proposes To Retain for Roadways on the NHS With a Design Speed Equal to or Greater Than 50 mph (80 km/h), Unless Otherwise Noted

1. Design speed is proposed to be retained as a controlling criterion for all facilities on the NHS. Design speed is different from the other controlling criteria in that it establishes the range of design values for many of the other geometric elements of the highway. Because of its effect on a highway's design, the design speed is a fundamental and very important choice that a designer makes. In recognition of the wide range of site-specific conditions, constraints, and contexts that designers face, the design standards allow a great deal of design flexibility by providing ranges of values for design speed. For most cases, the ranges provide adequate flexibility for designers to choose an appropriate design speed without the need for a design exception. If a limited portion of an alignment must be designed to a lower speed, it is generally more appropriate to evaluate specific geometric element(s) and treat those as design exceptions, instead of evaluating an exception for the design speed of the roadway.

2. Lane width is an important design criterion with respect to crash frequency and traffic operations on high-speed and rural highways. The design standards provide the flexibility to choose lane widths as narrow as 10 feet on some facilities.

3. Shoulder width has substantial effect on crash frequency and on traffic speeds on rural highways.

4. Horizontal curve radius, previously called horizontal alignment, has a documented relationship to crash frequency on rural highways of all types. Curve radius also influences traffic operations on urban/suburban arterials. Superelevation is the other main aspect of horizontal alignment and is being retained as independent controlling criterion.

5. Superelevation has a documented relationship to crash frequency on rural, two-lane highways and research suggests this would also be true on rural multilane highways and freeways. Superelevation is generally not provided on low-speed urban/suburban streets.

6. Stopping Sight Distance (SSD) is proposed to be retained as a controlling criterion because sufficiently long SSD is needed to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path. Research found that SSD less than specified by the design standards for crest vertical curve design, combined with a hidden feature such as a curve, intersection, or driveway, resulted in increased crashes on high speed roadways. Retention of SSD as a controlling criterion will ensure that deviations from this criterion are examined on a case-by-case basis, to determine whether site characteristics and crash history are indicative of potential areas needing attention. From an operational perspective, SSD generally does not affect operations on freeways under free-flow conditions. However, when freeways operate at near-capacity, limited SSD may further reduce capacity below the levels expected based on current predictive models. These impacts are typically examined during project development.

7. Maximum grade is proposed as a controlling criterion but minimum grade is not. The existing controlling criteria of 'grade' includes both maximum and minimum grade. Maximum grade is proposed to be retained due to its relationship to crash frequency on rural, two-lane highways and the effect of steep grades on traffic operations on high-speed roadways. Minimum grade is proposed to be excluded because while it does influence roadway drainage, minimum grade alone does not ensure sufficient drainage and does not rise to the level of the controlling criteria.

8. Cross slope is proposed to be retained as a controlling criterion to address drainage issues. While research has not been conducted to determine whether there is a relationship between the normal cross slope of roadway pavements and crash frequency, our experience is that inadequate drainage could contribute to vehicle loss of control under some circumstances. Due to the relationship between cross slope and drainage, especially when combined with minimum grades, cross slope is proposed to be retained as a controlling criterion.

9. Vertical clearance is proposed to be retained as a controlling criterion. While vertical clearance does not affect operations on the roadway other than for those vehicles that are taller than the available vertical clearance allows, vertical clearance crashes can have severe impacts on operations by damaging overpasses and other structures, resulting in extended road closures. In addition, inadequate vertical clearance on Interstate freeways impacts military defense routes and requires additional coordination with the Surface Deployment and Distribution Command Transportation Engineering Agency.

10. Design Loading Structural Capacity is related to the strength and service limit state designs, not to traffic operations or the likelihood of traffic crashes. Previously called 'structural capacity,' FHWA proposes to clarify that the applicable criterion covered herein relates to the design of the structure, not the load rating. Design loading structural capacity is important in maintaining a consistent minimum standard for safe load-carrying capacity and deviations from this criterion should be extremely rare. Design loading structural capacity is proposed to be retained as a controlling criterion regardless of the design speed for the project. Exceptions to design loading structural capacity on the NHS could impact the mobility of freight, emergency and military vehicles, and the traveling public and requires additional coordination with the FHWA Office of Infrastructure.

Design Documentation

As codified in 23 CFR 625.3(f), and in accordance with the delegated authority provided by FHWA Order M1100.1A, exceptions may be approved on a project basis for designs that do not conform to the minimum or limiting criteria set forth in the standards, policies, and standard specifications adopted in 23 CFR part 625. Under this proposal, formal design exceptions, subject to approval by FHWA, or on behalf of FHWA if an STA has assumed the responsibility through a Stewardship and Oversight agreement, would be required for projects on the NHS only when the controlling criteria are not met. The FHWA expects documentation of design exceptions to include all of the following:

- Specific design criteria that will not be met.
- Existing roadway characteristics.
- Alternatives considered.
- Analysis of standard criteria versus proposed design criteria.
  - ○ Supporting quantitative analysis of expected operational and safety performance.
  - ○ Right-of-way impacts.
  - ○ Impacts to human and natural environment.
  - ○ Impacts to the community.
  - ○ Impacts on the needs of all users of the facility.
  - ○ Project cost.
- Proposed mitigation measures.
- Compatibility with adjacent sections of roadway.
- Possibility of a future project bringing this section into compliance with applicable standards.

Design Speed and Design Loading Structural Capacity are fundamental criteria in the design of a project. Exceptions to these criteria should be extremely rare and FHWA expects the documentation to provide the following additional information.

- Design Speed exceptions must address:
  - ○ Length of section with reduced design speed compared to overall length of project.
  - ○ Measures used in transitions to adjacent sections with higher or lower design or operating speeds.
- Design Loading Structural Capacity exceptions must address:
  - ○ Verification of safe load-carrying capacity (load rating) for all State unrestricted legal loads or routine permit loads, and in the case of bridges on the Interstate, all Federal legal loads.

The FHWA encourages agencies to document all design decisions to demonstrate compliance with accepted engineering principles and the reasons for the decision. Deviations from criteria contained in the standards for projects on the NHS, but which are not considered to be controlling criteria, should be documented by the STA in accordance with State laws, regulations, directives, and safety standards. Deviations from criteria contained in standards adopted by a State for projects not on the NHS should be documented in accordance with State laws, regulations, directives, and safety standards. States can determine their own level of documentation depending on their State laws and risk management practices.

The proposed revisions to the controlling criteria and design documentation requirements will be published in final form after considering comments received regarding the proposed changes.

The FHWA requests comments on the revised guidance memorandum, which is available in the docket (FHWA–2015–0020). The FHWA will respond to comments received on the guidance in a second **Federal Register** notice, to be published after the close of the comment period. That second notice will include the final guidance memorandum that reflects any changes implemented as a result of comments received.

Authority: 23 U.S.C. 109 and 315; 23 CFR 1.32 and 625; 49 CFR 1.85.

Issued on: September 30, 2015.

Gregory G. Nadeau,

Administrator, Federal Highway Administration.

[FR Doc. 2015–25526 Filed 10–6–15; 8:45 am]

BILLING CODE 4910–22–P

DEPARTMENT OF TRANSPORTATION

Federal Motor Carrier Safety Administration

[Docket No. FMCSA–2014–0105]

Qualification of Drivers; Application for Exemptions; Hearing

AGENCY: Federal Motor Carrier Safety Administration (FMCSA), DOT.

ACTION: Notice of final disposition.

SUMMARY: FMCSA announces its decision to grant requests from 10 individuals for exemptions from the Agency's physical qualifications standard concerning hearing for interstate drivers. The current regulation prohibits hearing impaired individuals from operating CMVs in interstate commerce. After notice and opportunity for public comment, the Agency concluded that granting exemptions for these drivers to operate property-carrying CMVs will provide a level of safety that is equivalent to or greater than the level of safety maintained without the exemptions. The exemptions are valid for a 2-year period and may be renewed, and the exemptions preempt State laws and regulations.

DATES: The exemptions are effective October 7, 2015. The exemptions expire on October 10, 2017.

FOR FURTHER INFORMATION CONTACT: Charles A. Horan, III, Director, Office of Carrier, Driver and Vehicle Safety, (202) 366–4001, *fmcsamedical@dot.gov*, FMCSA, Department of Transportation, 1200 New Jersey Avenue SE., Room W64–224, Washington, DC 20590–0001. Office hours are 8:30 a.m. to 5 p.m., e.t., Monday through Friday, except Federal holidays.

SUPPLEMENTARY INFORMATION:

A. Electronic Access

You may see all the comments online through the Federal Document Management System (FDMS) at: *www.regulations.gov*.

Docket: For access to the docket to read background documents or comments, go to *www.regulations.gov* and/or Room W12–140 on the ground level of the West Building, 1200 New Jersey Avenue SE., Washington, DC, between 9 a.m. and 5 p.m., e.t., Monday through Friday, except Federal holidays.

Privacy Act: In accordance with 5 U.S.C. 553(c), DOT solicits comments from the public to better inform its rulemaking process. DOT posts these comments, without edit, including any personal information the commenter provides, to *www.regulations.gov*, as

NCHRP

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

REPORT 783

Evaluation of the 13 Controlling Criteria for Geometric Design

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

* Membership as of May 2014.

SECTION 2

Design Criteria, Traffic Operational and Safety Effects, and Mitigation Strategies for the 13 Controlling Criteria

This section presents the results of the review of design criteria, traffic operational and safety effects, and mitigation strategies for the 13 controlling criteria. This information concerning each of the controlling criteria is presented in Sections 2.1 through 2.13. The information presented in Section 2 is based primarily on published documentation. The primary sources consulted for each of the 13 controlling criteria are as follows:

- Design criteria are based primarily on the 2004 and 2011 editions of the AASHTO *Green Book* (*4, 5*), unless explicitly stated otherwise. Design criteria for freeways on the Interstate highway system are also presented in AASHTO's *A Policy on Design Standards—Interstate System* (*14*). Published FHWA guidance on the scope and interpretation of the 13 controlling criteria is also presented (*7*).
- Traffic operational effects are based primarily on the 2010 TRB *Highway Capacity Manual* (HCM) (*13*).
- Traffic safety effects are based primarily on the 2010 AASHTO *Highway Safety Manual* (HSM) (*12*).
- Mitigation strategies are based primarily on the FHWA guidance presented in *Mitigation Strategies for Design Exceptions* (*7*) and AASHTO's *A Guide for Achieving Flexibility in Highway Design* (*8*).

In addition, the discussion of the traffic operational and safety effects of the individual design criteria includes all relevant findings of the research conducted in this project, as reported in Section 4. Separate discussions of design criteria, traffic operational effects, and traffic safety effects are presented, where appropriate, for each of four roadway types: rural two-lane highways; rural multilane highways (nonfreeways); urban and suburban arterials (nonfreeways); and freeways. Throughout this report, the term "freeways" applies to both rural and urban freeways except where the terms "rural freeway" or "urban freeway" are used explicitly.

In cases where the primary sources present no information or only limited information on the traffic operational or safety effects of a particular issue, or where there may be concerns about the completeness of the primary sources, results of additional relevant research are presented. For safety effects, many such sources are cited in the FHWA Crash Modification Factors Clearinghouse (CMF Clearinghouse) website (*15*), which includes star ratings to assess the quality of the studies cited. The ratings range from one star (the weakest research) to five stars (the strongest research). Only CMFs included in the HSM or rated three stars or better in the FHWA CMF Clearinghouse website are cited in this section of the report.

Table 1 shows with circular bullets which of the 13 controlling criteria have documented traffic operational and safety effects for each of four roadway types (rural two-lane highways, rural multilane highways, urban and suburban arterials, and freeways). These documented traffic operational and safety effects are presented in Sections 2.1 through 2.13. The traffic operational effects of the 13 controlling criteria are summarized in Section 2.14. The traffic safety effects of the 13 controlling criteria are summarized in Section 2.15. The traffic operational and safety effects include findings from published literature and from research conducted as part of NCHRP Project 17-53, which are reported in Section 4.

2.1 Design Speed

AASHTO defines design speed as (*4*):

> Design speed is a selected speed used to determine the various geometric features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of the highway.

Design speed is unique among the 13 controlling criteria since it has no direct effect on the design of the roadway, but

Table 1. Summary table for operational and safety effects of the controlling criteria.

Design criteria	Traffic operational effects				Traffic safety effects			
	Rural two-lane highways	Rural multilane highways	Urban and suburban arterials	Freeways	Rural two-lane highways	Rural multilane highways	Urban and suburban arterials	Freeways
Design speed	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
Lane width	•	•	[b]	•	•	•	•	•
Shoulder width	•	•		•	•	•		•
Bridge width					[b]			
Structural capacity	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Horizontal alignment	•	[b]	[b]	•	•	[b]		•
Vertical alignment (sag vertical curve length)								
Grade	•	•		•	•			
Stopping sight distance					[b]			
Cross slope								
Superelevation					•			
Vertical clearance	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Horizontal clearance (lateral offset)	[c]	[c]		[c]	[d]	[d]		[d]

[a] There are no direct operational or safety effects of design speed; however, design speed may influence operations and safety indirectly through the criteria for lane width, horizontal alignment, vertical alignment, and stopping sight distance.
[b] New relationships were developed in this research.
[c] No effect anticipated when full shoulders are present.
[d] There are no known direct effects of lateral offset on safety; however, the influence of lateral offset on safety is known indirectly through the influence of shoulder width.

only an indirect effect. Once a design speed for a project is selected, however, that design speed influences the values (or value ranges) of other controlling criteria, including horizontal alignment, vertical alignment, stopping sight distance, and lane width. Thus, design speed actually serves as a design control rather than a design criterion.

Design speeds should reflect the speeds that drivers expect to travel, which is determined by the physical limitations of the roadway and surrounding traffic rather than by the functional class of the roadway. Specific recommendations for design speeds are provided in several exhibits in the *Green Book* and are based on roadway classification, type of terrain, and volume. Ranges are as follows:

- For local rural roads, design speeds range from 20 mph for low-volume roads in mountainous terrain to 50 mph on high-volume roads in level terrain.
- For rural arterials, the recommended design speed ranges from 40 to 75 mph based on terrain, driver expectancy, and alignment.
- For urban arterials, the design speed should fall between 30 and 60 mph. In more developed areas, such as central business districts, the lower end of that range should be used, while in suburban or developing areas, the higher end of the range may be appropriate.
- For urban freeways, a design speed in the range of 50 to 70 mph should be used with higher speeds being more desirable when alignment and interchange spacing permit. Where lower design speeds are used, speed enforcement may also be needed. For rural freeways, a 70 mph design speed is recommended. Lower design speeds that are consistent with driver expectations are appropriate in mountainous terrain.

Table 2 summarizes the *Green Book* guidance on design speed.

Another aspect of design speed also serves as part of the controlling criteria. *Green Book* Exhibit 10-56 provides guide values for selection of ramp design speeds as a function of the highway design speed. According to the *Green Book*, ramp

Table 2. Ranges for design speed by roadway functional class (*4, 7*).

Roadway functional classification	Terrain	Design speed (mph)	
		Rural	Urban
Freeway	Level	70	50 min
	Rolling	70	50 min
	Mountainous	50 to 60	50 min
Arterial	Level	60 to 75	30 to 60
	Rolling	50 to 60	30 to 60
	Mountainous	40 to 50	30 to 60
Collector	Level	40 to 60	30+
	Rolling	30 to 50	30+
	Mountainous	20 to 40	30+
Local	Level	30 to 50	20 to 30
	Rolling	20 to 40	20 to 30
	Mountainous	20 to 30	20 to 30

design speeds should not be less than the low range presented in Exhibit 10-56, with other specific guidance offered for particular types of ramps (loops as well as direct and semi-direct connections). Some states have adopted design policies requiring the use of middle or higher range values for certain cases, such as system interchanges.

Designers are occasionally confronted with situations in which the appropriate ramp design speed shown in *Green Book* Exhibit 10-56 may not be achievable. Such cases are almost always associated with the inability to achieve minimum radius for the controlling curvature of the exit or entrance ramp. Not meeting the lower (50 percent) range shown in *Green Book* Exhibit 10-56 requires a design exception per FHWA policy. Where the design issue involves curvature, a design exception should be prepared for the non-standard horizontal curve rather than for the use of a lower design speed for the ramp (*7*).

There are no explicit traffic operational effects of design speed. Any traffic operational and safety effects of design speed result from the other design elements that are influenced by design speed. Experience shows that vehicle speeds cannot be reduced merely by reducing the posted speed limit or the design speed. Adjustment of a broad range of design and roadway environment factors is needed to influence vehicle speeds.

In accordance with *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) criteria (*16*), posted speed limits are typically set to approximate the 85th percentile speed of traffic, on the assumption that most drivers select speeds that are reasonable for conditions. Design speed, posted speed, and the roadway environment should all send a clear and consistent message to drivers about the appropriate speed for the roadway.

A 2009 paper by Hauer (*17*) documents the current state of knowledge about the relationship between highway travel speed and safety. Hauer indicates that vehicle travel speeds are affected by the roadway design, speed limits and enforcement, traffic controls, and many other factors. The travel speeds that are chosen by drivers affect the safety performance of the roadway. Although higher speeds will tend to increase the severity of crashes, Hauer states that there is little evidence to support the notion that faster travel speeds necessarily result in a greater likelihood of a crash. However, since higher speeds increase crash severity, higher speeds may increase the likelihood of a reported crash. Hauer also indicates that travel speeds on roadways tend to change over time, and, although this fact is well documented, little is known about why these changes occur.

As indicated by the design speed ranges shown in Table 2, the AASHTO *Green Book* provides substantial flexibility in the choice of an appropriate design speed. As written, AASHTO policy presents little need for design exceptions, because the choice of a design speed is left to the discretion of the designer. FHWA's report, *Mitigation Strategies for Design Exceptions* (*7*), states that the selected design speed should be high enough that an appropriate regulatory speed limit will be less than or equal to it, but this is not a formal FHWA policy.

Mitigation strategies for design speed would typically involve revision of both design elements and the roadway environment to encourage lower vehicle speeds. The FHWA Interactive Highway Safety Design Model (IHSDM) includes a design consistency tool that can be used to evaluate mitigation strategies for design speed (*10*). However, the IHSDM design consistency tool is currently applicable only to rural two-lane highways.

In actual practice, as documented in Section 3 of this report, design exceptions for design speed appear to be seldom requested or approved by highway agencies. Highway agencies generally seek design exceptions for specific design elements that do not meet the criteria for the selected design speed rather than seeking a blanket exception to reduce the design speed. The rare exception is where a highway agency may deem it appropriate to utilize a lower design speed for an entire corridor (or a substantial segment of a corridor) due to topographic or environmental constraints.

2.2 Lane Width

Lane width determines the area where a vehicle can maneuver laterally without encroaching into the path of another vehicle or onto the shoulder. Table 3 summarizes the lane width design criteria in the AASHTO *Green Book*. Separate criteria have also been established for auxiliary lanes, including turn lanes at intersections and center two-way left-turn lanes. Formal design exceptions for lane width are required by FHWA policy for all travel lanes including auxiliary lanes and ramps that do not meet *Green Book* criteria. Some highway agencies have lane width policies that provide less flexibility than the *Green Book* (e.g., specifying the use of 12-ft lanes in nearly all cases). This approach is not required by FHWA policy and may result in more design exceptions than FHWA policy would require. The AASHTO *Green Book* also includes criteria for lane widening on horizontal curves to

Table 3. Ranges for lane width by roadway functional class (*4, 5, 7*).

Functional class	Lane width (ft)	
	Rural	Urban
Freeway	12	12
Ramps (one-lane)	12 to 30[a]	12 to 30[a]
Arterial	11 to 12	10 to 12
Collector	10 to 12	10 to 12
Local	9 to 12	9 to 12

[a] For wider ramps, some of the specified width may be provided by shoulders.

Table 4. Minimum width of traveled way for rural arterials (*4, 5*).

Design speed (mph)	Minimum width of traveled way (ft)[a] for specified design volume			
	Under 400 (veh/day)	400 to 1,500 (veh/day)	1,500 to 2,000 (veh/day)	Over 2,000 (veh/day)
40	22	22	22	24
45	22	22	22	24
50	22	22	24	24
55	22	22	24	24
60	24	24	24	24
65	24	24	24	24
70	24	24	24	24
75	24	24	24	24

[a] On roadways to be reconstructed, an existing 22-ft traveled way may be retained where alignment is satisfactory and there is no crash pattern suggesting the need for widening.
SOURCE: Based on *Green Book* Table 7-3 (abridged).

accommodate truck offtracking; a formal design exception is not required where lane widening is not provided on a horizontal curve (*7*).

2.2.1 Rural Two-Lane Highways

Design Criteria

Chapter 7 (Arterials) of the *Green Book* provides the following guidance for the design of lane widths on rural arterials. The *Green Book* recommends the lane widths shown in Table 4 on rural arterials as a function of design speed and design volume (expressed as an average daily traffic volume, or ADT). Where lane widths narrower than those shown in Table 4 are used, a design exception is required by FHWA policy. In the case that is described in Note a of Table 4, a design exception is not required, although the justification for use of 11-ft lanes should be documented in the project files (*7*).

Traffic Operational Effects

Chapter 15 (Two-Lane Highways) of the HCM provides the estimates shown in Table 5 for reduction in free-flow speed on two-lane highways with lane widths less than 12 ft or shoulder widths less than 6 ft.

The values in Table 5 are used to estimate the actual free-flow speed of traffic on a two-lane highway from the free-flow speed for base conditions, as follows:

$$\mathrm{FFS} = \mathrm{BFFS} - \mathrm{f_{LS}} - \mathrm{f_A} \quad (1)$$

where

FFS = free-flow speed (mph)
BFFS = base free-flow speed (mph)
f_{LS} = adjustment for lane shoulder width (mph) from Table 5
f_A = adjustment for access-point density (mph) from HCM Exhibit 15-8

FFS may also be estimated directly from field data. *FFS* is used in estimating the average travel speed (ATS_d), one of the service measures used to determine level of service (LOS) for two-lane highways.

The shoulder-width effects included in f_{LS} are discussed in Section 2.3.1 of this report.

Traffic Safety Effects

Chapter 10 (Rural Two-Lane Highways) of the HSM provides CMFs for lane widths on rural two-lane highways. The

Table 5. HCM adjustment to free-flow speed for lane and shoulder width on two-lane highways (*13*).

Lane width (ft)	Reduction in free-flow speed (mph) Shoulder width (ft)			
	≤ 0 < 2	≤ 2 < 4	≤ 4 < 6	≥ 6
≥ 9 < 10	6.4	4.8	3.5	2.2
≥ 10 < 11	5.3	3.7	2.4	1.1
≥ 11 < 12	4.7	3.0	1.7	0.4
≥ 12	4.2	2.6	1.3	0.0

NOTE: The values in Table 5 are used as f_{LS} in Equation 1.
SOURCE: Based on HCM Exhibit 15-7.

Table 6. CMF for lane width on rural two-lane roadway segments (*12, 18, 19*).

Lane width	Average annual daily traffic (AADT) (veh/day)		
	< 400	400 to 2000	> 2000
9 ft or less	1.05	$1.05 + 2.81 \times 10^{-4}(\text{AADT} - 400)$	1.50
10 ft	1.02	$1.02 + 1.75 \times 10^{-4}(\text{AADT} - 400)$	1.30
11 ft	1.01	$1.01 + 2.5 \times 10^{-5}(\text{AADT} - 400)$	1.05
12 ft or more	1.00	1.00	1.00

NOTE: The collision types related to lane width to which these CMFs apply are single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. Standard error of the CMF is unknown. To determine the CMF for changing lane width and/or AADT, divide the "new" condition CMF by the "existing" condition CMF.
SOURCE: Based on HSM Table 10-8.

CMF is calculated using the equations shown in Table 6 based on the lane width and the average annual daily traffic (AADT). A 12-ft lane is considered to be the base condition (CMF = 1.0). The lane-width CMF is illustrated graphically in Figure 1. The lane-width CMF illustrated in Table 6 and Figure 1 applies only to single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. The following equation can be used to adjust the lane-width CMF in Table 6 and Figure 1 to CMFs applicable to total crashes:

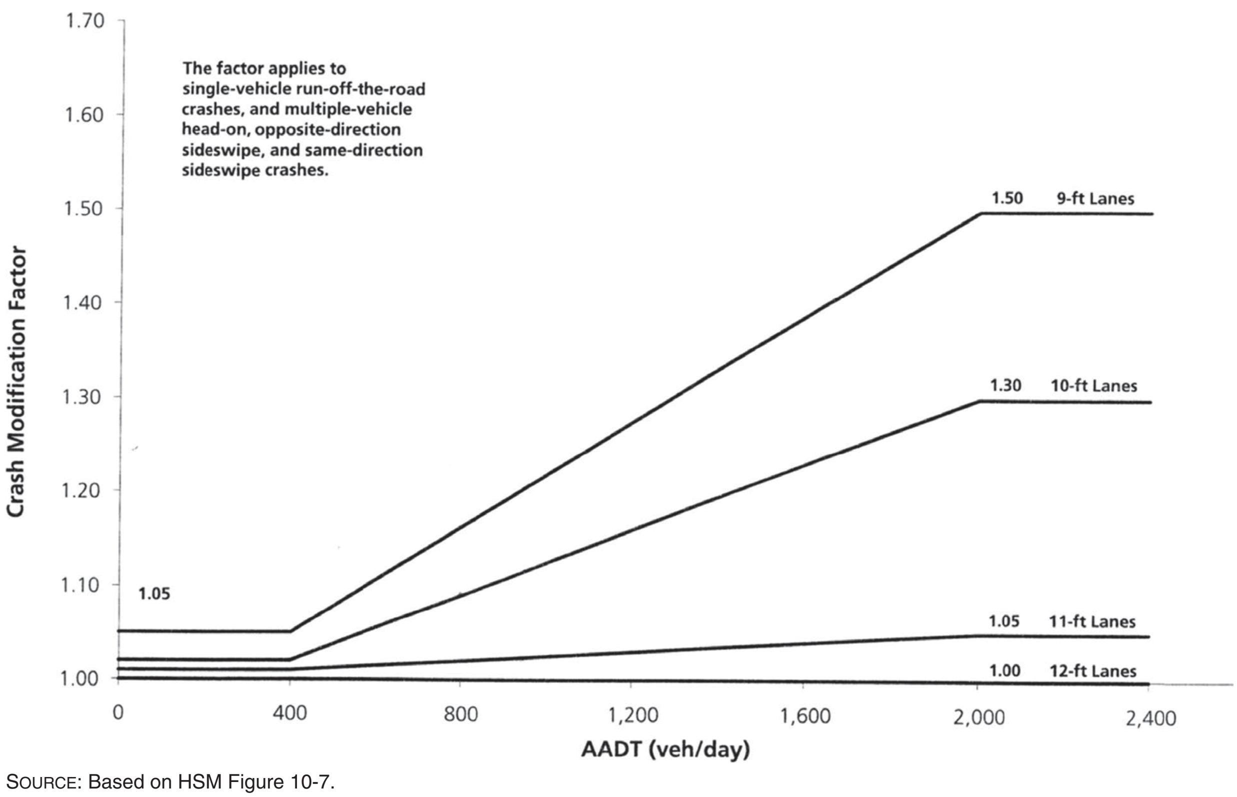
$$\text{CMF} = (\text{CMF}_{ra} - 1.0) \times p_{ra} + 1.0 \qquad (2)$$

where

CMF_{ra} = CMF for the effect of lane width on related crashes (i.e., single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes), such as the CMF for lane width shown in Table 6

p_{ra} = proportion of total crashes constituted by crash types related to lane and shoulder width

The proportion of related crashes, p_{ra}, (i.e., single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes) is estimated as 0.574 (i.e., 57.4 percent) based on



SOURCE: Based on HSM Figure 10-7.

Figure 1. CMF for lane width on rural two-lane roadway segments (*12*).

the default distribution of crash types presented in HSM Table 10-4. This default crash type distribution and, therefore, the value of p_{ra} may be updated from local data as part of the calibration process.

It should be noted that the CMFs for 11- and 12-ft lanes are not very different, which is consistent with both 11- and 12-ft lanes being shown as appropriate over broad ranges of conditions in Table 4.

2.2.2 Rural Multilane Highways

Design Criteria

Table 4 applies to rural multilane arterials as well as to rural two-lane arterials. Where lane widths narrower than those shown in Table 4 are used, a design exception is required by FHWA policy. In the case that is described in Note a of Table 4, a design exception is not required, although the justification for use of 11-ft lanes should be documented in the project files (*7*).

Traffic Operational Effects

Chapter 14 (Multilane Highways) of the HCM provides the estimated reduction in free-flow speed for rural and suburban multilane highways based on lane width as shown in Table 7.

The values in Table 7 are used to estimate the actual *FFS* of traffic on a multilane highway from the *BFFS*, as follows:

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A \tag{3}$$

where

f_{LW} = adjustment for lane width (mph) from Table 7
f_{LC} = adjustment for total lateral clearance (mph) from HCM Exhibit 14-9
f_M = adjustment for median type (mph) from HCM Exhibit 14-10
f_A = adjustment for access-point density (mph) from HCM Exhibit 14-11

Table 7. HCM adjustment to free-flow speed for average lane width on rural and suburban multilane highways (*13*).

Lane width (ft)	Reduction in free-flow speed (mph)
≥ 12	0.0
≥ 11	1.9
≥ 10	6.6

NOTE: The values in Table 7 are used as f_{LW} in Equation 3.
SOURCE: Based on HCM Exhibit 14-8.

FFS may also be estimated directly from field base. *FFS* is used to determine the mean speed of traffic(s) using the relationships show in HCM Exhibits 14-2 and 14-3 and the traffic density (*D*) using HCM Equation 14-5. Density is the service measure used to determine LOS for multilane highways.

Traffic Safety Effects

Chapter 11 (Rural Multilane Highways) of the HSM presents CMFs for lane widths on rural multilane roadways. The CMFs are calculated differently for undivided sections and divided sections, as shown in Tables 8 and 9. The calculation in either case is based on lane width and AADT. These CMFs are illustrated in Figures 2 and 3, respectively.

The CMFs shown in Tables 8 and 9 and Figures 2 and 3 are applicable to single-vehicle run-off-the-road crashes, multiple-vehicle head-on crashes, opposite-direction sideswipe crashes, and same-direction sideswipe crashes. Equation 2 can be used to convert these CMFs to CMFs for total crashes. The default value of p_{ra} in Equation 2 is 0.27 for rural multilane undivided highways and 0.50 for rural multilane divided highways.

Table 8. CMF for lane width on undivided rural multilane roadway segments (*12, 20*).

Lane width	Average annual daily traffic (AADT) (veh/day)		
	< 400	400 to 2000	> 2000
9 ft or less	1.04	$1.04 + 2.13 \times 10^{-4}(AADT - 400)$	1.38
10 ft	1.02	$1.02 + 1.31 \times 10^{-4}(AADT - 400)$	1.23
11 ft	1.01	$1.01 + 1.88 \times 10^{-5}(AADT - 400)$	1.04
12 ft or more	1.00	1.00	1.00

NOTE: The collision types related to lane width to which these CMFs apply are single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. Standard error of the CMF is unknown. To determine the CMF for changing lane width and/or AADT, divide the "new" condition CMF by the "existing" condition CMF.
SOURCE: Based on HSM Table 11-11.

Table 9. CMF for lane width on divided rural multilane roadway segment (*12, 20*).

Lane width	Average annual daily traffic (AADT) (vehicles/day) < 400	400 to 2000	> 2000
9 ft or less	1.03	$1.03 + 1.381 \times 10^{-4}(AADT - 400)$	1.25
10 ft	1.01	$1.01 + 8.75 \times 10^{-4}(AADT - 400)$	1.15
11 ft	1.01	$1.01 + 1.25 \times 10^{-5}(AADT - 400)$	1.03
12 ft or more	1.00	1.00	1.00

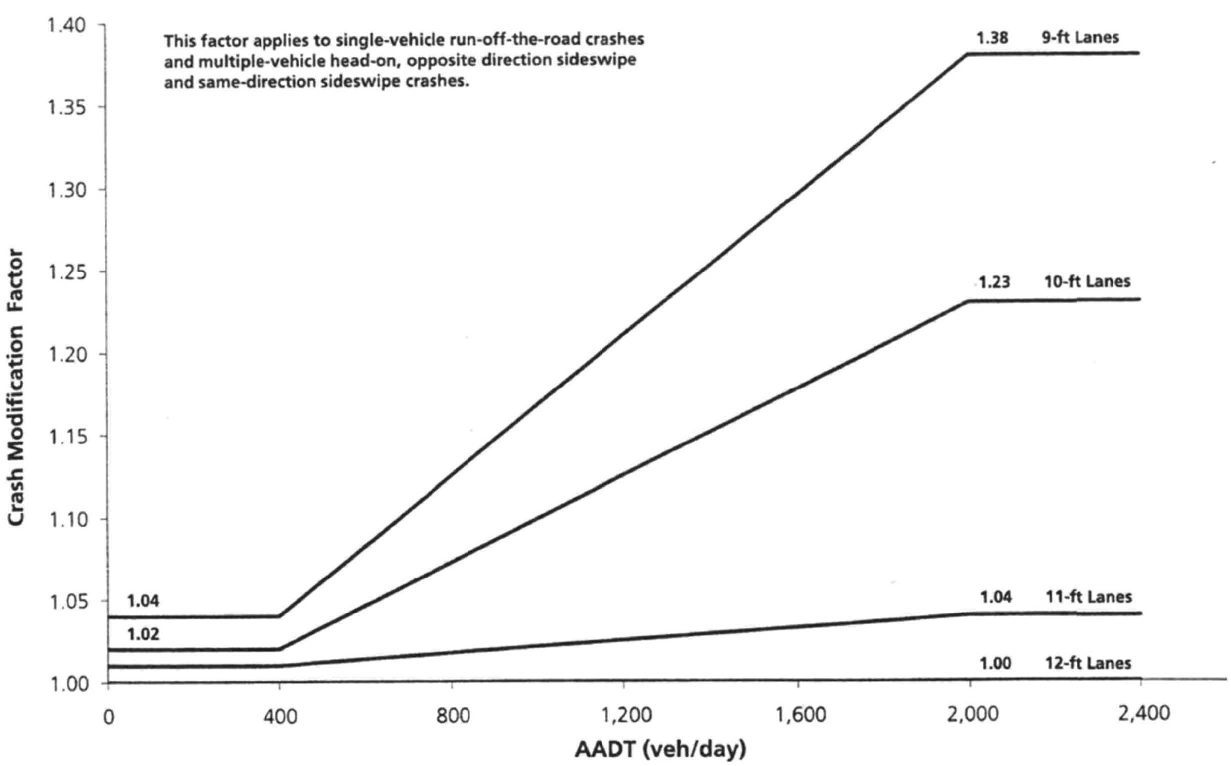
NOTE: The collision types related to lane width to which these CMFs apply are single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. Standard error of the CMF is unknown. To determine the CMF for changing lane width and/or AADT, divide the "new" condition CMF by the "existing" condition CMF.
SOURCE: Based on HSM Table 11-16.

2.2.3 Urban and Suburban Arterials

Design Criteria

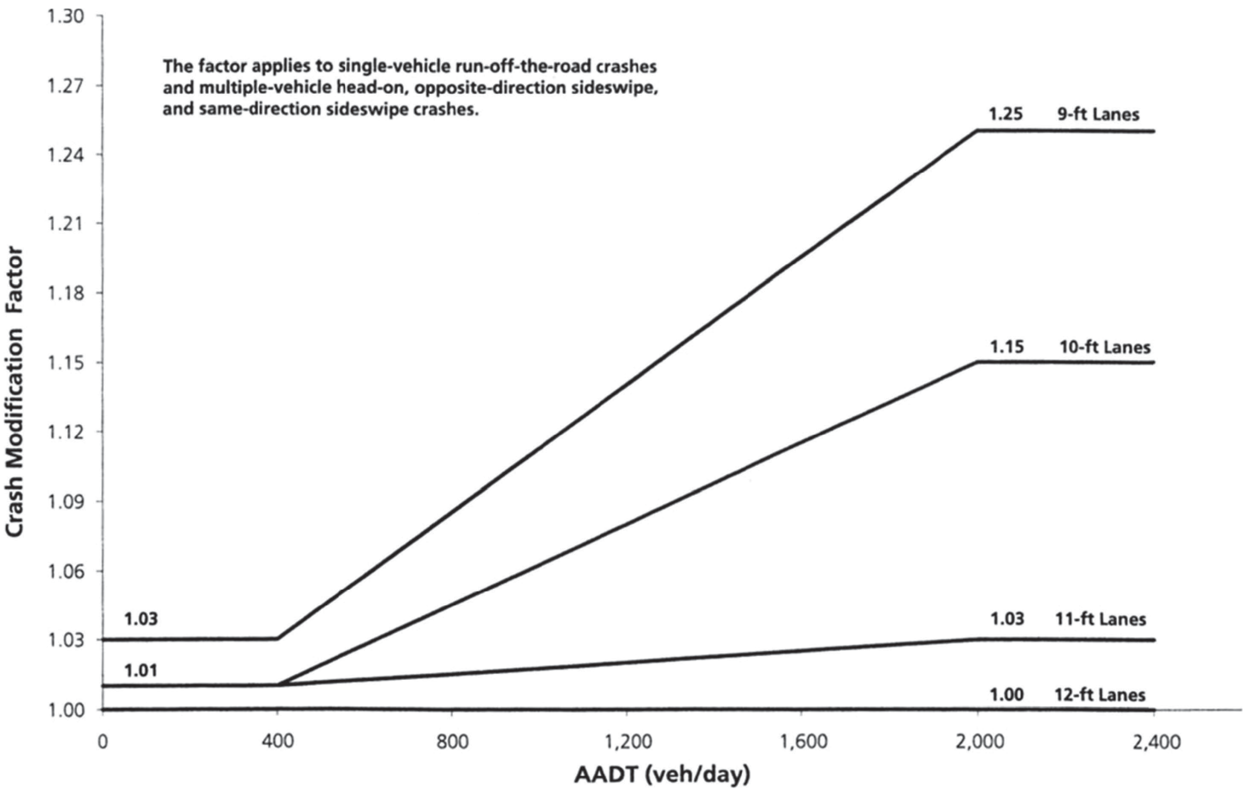
AASHTO policy provides substantial flexibility in the use of 10- to 12-ft lanes on urban arterials. In particular, Chapter 7 of the *Green Book* includes the following guidance:

- Lane widths of 12 ft are most desirable and should be used, where practical, on higher speed, free-flowing, principal arterials.
- Lane widths of 11 ft are used quite extensively for urban arterial street designs. Under interrupted-flow operating conditions at low speeds (45 mph or less), narrower lane widths are normally adequate and have some advantages. For example, narrower lane widths allow more lanes to be provided in some areas with restricted right-of-way and allow shorter pedestrian crossing times because of reduced crossing distances. Arterials with 11-ft lane widths are also more economical to construct. An 11-ft lane width is adequate for through lanes, continuous two-way left-turn lanes, and lanes adjacent to a painted median.



SOURCE: Based on HSM Figure 11-8.

Figure 2. CMF for lane width on undivided segments on rural multilane highways (12, 20).



SOURCE: Based on HSM Figure 11-10.

Figure 3. CMF for lane width on divided roadway segments on rural multilane highways (12, 20).

- Lane widths of 10 ft may be used in highly restricted areas having little or no truck traffic. Left-turn and combination lanes used for parking during off-peak hours and for traffic during peak hours may be 10 ft in width.

The *Green Book* also makes reference to the AASHTO bicycle guide (*21*) because use of narrow lane widths may be critical at many locations in reconstruction of existing arterials to provide space for bicycle facilities.

Traffic Operational Effects

Chapter 17 (Urban Street Segments) of the HCM includes a procedure to determine the effect of the features of an urban street segment on free-flow speed. However, lane width is not one of the factors that influences free-flow speed. This suggests that lane width either has no effect on the free-flow speed of an urban street segment or an effect that is very small in comparison to the factors that are in the procedure (see HCM Exhibit 17-5). This zero or negligible effect for lane width in the current HCM contrasts with the HCM 2000 (*22*), which speculated that lane width influenced free-flow speed for urban streets, but did not quantify that effect.

The HCM adjustment for lane width presented in Table 6 is applicable to suburban multilane highways, but not to urban streets. Recent research by Potts et al. (*23, 24*) investigated the effect of lane width on midblock vehicle speeds on urban and suburban arterials based on spot speed measurements at pairs of sites upstream and downstream of lane width transitions. The research of Potts et al. (*23, 24*) found that mean speeds at sites with wider lanes (ranging from 11.9 to 13.3 ft) were approximately 4 mph higher than mean speeds at sites with narrower lanes (ranging from 9.4 to 10.3 ft in width). This finding suggested that lane width has an effect on traffic operations. However, the sample size in the study was relatively small (five pairs of wide- and narrow-lane sites) and was not sufficient to develop a formal relationship between lane width and traffic speed.

A similar evaluation in the NCHRP Project 17-53 research considered a total of 23 additional sites on urban and suburban arterials in the Eastern, Midwest, and Western regions of the United States (see Section 4.1). This evaluation found that lane width had no effect on traffic speeds on urban and suburban arterials. Based on this finding, it appears that the HCM is correct in assuming that lane width has no effect on traffic speeds on urban and suburban arterials.

Chapter 18 (signalized intersections) of the HCM includes an adjustment factor for the effect of lane width on saturation flow rate at signalized intersections (see HCM Exhibit 18-3). However, given that this adjustment is applicable only to signalized intersection approaches and not to midblock sections of arterials, it is not presented in this report, since intersection design criteria are outside the scope of the research.

Traffic Safety Effects

Chapter 12 (Urban and Suburban Arterials) of the HSM does not include a CMF for lane width on urban and suburban arterials. Recent research by Potts et al. (*23, 24*) under NCHRP Project 03-72 found no difference in safety performance for urban and suburban arterials in lane widths ranging from 10 to 12 ft, with only limited exceptions that could represent random effects. Lanes narrower than 12 ft may be a design concern on streets with substantial volumes of bicycles, trucks, and buses.

2.2.4 Freeways

Design Criteria

According to the *Green Book*, freeway lanes should be 12 ft wide. Lane widths of 12 ft are also called for in the AASHTO design standards for the Interstate highway system.

Traffic Operational Effects

Chapter 11 (Basic Freeway Segments) of the HCM presents the estimated reduction in free-flow speed for freeways with lane widths less than 12 ft as shown in Table 10.

The values in Table 10 are used to estimate the actual free-flow speed of traffic on a freeway from the estimated free-flow speed for base conditions, 75.4 mph. This adjustment is made as follows:

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22\ TRD^{0.84} \tag{4}$$

where

f_{LW} = adjustment for lane width (mph) from Table 10
f_{LC} = adjustment for right-side lateral clearance (mph) from HCM Exhibit 11-9
TRD = total ramp density (ramps/mi)

Table 10. HCM adjustment to free-flow speed for lane width on freeways (*13*).

Lane width (ft)	Reduction in free-flow speed (mph)
12	0.0
11	1.9
10	6.6

NOTE: The values in this table are used as f_{LW} in Equation 4.
SOURCE: Based on HCM Exhibit 11-8.

FFS may also be estimated directly from field data. *FFS* is used to determine the mean speed of traffic (*S*) using the relationships shown in HCM Exhibits 11-2 and 11-3 and the traffic density (*D*) using HCM Equation 11-4. Density is the service measure used to determine LOS for freeways.

Traffic Safety Effects

Results from NCHRP Project 17-45, which developed a proposed HSM safety prediction methodology for freeways, include the following CMF for lane width on freeways where W_e = average lane width for all through lanes (ft) (*25*):

$$CMF = \exp\left(-0.0376\left(W_e - 12\right)\right), \text{ if } W_e < 13\text{ ft} \tag{5}$$

$$CMF = 0.963, \text{ if } W_e \geq 13\text{ ft} \tag{6}$$

The base condition for this CMF is a 12-ft lane width, (CMF = 1.0). W_e represents the average lane width for all through lanes on a freeway segment in both directions of travel excluding managed lanes and auxiliary lanes associated with a weaving section. The CMF is applicable to lane widths in the range of 10 to 14 ft. The CMF is intended for application to both multiple- and single-vehicle crashes on rural freeways with four to eight lanes and urban freeways with four to ten lanes.

2.2.5 Mitigation Strategies

Mitigation strategies for lane width are most important on higher speed roadways (speeds above 45 mph). On roadways with speeds of 45 mph or less, there are often good reasons for using narrow lanes as a flexibility measure to obtain other benefits: shorter pedestrian crossing distances, inclusion of turn lanes, medians, bicycle lanes, etc. These other benefits for road users, in and of themselves, constitute mitigation for the use of narrower lanes. The best use of available cross-section width should be determined on a case-by-case basis.

The mitigation strategies where narrower lanes are used on higher speed facilities include (*7*):

- Provide warning of lane width reduction
- Improve ability of drivers to stay within their travel lane through use of enhanced pavement markings, delineations, lighting, shoulder rumble strips, painted edge line rumble strips, and/or centerline rumble strips
- Improve ability to recover if driver leaves the lane (paved or partially paved shoulders, safety edge treatment)
- Reduce crash severity if the driver leaves the roadway (clear recovery area, traversable slopes, breakaway safety hardware, and barriers where appropriate)
- Provide pull-off areas where shoulder width is limited

Table 11. Ranges for minimum shoulder width by roadway functional class (*4, 5, 7*).

Functional class	Shoulder width (ft)	
	Rural	Urban
Freeway	4 to 12	4 to 12
Ramps (one-lane)	1 to 10	1 to 10
Arterial	2 to 8	2 to 8
Collector	2 to 8	2 to 8
Local	2 to 8	—

NOTE: Ranges shown include both right and left shoulder widths for ramps and divided highways.

Table 12. Minimum width of usable shoulder for rural arterials (*4, 5*).

Minimum width of usable shoulder (ft) for specified design volume			
Under 400 veh/day	400 to 1,500 veh/day	1,500 to 2,000 veh/day	Over 2,000 veh/day
4	6	6	8

NOTE: Usable shoulders on arterials should be paved; however, where volumes are low or a narrow section is needed to reduce construction impacts, the paved shoulder may be reduced to 2 ft.
SOURCE: Based on *Green Book* Table 7-3 (abridged).

2.3 Shoulder Width

Shoulder width affects both capacity and safety on roadways. A wide shoulder increases capacity by reducing lateral friction between traffic and roadside objects and thereby increasing driver comfort. Shoulders can reduce the likelihood of crashes in several ways, including providing a location for emergency stops and broken-down vehicles outside the traveled way, providing a space for drivers of errant vehicles to make steering corrections before leaving the roadway, and providing space for evasive maneuvers. Shoulders also provide space for enforcement activities, maintenance activities, and bicycle accommodations. Table 11 summarizes the range of minimum shoulder widths for travel lanes and ramps presented in the *Green Book.*

2.3.1 Rural Two-Lane Highways

Design Criteria

The shoulder widths presented in Table 12 are recommended in the *Green Book*, as a function of AADT. The usable shoulder-width values in Table 12 require a design exception if they are not met. Usable shoulder width is measured from the edge of the traveled way to the point of intersection of the shoulder slope and mild slope (for example, 1V:4H or flatter) or to the beginning of rounding to slopes steeper than 1V:4H (*7*).

Traffic Operational Effects

Chapter 15 (Two-Lane Highways) of the HCM presents the estimated reductions in free-flow speed for two-lane highways with lane widths less than 12 ft or shoulder widths less than 6 ft, as shown in Table 5. The values shown in Table 5 are used as f_{LS} in Equation 1 to estimate the free-flow speed on two-lane highways (see Section 2.2.1).

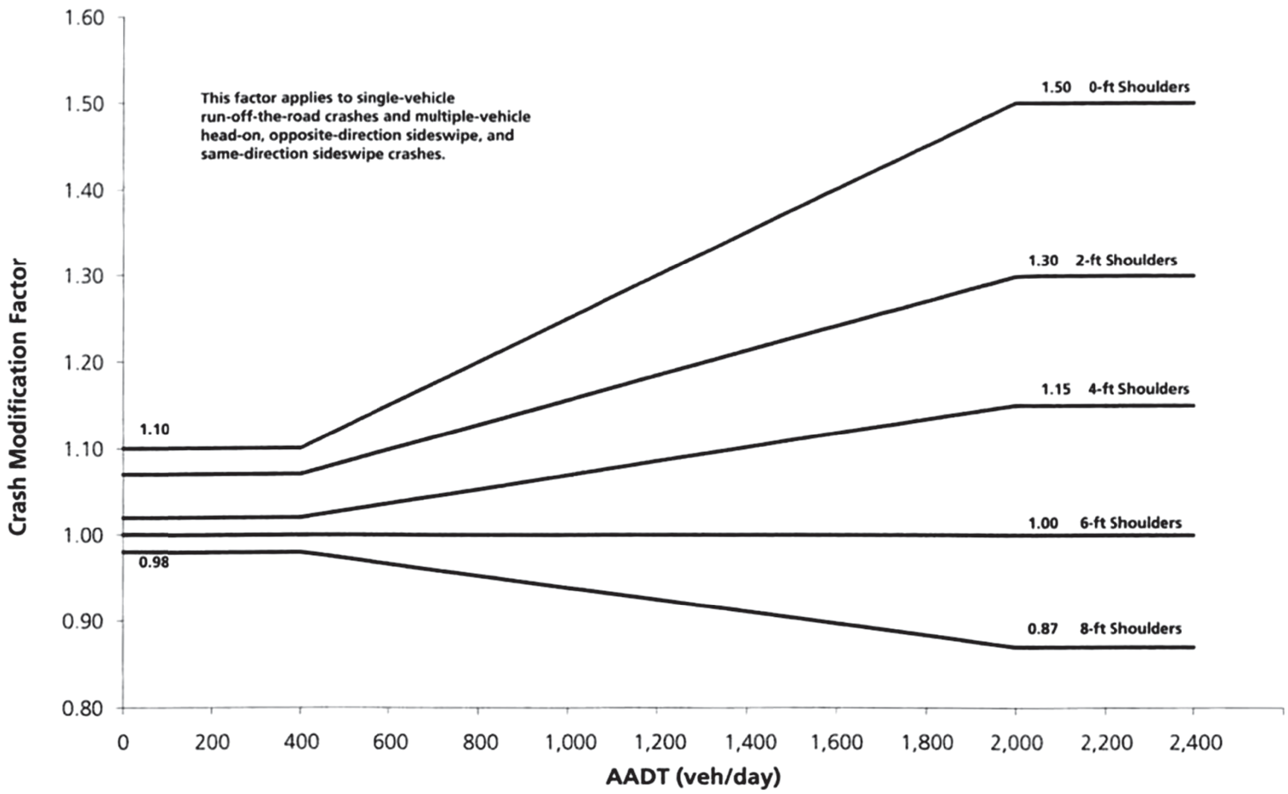
Traffic Safety Effects

Chapter 10 (Rural Two-Lane Highways) of the HSM provides CMFs for paved shoulders on rural two-lane roadways for specific crash types related to lane encroachment. The value of CMF_{wra} for shoulder width is calculated using the equations shown in Table 13 based on the shoulder width and the traffic volume (AADT). A 6-ft shoulder is considered to be the base condition (CMF = 1.0). Wider shoulders have CMFs less than 1.0, and narrower shoulders have CMFs

Table 13. CMFs for shoulder width on rural two-lane roadway segments (CMF_{wra}) (*12, 18*).

Shoulder width	Average annual daily traffic (AADT) (veh/day)		
	< 400	400 to 2000	> 2000
0 ft	1.10	$1.10 + 2.5 \times 10^{-4}(AADT - 400)$	1.50
2 ft	1.07	$1.07 + 1.43 \times 10^{-4}(AADT - 400)$	1.30
4 ft	1.02	$1.02 + 8.125 \times 10^{-5}(AADT - 400)$	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98 - 6.875 \times 10^{-5}(AADT - 400)$	0.87

NOTE: The collision types related to lane width to which these CMFs apply include single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. Standard error of the CMF is unknown. To determine the CMF for changing paved shoulder width and/or AADT, divide the “new” condition CMF by the “existing” condition CMF.
SOURCE: Based on HSM Table 10-9. The values from Table 13 are used as CMF_{wra} in Equation 7.



SOURCE: Based on HSM Figure 10-8.

Figure 4. CMF for shoulder width on roadway segments for two-lane highway **(12, 18)*.***

greater than 1.0. The shoulder-width CMF for rural two-lane highways is illustrated in Figure 4.

The base condition for shoulder type is paved (CMF = 1.0). Table 14 presents values for CMF_{tra}, which adjusts for the safety effects of gravel, turf, and composite shoulders as a function of shoulder width.

A combined CMF for shoulder width and type is computed as

$$CMF = (CMF_{wra} \times CMF_{tra} - 1.0) \times p_{ra} + 1.0 \qquad (7)$$

where

CMF_{wra} = crash modification factor for shoulder width from the equations in Table 13

CMF_{tra} = crash modification factor for shoulder type from Table 14

If the shoulder types and/or widths for the two directions of a roadway segment differ, the CMFs are determined separately for the shoulder type and width in each direction of travel and the resulting CMFs are then averaged.

The CMFs for shoulder width and type shown above apply only to the collision types that are most likely to be affected by shoulder width and type: single-vehicle run-off-the-road crashes, multiple-vehicle head-on crashes, opposite-direction sideswipe crashes, and same-direction sideswipe crashes. The CMFs expressed on this basis are, therefore, adjusted to total crashes using Equation 7. The HSM default value for p_{ra} for two-lane highways in Equation 7 is 0.574.

Table 14. CMFs for shoulder types and shoulder width on roadway segments (CMF_{tra}) (*12, 18*).

Shoulder type	Shoulder width (ft)						
	0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

NOTE: The values for composite shoulders in this table represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.
SOURCE: Based on HSM Table 10-10.

Table 15. Recommended shoulder widths for rural multilane divided arterials (*4, 5*).

Number of lanes in single direction	Recommended right (outside) shoulder width (ft)	Recommended left (inside) shoulder width (ft)
2 lanes	8	4
3 or more lanes	8	8

SOURCE: Adapted from *Green Book* Chapter 7.

2.3.2 Rural Multilane Highways

Design Criteria

The *Green Book* states that the design criteria for shoulder width on rural two-lane highways presented in Table 12 are generally applicable to rural undivided multilane arterials, as well. For rural divided multilane arterials, the shoulder widths presented in Table 15 are recommended.

Traffic Operational Effects

Chapter 14 (Multilane Highways) of the HSM estimates free-flow speed based on the total lateral clearance, defined as the sum of the lateral clearance on the left side of the roadway (maximum of 6 ft) and the right side of the roadway (maximum of 6 ft). Lateral clearance is defined as the distance from the edge of the travel lane to the nearest obstruction. Thus, roadways with wide shoulders inherently have larger lateral clearance values than roadways with narrow shoulders. Total lateral clearance for multilane highways is generally interpreted as equivalent to the sum of the left (inside) and right (outside) shoulder widths, since some objects (e.g., guardrail) may be located immediately outside the shoulders. The free-flow speed reduction values are shown in Table 16; these values are used in Equation 3 (see Section 2.2.2).

In addition, Chapter 14 of the HCM predicts a free-flow speed reduction of 1.6 mph for an undivided roadway relative to a divided highway or a highway with a two-way left-turn lane. This value is used in f_M in Equation 3, where applicable.

Traffic Safety Effects

Chapter 11 (Rural Multilane Highways) of the HSM presents CMFs for paved shoulders on rural multilane roadways. CMFs are calculated differently for undivided and divided roadways. CMFs for undivided sections of multilane highways are calculated using the same equations as two-lane highways, as shown in Table 13 (see also Figure 4). The base condition for this CMF is a 6-ft shoulder (CMF = 1.0). As for rural two-lane highways, this CMF is adjusted to total crashes using Equation 7. The HSM default value for p_{ra} for rural multilane undivided highways used in Equation 7 is 0.27.

CMFs for divided sections of multilane highways are presented in Table 17. The base condition (CMF = 1.0) is an 8-ft shoulder. This CMF applies to total crashes and is not adjusted using a p_{ra} value.

2.3.3 Urban and Suburban Arterials

Design Criteria

Chapter 7 of the *Green Book* states that shoulders are desirable on any highway, but high right-of-way costs in urban areas may often preclude their use. When sufficient right-of-way is available, the design criteria previously presented for rural highways apply. Shoulders are not required by the *Green Book* for urban areas, and many such roadways are built using curbed cross sections, rather than shoulders.

Traffic Operational Effects

Chapter 17 (Urban Street Segments) of the HCM includes a procedure to determine the effect of the features of an urban street segment on free-flow speed. However, shoulder width

Table 16. Adjustment to free-flow speed for lateral clearance on rural and suburban multilane highways (*13*).

Four-lane highways		Six-lane highways	
Total lateral clearance (ft)	Reduction in free-flow speed (mph)	Total lateral clearance (ft)	Reduction in free-flow speed (mph)
12	0.0	12	0.0
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9

NOTE: The values for reduction in free-flow speed presented in this table are used as f_{LW} in Equation 3.
SOURCE: Based on HCM Exhibit 14-9.

Table 17. CMFs for paved right (outside) shoulder width on multilane divided highway segments (*12, 26*).

Average paved shoulder width				
0 ft	2 ft	4 ft	6 ft	8 ft or more
1.18	1.13	1.09	1.04	1.00

SOURCE: Based on HSM Table 11-17.

is not one of the factors that influences free-flow speed. This suggests that shoulder width either has no effect on the free-flow speed on an urban street segment or an effect that is very small in comparison to the factors that are in the procedure (see HCM Exhibit 17-5). This contrasts with the HCM 2000 (*22*) which speculated that shoulder width influenced free-flow speed for urban streets, but did not quantify that effect.

Traffic Safety Effects

The HSM does not provide a CMF for shoulder width on urban and suburban arterials.

2.3.4 Freeways

Design Criteria

Chapter 8 of the *Green Book* recommends the shoulder widths for freeways shown in Table 18.

The AASHTO policy on design standards for the Interstate highway system (*14*) requires a right (outside) shoulder with 10 ft of paved width. Where truck traffic exceeds a directional design hour volume (DDHV) of 250, a paved shoulder width of 12 ft should be considered. On a four-lane section, the paved width of the left (inside) shoulder is required to be at least 4 ft. On sections with six or more lanes, a left (inside) shoulder with a 10-ft width should be provided. Where truck traffic exceeds 250 DDHV, a paved width of 12 ft should be considered for the left (inside) shoulder. On four- to six-lane freeways in mountainous terrain, 8-ft paved right (outside) shoulders and 4-ft paved left (inside) shoulders may be used. On sections with eight or more lanes in mountainous terrain, a minimum paved shoulder width of 8 ft should be used on both sides of the roadway.

Traffic Operational Effects

Chapter 11 (Basic Freeway Segments) of the HCM estimates free-flow speed based on the lateral clearance on the right side of the roadway. Lateral clearance is measured from the edge of the travel lane to the edge of the paved shoulder. If the right-side lateral clearance is greater than or equal to 6 ft, no reduction in free-flow speed is made. The amount of free-flow speed reduction increases as the right-side lateral clearance decreases. Left-side lateral clearance is assumed to be greater than or equal to 2 ft for all cases. The free-flow speed reductions for right shoulder lateral clearance (generally interpreted as equivalent to right [outside] shoulder width) are shown in Table 19. The values in Table 19 are used as f_{LC} in Equation 4 to determine free-flow speed (see Section 2.2.4).

Traffic Safety Effects

Results from NCHRP Project 17-45, which developed a proposed HSM safety prediction methodology for freeways, include CMFs for both right (outside) shoulder width and left (inside) shoulder width on freeways (*25*). The CMF for right (outside) shoulder width (where W_s = average right [outside] shoulder width for both directions of travel combined [ft]) is the following:

- For fatal-and-injury single-vehicle crashes on tangent sections,

$$CMF = \exp\left(-0.0647\left(W_s - 10\right)\right) \quad (8)$$

- For fatal-and-injury single-vehicle crashes on horizontal curves,

$$CMF = \exp\left(-0.097\left(W_s - 10\right)\right) \quad (9)$$

- For property-damage-only single-vehicle crashes on tangent sections,

$$CMF = 1.0 \quad (10)$$

Table 18. Recommended shoulder widths for freeways (*4, 5*).

Side of roadway	DDHV for truck traffic (veh/h)	Total number of freeway lanes	Recommended shoulder width (ft)
Right shoulder	≤250	All	10
Right shoulder	>250	All	12
Left shoulder	≤250	Less than 6	4
Left shoulder	≤250	6 or more	10
Left shoulder	>250	All	12

SOURCE: Adapted from Chapter 8 of the AASHTO *Green Book*.

Table 19. Adjustments for free-flow speed right-side lateral clearance on freeways (*13*).

Right Shoulder Lateral Clearance (ft)	Reduction in free-flow speed (mph) Number of lanes in one direction			
	2 lanes	3 lanes	4 lanes	≥5 lanes
≥ 6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

NOTE: The values in this table are used as f_{LC} in Equation 4.
SOURCE: Based on HCM Exhibit 11-9.

- For property-damage-only single-vehicle crashes on horizontal curves,

$$CMF = \exp\left(-0.0840\left(W_s - 10\right)\right) \tag{11}$$

The base condition for this CMF is a 10-ft shoulder width (CMF = 1.0). The CMF is applicable to shoulders in the range of 4 to 14 ft. This CMF applies only to single-vehicle crashes; right (outside) shoulder width does not appear to have any effect on multiple-vehicle crashes.

The CMF for left (inside) shoulder width (where W_{is} = average inside shoulder width for both directions of travel combined [ft]) is the following:

- For fatal-and-injury crashes,

$$CMF = \exp\left(-0.0172\left(W_{is} - 6\right)\right) \tag{12}$$

- For property-damage-only crashes,

$$CMF = \exp\left(-0.0153\left(W_{is} - 6\right)\right) \tag{13}$$

The base condition for this CMF is a 6-ft shoulder width. The CMF is applicable to left (inside) shoulders in the range of 2 to 12 ft. The CMF applies to both multiple- and single-vehicle crashes.

2.3.5 Mitigation Strategies

All the mitigation strategies for lane width presented in Section 2.2.5 also apply to shoulder width, with the obvious exception that adding paved or partially paved shoulders does not apply because the lack of a full shoulder is the condition to be mitigated.

2.4 Bridge Width

Bridge width is the total width of all lanes and shoulders on a bridge, measured between the points on the bridge rail, curb, or other vertical elements that project farthest onto the roadway. A bridge width that meets design criteria maintains the minimum acceptable lane and shoulder width for the particular design condition as defined by area, functional class, design speed, and traffic volume. FHWA policy requires a design exception when a bridge is proposed to be constructed or retained with narrower lanes, shoulders, or both (*7*). Chapter 7 (Arterials) of the *Green Book* includes specific guidance on bridge widths that may remain in place on reconstruction projects (see Sections 2.4.1 and 2.4.2).

Potential concerns associated with narrow bridges are twofold. Narrow bridges that are relatively short represent a discontinuity that may affect driver behavior. The narrowed cross section can make some drivers uncomfortable and cause them to dramatically reduce speed, increasing the risk of rear-end crashes and degrading operations on high-speed, high-volume facilities. The bridge rail may be close enough to the travel lanes to cause drivers to move toward the centerline or into adjacent lanes. In narrow bridges, the bridge railing itself is closer to the edge of pavement and thus represents a roadside hazard. Even when properly designed and delineated, there is an increased risk of a roadside collision with the bridge railing or bridge end being closer to the edge of traveled way.

A second set of concerns is evident for narrow bridges that are longer (say, greater than 500 ft in length). The safety and operational concerns at narrow bridges are similar to those on roads with narrow shoulders. There may be inadequate space for storage of disabled vehicles, enforcement activities, emergency response, and maintenance work. The lack of shoulder width on the bridge may make it impossible to avoid a crash or object on the roadway ahead. In addition, options are limited for non-motorized users such as bicyclists, forcing them onto the traveled lanes or close to the bridge rail.

Narrow bridges on horizontal curves can have limited horizontal stopping sight distance past the bridge rail. Operations can be degraded, particularly on long bridges on high-speed roadways, because of speed reductions as drivers enter the narrowed cross section as well as decreased driver comfort on the bridge.

2.4.1 Rural Two-Lane Highways

Design Criteria

The minimum lane widths and shoulder widths shown in Tables 4 and 12, based on *Green Book* Exhibit 7-3, serve as the recommended minimum bridge widths for rural two-lane arterials. The combined minimum widths (lane width plus shoulder width) range from 30 ft (for a design speed of 40 mph and ADT less than 400 veh/day) to 40 ft (for a design speed of 75 mph and an ADT above 2,000 veh/day). On long bridges, defined as bridges with lengths of more than 200 ft, the offset to the parapet, rail, or barrier should be at least 4 ft from the edge of the traveled way or both sides of the roadway. Chapter 7 of the *Green Book* indicates that bridges with widths equal to the width of the traveled way plus 2 ft of clearance on each side may remain in place in reconstruction projects on arterials.

Traffic Operational Effects

Chapter 15 (Two-Lane Highways) of the HCM provides estimates for free-flow speeds on rural two-lane highways based on lane width and shoulder width. Bridges wide enough to accommodate 12-ft lanes and 6-ft shoulders will not reduce the free-flow speed below the base free-flow speed of the roadway; bridges of lesser widths will result in reduced free-flow speeds. Sections 2.2.1 and 2.3.1 of this report present more detailed information. The actual reduction in free-flow speed may be even greater than suggested in the HCM, particularly for long bridges, because the lateral obstruction is generally presented for the entire length of the bridge.

Traffic Safety Effects

The effects of lane and shoulder widths on safety for rural two-lane highways have been documented in Sections 2.2.1 and 2.3.1 of this report. While the design criteria for bridge width are based on the lane and shoulder width design criteria, it seems likely that safety might be more sensitive to bridge width than the lane and shoulder width, because every bridge has lateral obstructions (i.e., bridge rail or curb) at the outside edge of the shoulder.

Turner (*27*) conducted research to predict crash rates as a function of bridge width, but the results appear potentially biased because only bridges that had experienced at least one crash were studied. A recent study by Bigelow et al. (*28*) in the FHWA CMF Clearinghouse provides a CMF for changing bridge width (bridge minus roadway width) from X to Y. The CMF is

$$CMF = 100 * (1 - \exp(-0.116(Y - X))) \quad (14)$$

where

X = bridge width before improvement (ft)
Y = bridge width after improvement (ft)

This is applicable to all crash types and severities. However, this CMF applies only to low-volume roads with AADT less than or equal to 400 veh/day and speed limits greater than or equal to 45 mph.

Research conducted under NCHRP Project 17-53 (see Section 4.3) included analysis of the crash history of 624 bridges on rural two-lane highways in California and 337 bridges on rural two-lane highways in Washington and found no statistically significant effect of differences between roadway width on the approach roadway and on the bridge on crash frequency.

2.4.2 Rural Multilane Highways

Design Criteria

Design criteria for bridge widths on rural multilane highways are based on the lane and shoulder-width design criteria presented in Sections 2.2.2 and 2.3.2. Those design criteria in Chapter 7 of the *Green Book* recommend 12-ft lane widths for rural divided multilane arterials. For long bridges over 200 ft in length, the *Green Book* states that 4-ft right and left shoulders are acceptable. For shorter bridges, the normal recommendation of an 8-ft right shoulder applies. Chapter 7 of the *Green Book* indicates that bridges with widths equal to the width of the traveled way plus 2 ft of clearance on each side may remain in place in reconstruction projects.

Traffic Operational Effects

Chapter 14 (Multilane Highways) of the HCM provides estimates for free-flow speeds on multilane highways based on lane width and lateral clearance. Bridges wide enough to accommodate 12-ft lanes and at least 6 ft of lateral clearance on both the left and right sides of the road will not reduce the free-flow speed below the base level; bridges of lesser widths will result in reduced free-flow speed levels. Sections 2.2.2 and 2.3.2 of this report present more detailed information. The actual reduction in free-flow speed may be even greater than suggested in the HCM, particularly for long bridges, because the lateral obstruction is generally present for the entire length of the bridge.

Traffic Safety Effects

See discussion in Section 2.4.1 of this report.

2.4.3 Urban and Suburban Arterials

Design Criteria

Chapter 7 of the *Green Book* states that the minimum clear width for new bridges should be the same as the minimum curb-to-curb distance of the roadway for general conditions. For bridges that exceed 200 ft in length, the offsets to parapets, rails, or barriers may be reduced to 4 ft where shoulders or parking lanes are provided on the arterial.

Traffic Operational Effects

According to the "Limitations of the Methodology" discussion in Chapter 17 (Urban Streets) of the HCM, the HCM urban streets methodology does not directly account for capacity constraints such as a narrow bridge between intersections.

Traffic Safety Effects

See discussion in Section 2.4.1 of this report.

2.4.4 Freeways

Design Criteria

Minimum widths for lanes and shoulders on freeways are presented in Chapter 8 of the *Green Book* and have been summarized in Sections 2.2.4 and 2.3.4 of this report. A total bridge width for a freeway would depend on these minimum width values. As a general example, the following widths are recommended for a two-way viaduct freeway with ramps:

- Median width: 10 to 22 ft
- Lane width: 12 ft
- Right shoulder width: 10 ft
- Left shoulder width: 4 to 10 ft
- Parapet width: 2 ft
- Clearance between structure and building line: 15 ft

Traffic Operational Effects

Chapter 11 (Basic Freeway Segments) of the HCM provides estimates for free-flow speeds on freeways based on lane width and lateral clearance. Bridges wide enough to accommodate 12-ft lanes, at least 6 ft of right-side lateral clearance, and at least 2 ft of left-side lateral clearance will not reduce the free-flow speed below the base value; bridges of lesser widths will result in reduced free-flow speed values. Sections 2.2.4 and 2.3.4 of this report present more detailed information. The actual reduction in free-flow speed may be even greater than suggested in the HCM, particularly for long bridges, because the lateral obstruction is generally presented for the entire length of the bridge.

Traffic Safety Effects

See discussion in Section 2.4.1 of this report.

2.4.5 Mitigation Strategies

Strategies for mitigating narrow bridge widths are directed primarily at improving a driver's ability to see or to anticipate the narrowed cross section of the bridge, the bridge rail, and the lane lines. Typical mitigation strategies include the following (*7*):

- Advance signing
- Improved delineation (pavement makings, lane delineation, roadside reflectors, high-visibility bridge rail)
- Bridge lighting
- Skid-resistant pavement
- Anti-icing systems
- Crashworthy bridge rail and approach guardrail
- Emergency pull-off areas
- Surveillance (for long, high-volume bridges)

2.5 Structural Capacity

Structural capacity has no effect on traffic operations, and its effect on safety is related only to the probability of a structural failure, not to the likelihood of traffic crashes. For this reason, structural capacity is not reviewed here and will not be addressed in this research.

2.6 Horizontal Alignment

Horizontal alignment involves design of the horizontal curves and tangents along a roadway section. In the context of the controlling criteria for design, horizontal alignment addresses only horizontal curves, not tangent sections, and the horizontal alignment criterion addresses only curve radius. Superelevation of horizontal curves is addressed by a separate controlling criterion. While the length of a horizontal curve and the length of tangent preceding a horizontal curve may influence traffic operations and safety and should be considered as part of the design process, they are not part of the controlling criteria and do not require design exceptions.

Chapter 3 of the *Green Book* provides guidance for selecting minimum radii for horizontal curves based on design speed, the maximum superelevation rate (e_{max}), and the maximum side friction factor (f_{max}), which sets an upper limit on lateral acceleration based on driver comfort. This methodology is applicable to each of the road types discussed below, although additional guidance is provided for each road type individually as well. Table 20 presents design criteria for minimum curve radius for three selected maximum superelevation rates.

Table 20. Design criteria for minimum curve radius for three selected maximum superelevation rates (*4, 5*).

Design speed (mph)	Maximum *e* (%)	Maximum *f*	Total (*e*/100 + *f*)	Calculated minimum radius (ft)	Rounded minimum radius (ft)
10	6.0	0.38	0.44	15.2	15
15	6.0	0.32	0.38	39.5	39
20	6.0	0.27	0.33	80.8	81
25	6.0	0.23	0.29	143.7	144
30	6.0	0.20	0.26	230.8	231
35	6.0	0.18	0.24	340.3	340
40	6.0	0.16	0.22	484.8	485
45	6.0	0.15	0.21	642.9	643
50	6.0	0.14	0.20	833.3	833
55	6.0	0.13	0.19	1,061.4	1,060
60	6.0	0.12	0.18	1,333.3	1,330
65	6.0	0.11	0.17	1,656.6	1,660
70	6.0	1.10	0.16	2,041.7	2,040
75	6.0	0.09	0.15	2,500.0	2,500
80	6.0	0.08	0.14	3,047.6	3,050
10	8.0	0.38	0.46	14.5	14
15	8.0	0.32	0.40	37.5	38
20	8.0	0.27	0.35	76.2	76
25	8.0	0.23	0.31	134.4	134
30	8.0	0.20	0.28	214.3	214
35	8.0	0.18	0.26	314.1	314
40	8.0	0.16	0.24	444.4	444
45	8.0	0.15	0.23	587.0	587
50	8.0	0.14	0.22	757.6	758
55	8.0	0.13	0.21	960.3	960
60	8.0	0.12	0.20	1,200.0	1,200
65	8.0	0.11	1.09	1,482.5	1,480
70	8.0	1.10	0.18	1,847.8	1,810
75	8.0	0.09	0.7	2,205.9	2,210
80	8.0	0.08	1.16	2,666.7	2,670
10	12.0	0.38	0.50	13.3	13
15	12.0	0.32	0.44	34.1	34
20	12.0	0.27	0.39	68.4	68
25	12.0	0.23	3.35	119.0	119
30	12.0	0.20	0.32	187.5	188
35	12.0	0.18	0.30	272.2	272
40	12.0	0.16	0.28	381.0	381
45	12.0	0.15	0.27	500.0	500
50	12.0	0.14	0.26	641.0	641
55	12.0	0.13	0.25	806.7	807
60	12.0	0.12	0.24	1,000.0	1,000
65	12.0	0.11	0.23	1,224.6	1,220
70	12.0	0.10	0.22	1,484.8	1,480
75	12.0	0.099	0.24	1,785.7	1,790
80	12.0	0.08	0.20	2,133.3	2,130

SOURCE: Based on *Green Book* Table 3-7 (abridged).

2.6.1 Rural Two-Lane Highways

Design Criteria

The design criteria for minimum curve radius presented in Table 20 apply to rural two-lane highways.

Traffic Operational Effects

Chapter 15 (Two-lane Highways) of the HCM uses free-flow speed in the determination of LOS. The chapter states that the base free-flow speed is the speed that would be expected on the basis of the facility's horizontal and vertical alignment, if standard lane and shoulder widths were present and there were no roadside access points. However, the HSM provides no methodology to determine the effect of horizontal curvature on base free-flow speed.

The IHSDM design consistency module (*10, 29*) includes a series of models for predicting the reduction in vehicle speed on horizontal curves from the design speed or tangent speed. These models are presented in Table 21. It should be noted

Table 21. IHSDM speed prediction equations for passenger vehicles[a] (*10, 29*).

AC EQ#[b]	Alignment condition	Equation[c]	# of sites	R^2	MSE
1.	Horizontal curve on grade: –9% ≤ G < –4%	$V_{85} = 102.10 - \frac{3077.13}{R}$	21	0.58	51.95
2.	Horizontal curve on grade: –4% ≤ G < 0%	$V_{85} = 105.98 - \frac{3707.90}{R}$	25	0.76	28.46
3.	Horizontal curve on grade: –0% ≤ G < 4%	$V_{85} = 104.82 - \frac{3574.51}{R}$	25	0.76	24.34
4.	Horizontal curve on grade: –4% ≤ G < 9%	$V_{85} = 96.61 - \frac{2752.19}{R}$	23	0.53	52.54
5.	Horizontal curve combined with sag vertical curve	$V_{85} = 105.32 - \frac{3438.19}{R}$	25	0.92	10.47
6.	Horizontal curve combined with non-limited sight distance crest vertical curve	[d]	13	n/a	n/a
7.	Horizontal curve combined with limited-sight-distance crest vertical curve (i.e., K ≤ 43 m/%)	$V_{85} = 103.24 - \frac{3576.51}{R}$	22	0.74	20.06
8.	Sag vertical curve on horizontal tangent	V_{85} = assumed desired speed	7	n/a	n/a
9.	Vertical crest with non-limited-sight-distance (i.e., K > 43 m/%) on horizontal tangent	V_{85} = assumed desired speed	6	n/a	n/a
10.	Vertical crest with limited sight distance (i.e., K ≤ 43 m/%) on horizontal tangent	$V_{85} = 105.08 - \frac{149.69}{K}$	9	0.60	31.10

[a] Check the speeds predicted from Equations 1 or 2 in this table (for the downgrade) and Equations 3 or 4 in this table (for the upgrade) and use the lowest speed. This will ensure that the speed predicted along the combined curve will not be better than if just the horizontal curve was present (i.e., that the inclusion of a limited-sight-distance crest vertical curve will result in a higher speed).
[b] AC EQ# = Alignment condition equation number; MSE = mean squared error.
[c] Where: V_{85} = 85th percentile speed of passenger cars (km/h) K = rate of vertical curvature
R = radius of curvature (m) G = grade (%)
[d] Use lowest speed of the speeds predicted from Equations 1 or 2 in this table (for the downgrade) and Equations 3 or 4 in this table (for the upgrade).

that Table 21, as it appears in the original research, uses metric units for speed and curve radius.

Traffic Safety Effects

Chapter 10 (Rural Two-Lane Highways) of the HSM provides a CMF for horizontal curves on rural two-lane roads which is computed as shown in Equation 15:

$$CMF = \frac{(1.55 \times L_c)\left(\frac{80.2}{R}\right) - (0.012 \times S)}{(1.55 \times L_c)} \quad (15)$$

where

L_c = Length of horizontal curve including length of spiral transitions, if present (mi)
R = Radius of curvature (ft)
S = 1 if spiral transition curve is present: 0 if spiral transition curve is not present

The base condition (CMF = 1.0) is a tangent segment with no curvature. This CMF applies to total crashes and is based on research by Zegeer et al. (*30*).

An alternative CMF that incorporates the effects of both horizontal curvature and grade on straight grades (i.e., grades with constant percent grade) has been developed by Bauer and Harwood (*31*) in an FHWA study for consideration for a future edition of the HSM:

- For fatal-and injury-crashes,

$$CMF_{SG,FI} = \begin{cases} \exp\left[\begin{array}{l} 0.044\,G + 0.19\ln\left(2 \times \frac{5730}{R}\right) \\ + 4.52\left(\frac{1}{R}\right)\left(\frac{1}{L_C}\right) \end{array}\right] & \text{for horizontal curves} \\ \exp[0.044\,G] & \text{for tangents on nonlevel grades} \\ 1.0 & \text{for level tangents (base condition)} \end{cases} \quad (16)$$

- For property-damage-only crashes,

$$CMF_{SG,PDO} = \begin{cases} \exp\left[0.040\,G + 0.13\ln\left(2\times\frac{5730}{R}\right) + 3.80\left(\frac{1}{R}\right)\left(\frac{1}{L_C}\right)\right] & \textit{for horizontal curves} \\ \exp[0.040\,G] & \textit{for tangents on nonlevel grades} \\ 1.0 & \textit{for level tangents (base condition)} \end{cases} \quad (17)$$

where

G = absolute value of percent grade

2.6.2 Rural Multilane Highways

Design Criteria

The design criteria for minimum curve radius presented in Table 20 apply to rural multilane highways.

Traffic Operational Effects

Chapter 14 (Multilane Highways) of the HCM uses free-flow speed in the determination of LOS. The chapter states that the base free-flow speed is the speed that would be expected on the basis of the facility's horizontal and vertical alignment, if standard lane and shoulder widths were present and there were no roadside access points. However, the HCM provides no methodology to determine the effect of horizontal curvature on base free-flow speed.

Research conducted under NCHRP Project 17-53 (see Section 4.4) quantified the effect of horizontal curve radius on traffic speed for rural multilane highways as follows:

$$\text{Speed}_{\text{curve}} = \text{Speed}_{\text{approach}} - \frac{3136}{R} \quad (18)$$

where

$\text{Speed}_{\text{curve}}$ = Speed of traffic on horizontal curve (mph)
$\text{Speed}_{\text{approach}}$ = Speed of traffic on tangent approaching curve (mph)
R = Radius of curvature (ft)

Traffic Safety Effects

Chapter 11 (Rural Multilane Highways) of the HSM does not include any CMFs for horizontal curves on rural multilane highways. Thus, the safety effect of horizontal curves on rural multilane highways has not been documented. There are several CMFs for horizontal curve radius in the FHWA CMF Clearinghouse, but none of these is specifically applicable to rural multilane highways.

Research conducted under NCHRP Project 17-53 (see Section 4.4) developed the following CMFs for the effect of horizontal curvature on rural four-lane divided highways:

- For fatal-and-injury crashes,

$$\text{CMF} = \exp\left(-0.87L_c + 0.22\ln\left(2\times\frac{5730}{R}\right)\right) \quad (19)$$

- For property-damage-only crashes,

$$\text{CMF} = \exp\left(-0.95L_c + 0.26\ln\left(2\times\frac{5730}{R}\right)\right) \quad (20)$$

No comparable CMFs are available for rural four-lane undivided highways.

2.6.3 Urban and Suburban Arterials

Design Criteria

The design criteria for minimum curve radius presented in Table 20 apply to urban and suburban arterials. On low-speed urban streets, with design speeds of 45 mph or less, minimum radii sharper than those shown in Table 20 can be used (see *Green Book* Exhibit 3-16).

Traffic Operational Effects

Chapter 17 (Urban Street Segments) of the HSM includes a method for estimating the free-flow speed for an urban street section. The factors considered include speed limit, median type, curb presence, and access-point density. There is no effect of horizontal alignment in the procedure. In essence, the procedure assumes that the effect of curvature on speed is minimal.

Research conducted under NCHRP Project 17-53 (see Section 4.4) quantified the effect of horizontal curve radius on traffic speed urban and suburban arterials as follows:

$$\text{Speed}_{\text{curve}} = \text{Speed}_{\text{approach}} - \frac{2203}{R} \quad (21)$$

Traffic Safety Effects

Chapter 12 (Urban and Suburban Arterials) of the HSM does not include any CMFs for the effect of horizontal curves on urban and suburban arterials. Recent research by Hauer et al. (*32*) observed on-road crash frequencies for horizontal curves on urban four-lane undivided arterials to be lower than tangent sections in the same corridors; the opposite was found to be the case for run-off-road crashes. Since on-road crashes are predominant on urban arterials, Hauer et al.

concluded that the role of horizontal curvature in safety for this type of road may need reconsideration. There are several CMFs for horizontal curve radius in the FHWA CMF Clearinghouse, but none of these is specifically applicable to urban and suburban arterials.

2.6.4 Freeways

Design Criteria

The design criteria for minimum curve radius presented in Table 20 apply to freeways.

Traffic Operational Effects

Chapter 11 (Multilane Highways) of the HCM uses free-flow speed in the determination of LOS. The chapter states that the base free-flow speed is the speed that would be expected on the basis of the facility's horizontal and vertical alignment, if standard lane and shoulder widths were present and there were no roadside access points. However, no methodology to determine the effect of horizontal curvature on base free-flow speed is provided in the HCM.

Traffic Safety Effects

Results from NCHRP Project 17-45, which developed a proposed HSM safety prediction methodology for freeways, includes a CMF for the safety effect of horizontal curves on safety (*25*). The CMFs for horizontal curves (where R = radius of curvature [ft])are the following:

- For fatal-and-injury multiple-vehicle crashes,

$$CMF = 1.0 + 0.0172 \times \left(\frac{5730}{R}\right)^2 \quad (22)$$

- For property-damage-only multiple-vehicle crashes,

$$CMF = 1.0 + 0.0340 \times \left(\frac{5730}{R}\right)^2 \quad (23)$$

- For fatal-and-injury single-vehicle crashes,

$$CMF = 1.0 + 0.0719 \times \left(\frac{5730}{R}\right)^2 \quad (24)$$

- For property-damage-only single-vehicle crashes,

$$CMF = 1.0 + 0.0626 \times \left(\frac{5730}{R}\right)^2 \quad (25)$$

2.6.5 Mitigation Strategies

Mitigation strategies for horizontal curves with sharper radii than established design criteria include the following (*7*):

- Advance warning with signing and pavement markings
- Dynamic message signs
- Delineation (chevrons, post-mounted delineators, reflectors on barriers)
- Roadway widening
- Skid-resistant pavement
- Lighting
- Shoulder, painted edgeline, or centerline rumble strips
- Paved or partially paved shoulders
- Safety edge treatment
- Roadside improvements (clear recovery area, traversable slopes, breakaway safety hardware, barrier where appropriate)

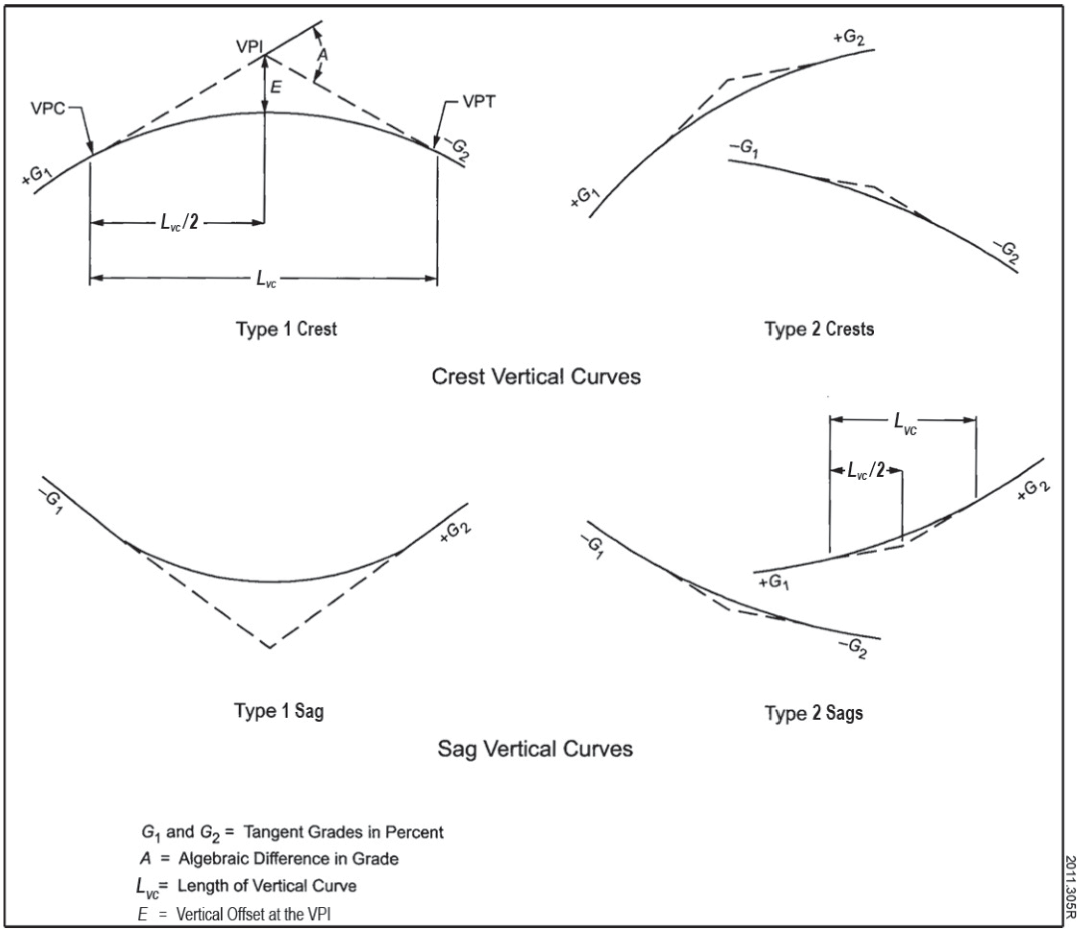
2.7 Vertical Alignment

Vertical alignment generally consists of two elements: grades and vertical curves. Both of these elements are considered in the controlling criteria. Grade is treated as a separate controlling criterion (see Section 2.8). Two types of vertical curves are considered in vertical alignment design: crest vertical curves and sag vertical curves. Both crest and sag vertical curves have two types, known as Type 1 and Type 2, as illustrated in Figure 5. The *Green Book* design criteria for crest vertical curve lengths are illustrated in Figure 6. Crest vertical curve length is selected primarily to achieve minimum stopping sight distance on the vertical curve. Stopping sight distance is treated as a separate controlling criterion (see Section 2.9). Thus, the only element of vertical alignment not dealt with by a separate controlling criterion is sag vertical curve length. Sag vertical curve length is normally selected so that the curve does not restrict the length of roadway illuminated by vehicle headlights, which would reduce stopping sight distance at night. Figure 7 presents the *Green Book* design criteria for sag vertical curve length. The parameter, K, in Figures 6 and 7 is the ratio of the algebraic difference in grade, A, to the length of the vertical curve. Recent research on sag vertical curves is documented in *NCHRP Web-Only Document 198: Sag Vertical Curve Design Criteria for Headlight Sight Distance.*

2.7.1 Rural Two-Lane Highways

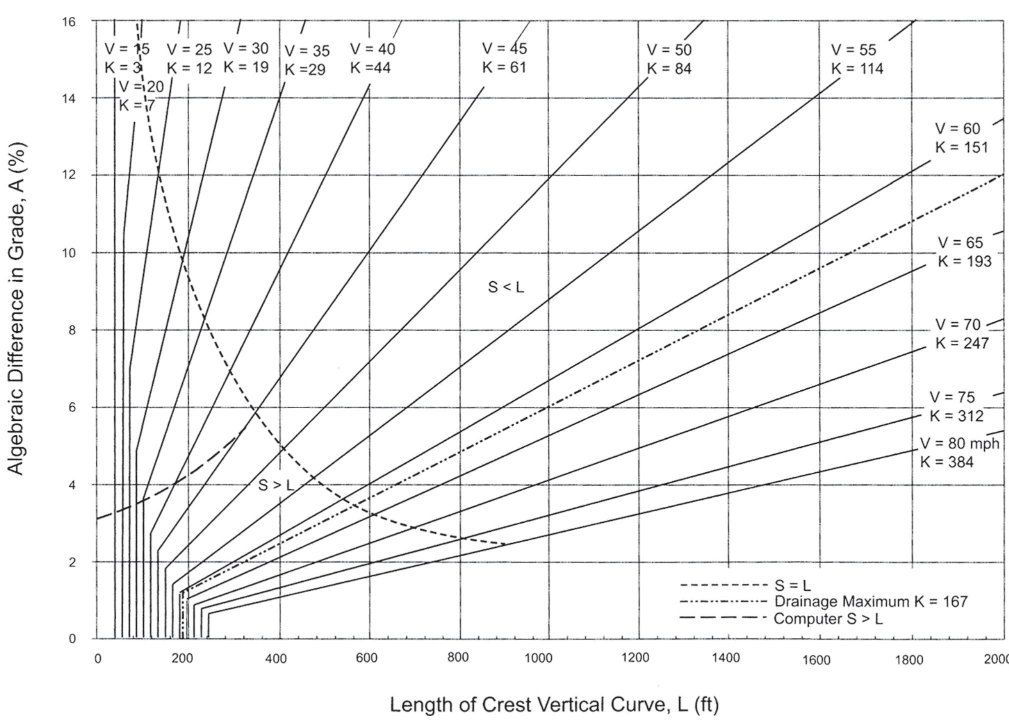
Design Criteria

The design criteria for crest and sag vertical curves, presented in Figures 6 and 7, respectively, are applicable to rural two-lane highways.



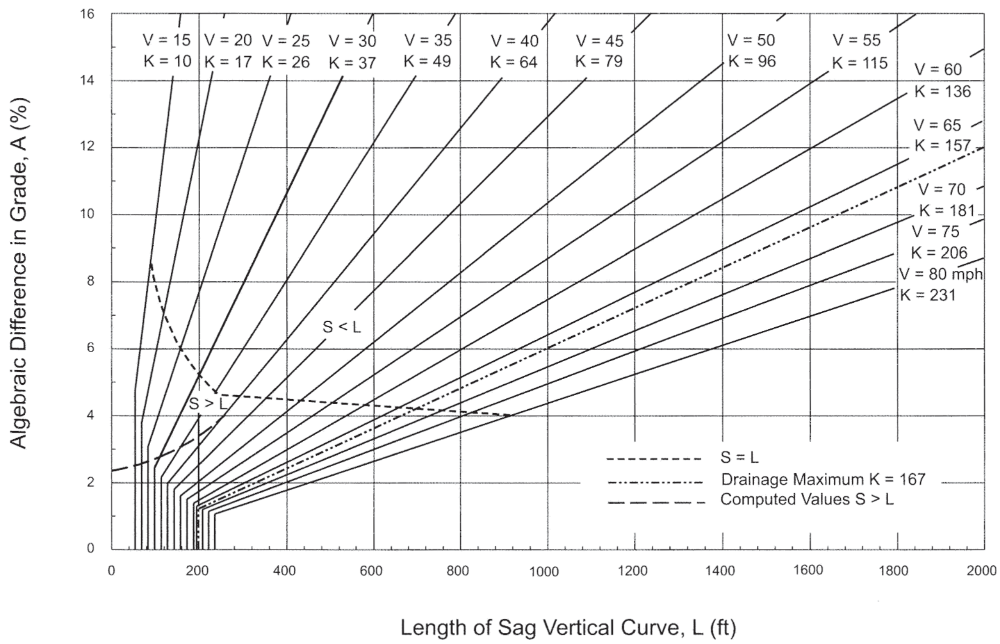
SOURCE: Based on *Green Book* Figure 3-41.

Figure 5. Types of vertical curves (4, 5).



SOURCE: Based on *Green Book* Figure 3-43.

Figure 6. Design controls for crest vertical curves—open road conditions (4, 5).



SOURCE: Based on *Green Book* Figure 3-44.

Figure 7. Design controls for sag vertical curves—open road conditions (4, 5).

Traffic Operational Effects

Chapter 15 (Two-Lane Highways) of the HCM provides a methodology for adjusting the LOS boundaries on rural two-lane highways to account for vertical alignment, considering general terrain classes or specific grades, as well as the percentages in the traffic flow of two types of heavy vehicles (trucks and recreational vehicles). Since these vertical alignment effects are primarily a function of grade, they are discussed in Section 2.8 of this report. Crest vertical curve effects are addressed in Section 2.9 of this report. There are no known quantifiable operational effects of sag vertical curve length; it is likely that any such effects are minimal as long as the ride comfort criteria in *Green Book* Equation 3-51 are met.

Traffic Safety Effects

Chapter 10 (Rural Two-Lane Highways) of the HSM includes a factor for the effect of grade on safety; this effect is discussed in Section 2.8 of this report. Chapter 10 (HSM) does not include any effect of crest or sag vertical curves on safety. The effect of crest vertical curves on safety is likely related to stopping sight distance and is discussed in Section 2.9 of this report. There is no known effect of sag vertical curve length on safety. Sag vertical curve length is essentially irrelevant to safety under daytime conditions, because the driver can see beyond the sag vertical curve unless a horizontal curve is present. At night, drivers at speeds of 50 mph or more generally outdrive their headlights. This is generally true whatever the vertical alignment, so there is no special risk on sag vertical curves. Furthermore, as discussed in Section 2.9, the object most likely to be struck by a driver in a limited-sight-distance situation is another vehicle on the roadway ahead. The taillights of such vehicles and the dispersion of light from their headlights should make such vehicles clearly visible at night, even beyond the limits of the sag vertical curve unless a horizontal curve is also present. Thus, it seems unlikely that sag vertical curve length would have much effect on safety. An important exception occurs when an overpass that might block the driver's view of the road ahead is located on a sag vertical curve. This situation is addressed explicitly in *Green Book* Chapter 3. It should also be noted that overpass structures on rural two-lane highways are not common.

Recent research for FHWA by Bauer and Harwood (*31*) completed since the publication of the first edition of the HSM, developed the following CMFs for Type 1 crest vertical curves (L_{VC} = length of vertical curve):

- For fatal-and injury-crashes,

$$CMF_{C1,FI} = \begin{cases} \exp\left[0.0088\left(\frac{5730}{R}\right)\frac{L_{VC}}{K}\right] & \textit{for horizontal curves} \\ 1.0 & \textit{for tangents at Type 1 crests} \\ 1.0 & \textit{for level tangents (base condition)} \end{cases} \quad (26)$$

- For property-damage-only crashes,

$$CMF_{C1,PDO} = \begin{cases} \exp\left[0.0046\left(\frac{5730}{R}\right)\frac{L_{VC}}{K}\right] & \textit{for horizontal curves} \\ 1.0 & \textit{for tangents at Type 1 crests} \\ 1.0 & \textit{for level tangents (base condition)} \end{cases} \quad (27)$$

The equivalent CMFs for Type 2 crest vertical curves are the following:

- For fatal-and injury-crashes,

$$CMF_{C2,FI} = \begin{cases} \exp\left[0.20 \ln\left(2\times\frac{5730}{R}\right)\right] & \textit{for horizontal curves} \\ 1.0 & \textit{for tangents at Type 2 crests} \\ 1.0 & \textit{for level tangents (base condition)} \end{cases} \quad (28)$$

- For property-damage-only crashes,

$$CMF_{C2,PDO} = \begin{cases} \exp\left[0.10 \ln\left(2\times\frac{5730}{R}\right)\right] & \textit{for horizontal curves} \\ 1.0 & \textit{for tangents at Type 2 crests} \\ 1.0 & \textit{for level tangents (base condition)} \end{cases} \quad (29)$$

Bauer and Harwood (*31*) also developed the following CMFs for Type 1 sag vertical curves:

- For fatal-and injury-crashes,

$$CMF_{S1,FI} = \begin{cases} \exp\left[\begin{matrix} 10.51\frac{1}{K} + 0.011 \\ \left(\frac{5730}{R}\right)\frac{L_{VC}}{K} \end{matrix}\right] & \textit{for horizontal curves} \\ \exp\left[10.51\frac{1}{K}\right] & \textit{for tangents at Type 1 sags} \\ 1.0 & \textit{for level tangents (base condition)} \end{cases} \quad (30)$$

- For property-damage-only crashes,

$$CMF_{S1,PDO} = \begin{cases} \exp\left[8.62\frac{1}{K} + 0.010\left(\frac{5730}{R}\right)\frac{L_{VC}}{K}\right] & \textit{for horizontal curves} \\ \exp\left[8.62\frac{1}{K}\right] & \textit{for tangents at Type 1 sags} \\ 1.0 & \textit{for level tangents (base condition)} \end{cases} \quad (31)$$

The equivalent CMFs for Type 2 sag vertical curves are the following:

- For fatal-and injury-crashes,

$$CMF_{S2,FI} = \begin{cases} \exp\left[0.188 \ln\left(2\times\frac{5730}{R}\right)\right] & \textit{for horizontal curves} \\ 1.0 & \textit{for tangents at Type 2 sags} \\ 1.0 & \textit{for level tangents (base condition)} \end{cases} \quad (32)$$

- For property-damage-only crashes,

$$CMF_{S2,PDO} = \begin{cases} \exp\left[0.022\left(\frac{5730}{R}\right)A\right] & \textit{for horizontal curves} \\ 1.0 & \textit{for tangents at Type 2 sags} \\ 1.0 & \textit{for level tangents (base condition)} \end{cases} \quad (33)$$

2.7.2 Rural Multilane Highways

Design Criteria

The design criteria for crest and sag vertical curves, presented in Figures 6 and 7, respectively, are applicable to rural multilane highways.

Traffic Operational Effects

Chapter 14 (Multilane Highways) of the HCM provides a methodology for adjusting the LOS boundaries on a multilane highway to account for vertical alignment considering general terrain classes or specific grades, as well as the percentages in the traffic flow of two types of heavy vehicles (trucks and recreational vehicles). Since these vertical alignment effects are primarily a function of grade, they are discussed in Section 2.8. Crest vertical curve effects are addressed in Section 2.9 of this report. There are no known quantifiable operational effects of sag vertical curve length; it is likely that such effects are minimal, as long as the ride comfort criteria in *Green Book* Equation 3-51 are met.

Traffic Safety Effects

Chapter 11 (Rural Multilane Highways) of the HSM does not include any factors to account for the effects of grade, crest vertical curve length, or sag vertical curve length on safety. Based on the reasoning presented in Section 2.7.1, sag vertical curve length in particular seems unlikely to have much influence on safety except where an overpass is located on a sag vertical curve.

2.7.3 Urban and Suburban Arterials

Design Criteria

The design criteria for crest and sag vertical curves, presented in Figures 6 and 7, respectively, are applicable to urban and suburban arterials.

Traffic Operational Effects

Chapter 17 (Urban Street Segments) of the HCM recommends that free-flow speeds for urban street segments be measured in the field or estimated based on the street's functional and design categories. No specific quantitative procedures are provided.

Traffic Safety Effects

Chapter 12 (Urban and Suburban Arterials) of the HSM does not include any factors to account for the effects of grade, crest vertical curve length, or sag vertical curve length on safety. Crest vertical curve effects are addressed in Section 2.9 of this report. There are no known quantifiable operational effects of sag vertical curve length; it is likely that such effects are minimal, as long as the ride comfort criteria in *Green Book* Equation 3-51 are met.

2.7.4 Freeways

Design Criteria

The design criteria for crest and sag vertical curve length, presented in Figures 6 and 7, respectively, are applicable to freeways.

Traffic Operational Effects

Chapter 11 (Basic Freeway Segments) of the HCM provides a methodology for adjusting the LOS boundaries on a freeway to account for vertical alignment considering general terrain classes or specific grades, as well as the percentages in the traffic flow of two types of heavy vehicles (trucks and recreational vehicles). Since these vertical alignment effects are primarily a function of grade, they are discussed in Section 2.8. Crest vertical curve effects are addressed in Section 2.9 of this report. There are no known quantifiable operational effects of sag vertical curve length; it is likely that such effects are minimal.

Traffic Safety Effects

The HSM safety prediction methodology for freeways developed in NCHRP Project 17-45 does not include any safety effects for grades, crest vertical curve length, or sag vertical curve length (*25*).

2.7.5 Mitigation Strategies

Most design exceptions for vertical alignment are related to grades and crest vertical curves. Appropriate mitigation strategies for grades and crest vertical curves are discussed in Sections 2.8 and 2.9, respectively. Sag vertical curve lengths that do not meet established criteria do not often need design exceptions (*7*). Mitigation of sag vertical curve lengths that do not meet established criteria is unlikely to be needed unless there is a specific crash pattern of rear-end crashes or an overpass is present on the sag vertical curve. If mitigation is needed, the provision of lighting is an obvious strategy.

2.8 Grade

Grade is the rate of change of vertical elevation along a roadway. The controlling criterion for grade includes both maximum and minimum grades. Maximum grades are established for specific roadway types and functional classes (see below). A design exception is needed where steeper grades are to be provided or retained.

Chapter 3 of the *Green Book* provides general guidance for selecting acceptable grades for roadways. Generally, a maximum grade of 5 percent is appropriate for a design speed of 70 mph, while maximum grades of 7 to 12 percent are appropriate for design speeds of 30 to 50 mph.

Green Book Exhibits 3-55 and 3-56 (not shown here) estimate running speeds of typical heavy trucks based on the percent grade and the length of the roadway section at that grade. These exhibits or the Truck Speed Performance Model (TSPM) developed by Harwood et al. (*33*) can be used to

Table 22. Maximum grade for rural arterials (*4, 5*).

Type of terrain	Maximum grade (%) for specified design speed								
	40 mph	45 mph	50 mph	55 mph	60 mph	65 mph	70 mph	75 mph	80 mph
Level	5	5	4	4	3	3	3	3	3
Rolling	6	6	5	5	4	4	4	4	4
Mountainous	8	7	7	6	6	5	5	5	5

SOURCE: Based on AASHTO *Green Book* Table 7-2.

establish critical lengths of grade that would produce a differential of 15 mph or more between the minimum speed of trucks and the average speed of traffic. Depending on traffic and truck volumes, locations with critical length of grade may warrant the addition of truck climbing lanes. However, the truck climbing lane criteria are not part of the controlling criterion for grade and do not require design exceptions. In fact, quite the opposite is true—the critical length of grade criteria merely suggest locations where truck climbing lanes might be considered.

2.8.1 Rural Two-Lane Highways

Design Criteria

Chapter 7 of the *Green Book* provides additional guidance for maximum grade selection for rural arterials, including rural two-lane highways. Table 22 shows the recommended maximum grades for rural arterials based on terrain type and design speed.

Traffic Operational Effects

Chapter 15 (Two-Lane Highways) of the HCM provides a methodology for adjusting demand flow rates for two-lane highways based on grade. Two adjustment factors in Chapter 15 (HCM) are affected by grade: the grade adjustment factor (f_g) and the heavy vehicle adjustment factor (f_{HV}). Separate adjustments are made in the computations for the two service measures for two-lane highways: average travel speed and percent time spent following.

Table 23. Grade adjustment factor (f_g) to determine speeds on two-way and directional segments for two-lane highways (*13*).

One-direction demand flow rate (veh/h)	Type of terrain	
	Level terrain and specific downgrades	Rolling terrain
≤ 100	1.00	0.67
200	1.00	0.75
300	1.00	0.83
400	1.00	0.90
500	1.00	0.95
600	1.00	0.97
700	1.00	0.98
800	1.00	0.99
≥ 900	1.00	1.00

SOURCE: Based on HCM Exhibit 15-9.

Average Travel Speeds. The grade adjustment factor, f_g, accounts for vehicles traveling more slowly on grades than they would on a level roadway. A smaller value of f_g will result in a higher demand flow rate. Table 23 presents values of f_g for various flow rates for level or rolling terrain. For segments with mountainous terrain, or on any segment with a grade steeper than 3 percent over a distance of 0.6 mi or more, the procedure for calculating f_g relies on more extensive criteria partially illustrated in Table 24.

Table 24. Grade adjustment factor for estimating travel speed on specific upgrades for two-lane highways (*13*).

Grade (%)	Grade length (mi)	Grade adjustment factor, f_g								
		Directional demand flow rate v_{vph} (veh/h)								
		≤ 100	200	300	400	500	600	700	800	≥ 900
≥ 3 < 3.5	0.25	0.78	0.84	0.87	0.91	1.00	1.00	1.00	1.00	1.00
	0.50	0.75	0.83	0.86	0.90	1.00	1.00	1.00	1.00	1.00
	0.75	0.73	0.81	0.85	0.89	1.00	1.00	1.00	1.00	1.00
	1.00	0.73	0.79	0.83	0.88	1.00	1.00	1.00	1.00	1.00
	1.50	0.73	0.79	0.83	0.87	0.99	0.99	1.00	1.00	1.00
	2.00	0.73	0.79	0.82	0.86	0.98	0.98	0.99	1.00	1.00
	3.00	0.73	0.78	0.82	0.85	0.95	0.96	0.96	0.97	0.98
	≥ 4.00	0.73	0.78	0.81	0.85	0.94	0.94	0.95	0.95	0.96

SOURCE: Based on HCM Exhibit 15-10.

Table 25. Passenger-car equivalents for trucks (E_T) and recreational vehicles (RVs) (E_R) to determine speeds on directional segments for two-lane highways (*13*).

Vehicle type	Directional demand flow rate, V_{vph} (veh/h)	Passenger-car equivalents for level terrain and specific downgrades	Passenger-car equivalents for rolling terrain
Trucks, E_T	≤ 100	1.9	2.7
	200	1.5	2.3
	300	1.4	2.1
	400	1.3	2.0
	500	1.2	1.8
	600	1.1	1.7
	700	1.1	1.6
	800	1.1	1.4
	≥900	1.0	1.3
RV_s, E_R	All flows	1.0	1.1

SOURCE: Based on HCM Exhibit 15-11.

The heavy vehicle adjustment factor, f_{HV}, accounts for heavy vehicles traveling more slowly on grades than passenger cars. A larger value of the passenger-car equivalence factors for heavy vehicles, E_T or E_R, results in a higher demand flow rate. Table 25 presents passenger-car equivalence factors for trucks (E_T) and recreational vehicles (E_R). For segments with mountainous terrain, or on any segment with a grade steeper than 3 percent over a distance of 0.6 mi or more, the procedures for calculating f_{HV} rely on the more extensive criteria in Tables 26 and 27.

The demand flow rate in the analysis direction of travel for use in the average travel speed determination is computed as:

$$v_d = \frac{V_d}{PHF \times f_g \times f_{HV}} \tag{34}$$

where

v_d = demand flow rate for analysis direction (pc/L)
PHF = peak hour factor

Table 26. Passenger-car equivalents for trucks for estimating travel speed on specific upgrades for two-lane highways (*13*).

Grade (%)	Grade length (mi)	Passenger-car equivalent for trucks, E_T — Directional demand flow rate v_{vph} (veh/h): ≤ 100	200	300	400	500	600	700	800	≥ 900
≥ 3 < 3.5	0.25	2.6	2.4	2.3	2.2	1.8	1.8	1.7	1.3	1.1
	0.50	3.7	3.4	3.3	3.2	2.7	2.6	2.6	2.3	2.0
	0.75	4.6	4.4	4.3	4.2	3.7	3.6	3.4	2.4	1.9
	1.00	5.2	5.0	4.9	4.9	4.4	4.2	4.1	3.0	1.6
	1.50	6.2	6.0	5.9	5.8	5.3	5.0	4.8	3.6	2.9
	2.00	7.3	6.9	6.7	6.5	5.7	5.5	5.3	4.1	3.5
	3.00	8.4	8.0	7.7	7.5	6.5	6.2	6.0	4.6	3.9
	≥ 4.00	9.4	8.8	8.6	8.3	7.2	6.9	6.6	4.8	3.7

SOURCE: Based on HCM Exhibit 15-12.

Table 27. Passenger-car equivalents for RVs for estimating travel speed on specific upgrades for two-lane highways (*13*).

Grade (%)	Grade length (mi)	Passenger-car equivalent for RV_s, E_R — Directional demand flow rate v_{vph} (veh/h): ≤ 100	200	300	400	500	600	700	800	≥ 900
≥ 3 < 3.5	≤ 0.25	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0
	> 0.25 ≤ 0.75	1.2	1.2	1.1	1.1	1.0	1.0	1.0	1.0	1.0
	> 0.75 ≤ 1.25	1.3	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.0
	> 1.25 ≤ 2.25	1.4	1.3	1.2	1.1	1.0	1.0	1.0	1.0	1.0
	> 2.25	1.5	1.4	1.3	1.2	1.0	1.0	1.0	1.0	1.0

SOURCE: Based on HCM Exhibit 15-13.

f_g = grade adjustment factor from Table 23 or 24

f_{HV} = heavy vehicle adjustment factor from HCM Equations 15-4 or 15-5, which utilize data from Tables 25 through 27

The demand flow rate in the opposing direction is determined in a manner entirely analogous to Equation 34. The service measure average travel speed, which is one of two measures used to determine LOS, is then determined with HCM Equation 15-6.

Percent Time Spent Following. The demand flow rates are determined slightly differently when used for percent time spent following rather than average travel speed as the service measure. Similar to the methodology for speed calculations, two adjustment factors are affected by grade: the grade adjustment factor (f_g), and the heavy vehicle adjustment factor (f_{HV}). Demand flow rate for the analysis and opposing directions is determined using Equation 34. However, for these calculations, Tables 28 through 31 are used instead of Tables 23 through 27 to determine the values of f_g and f_{HV}.

Table 28. Grade adjustment factor (f_g) to determine percent time spent following on directional segments for two-lane highways (*13*).

Directional demand flow rate (veh/h)	Level terrain and specific downgrades	Rolling terrain
≤ 100	1.00	0.73
200	1.00	0.80
300	1.00	0.85
400	1.00	0.90
500	1.00	0.96
600	1.00	0.97
700	1.00	0.99
800	1.00	1.00
≥900	1.00	1.00

SOURCE: Based on HCM Exhibit 15-16.

Traffic Safety Effects

Chapter 10 (Rural Two-Lane Highways) of the HSM presents the CMF for grade on two-lane highways as shown in Table 32. Table 32 presents the CMF by terrain categories.

Table 29. Grade adjustment factor (f_g) for estimating percent time spent following on specific upgrades for two-lane highways (*13*).

Grade (%)	Grade length (mi)	Grade adjustment factor, f_g								
		Directional demand flow rate v_{vph} (veh/h)								
		≤ 100	200	300	400	500	600	700	800	≥ 900
≥ 3 < 3.5	0.25	1.00	0.99	0.97	2.2	1.8	1.8	1.7	1.3	1.1
	0.50	1.00	0.99	0.98	3.2	2.7	2.6	2.6	2.3	2.0
	0.75	1.00	0.99	0.98	4.2	3.7	3.6	3.4	2.4	1.9
	1.00	1.00	0.99	0.98	4.9	4.4	4.2	4.1	3.0	1.6
	1.50	1.00	0.99	0.98	5.8	5.3	5.0	4.8	3.6	2.9
	2.00	1.00	0.99	0.98	6.5	5.7	5.5	5.3	4.1	3.5
	3.00	1.00	1.00	0.99	7.5	6.5	6.2	6.0	4.6	3.9
	≥ 4.00	1.00	1.00	1.00	8.3	7.2	6.9	6.6	4.8	3.7

SOURCE: Based on HCM Exhibit 15-17.

Table 30. Passenger-car equivalents for trucks (E_T) and RVs (E_R) for estimating percent time spent following on directional segments for two-lane highways (*13*).

Vehicle type	Directional demand flow rate (veh/h)	Passenger-car equivalents for level and specific downgrades	Passenger-car equivalents for rolling terrain
Trucks, E_T	≤ 100	1.1	1.9
	200	1.1	1.8
	300	1.1	1.7
	400	1.1	1.6
	500	1.0	1.4
	600	1.0	1.2
	700	1.0	1.0
	800	1.0	1.0
	≥ 900	1.0	1.0
RV_s, E_R	All	1.0	1.0

SOURCE: Based on HCM Exhibit 15-18.

Table 31. Passenger-car equivalents for trucks for estimating percent time spent following on specific upgrades for two-lane highways (*13*).

Grade (%)	Grade length (mi)	Passenger-car equivalent for trucks E_T — Directional demand flow rate v_{vph} (veh/h)								
		≤ 100	200	300	400	500	600	700	800	≥ 900
≥ 3 < 3.5	≤ 2.00	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	3.00	1.5	1.3	1.3	1.2	1.0	1.0	1.0	1.0	1.0
	≥ 4.00	1.6	1.4	1.3	1.3	1.0	1.0	1.0	1.0	1.0
≥ 3 < 4.5	≤ 1.00	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1.50	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	2.00	1.6	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	3.00	1.8	1.4	1.1	1.2	1.2	1.2	1.2	1.2	1.2
	≥ 4.00	2.1	1.9	1.8	1.7	1.4	1.4	1.4	1.4	1.4

SOURCE: Based on HCM Exhibit 15-19.

Table 32. CMF for grade of roadway segments (*12*).

Level grade (≤ 3%)	Moderate terrain (3% < grade ≤ 6%)	Steep terrain (> 6%)
1.00	1.10	1.16

SOURCE: Based on HSM Table 10-11.

The underlying research (*34, 35*) presents the CMF as a continuous function rather than a step function, as follows:

$$CMF = (1.0 + 0.016\,G) \tag{35}$$

where

G = absolute value of percent grade. In other words, the CMF increases by 0.016 for each percent grade.

2.8.2 Rural Multilane Highways

Design Criteria

The maximum grade criteria presented in Table 22 also apply to rural multilane highways.

Traffic Operational Effects

Chapter 14 (Multilane Highways) of the HCM presents a methodology for determining the effect of grades on operations of multilane highways. The procedure is similar to the procedure described above for two-lane highways. The multilane highway methodology is much simpler—the only factor that is used in determining the LOS boundaries is the f_{HV} factor.

The heavy vehicles adjustment factor, f_{HV}, adjusts the demand flow rate to account for the fact that heavy vehicles generally travel more slowly on grades than passenger cars. A larger value of E_T (or E_R) results in a higher demand flow rate. Table 33 presents passenger equivalence factors for trucks and buses (E_T) and RVs (E_R). For segments with a grade between 2 and 3 percent for more than 0.5 mi or with a grade steeper than 3 percent for more than 0.25 mi, the procedures for calculating E_T and E_R rely on the more extensive Tables 34, 35, and 36. The value of f_{HV} is determined with HCM Equation 14-4, the demand flow rate is determined with HCM Equation 14-3, and density, the service measure for multilane highways, is determined with HCM Equation 14-5.

Traffic Safety Effects

Chapter 11 of the HSM does not include a CMF for grade on rural multilane highways.

2.8.3 Urban and Suburban Arterials

Design Criteria

Table 37 presents recommended maximum grades for urban arterials. The *Green Book* states that when these cannot be attained, climbing lanes should be considered; in this

Table 33. Passenger-car equivalents for heavy vehicles in general terrain segments on multilane highways (*13*).

Passenger-car equivalent	Type of terrain		
	Level	Rolling	Mountainous
E_T (trucks and buses)	1.5	2.5	4.5
E_R (RVs)	1.2	2.0	4.0

SOURCE: Based on HCM Exhibit 14-12.

Table 34. Passenger-car equivalents for trucks and buses on upgrades on multilane highways (*13*).

Upgrade (%)	Length (mi)	E_T Percentage of trucks and buses 2%	4%	5%	6%	8%	10%	15%	20%	25%
≤ 2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
> 2 to 3	0.00 to 0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25 to 0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.50 to 0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.75 to 1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.00 to 1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0

SOURCE: Based on HCM Exhibit 14-13 (abridged).

Table 35. Passenger-car equivalents for RVs on upgrades on multilane highways (*13*).

Upgrade (%)	Length (mi)	E_R Percentage of RVs 2%	4%	5%	6%	8%	10%	15%	20%	25%
≤ 2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
> 2 to 3	0.00 to 0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
> 3 to 4	0.00 to 0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.25 to 0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5

SOURCE: Based on HCM Exhibit 14-14 (abridged).

Table 36. Passenger-car equivalents for trucks (E_T) on specific downgrades on rural and suburban multilane highways (*13*).

Percent downgrade	Length of grade (mi)	Proportion of trucks and buses 5%	10%	15%	20%
< 4	All	1.5	1.5	1.5	1.5
4 to 5	≤ 4	1.5	1.5	1.5	1.5
	> 4	2.0	2.0	2.0	1.5
> 5 to 6	≤ 4	1.5	1.5	1.5	1.5
	> 4	5.5	4.0	4.0	3.0
> 6	≤ 4	1.5	1.5	1.5	1.5
	> 4	7.5	6.0	5.5	4.5

SOURCE: Based on HCM Exhibit 14-15.

case, the use of a climbing lane would be considered a mitigation strategy and not part of the controlling criterion.

Traffic Operational Effects

According to Chapter 17 (Urban Street Segments) of the HCM, one of the first steps in determining the LOS for an urban street is determining the free-flow speed of traffic on the road segment. The steeper the upgrade of a roadway segment, the slower the free-flow speed will be. Chapter 17 (HCM) recommends that the free-flow speed be measured if possible; otherwise it must be estimated based on the street's functional and design categories. No methodology is provided for estimating the effect of grade on free-flow speed for an urban street.

Table 37. Maximum grades for urban arterials (*13*).

Type of terrain	Maximum grade (%) for specified design speed 30 mph	35 mph	40 mph	45 mph	50 mph	55 mph	60 mph
Level	8	7	7	6	6	5	5
Rolling	9	8	8	7	7	6	6
Mountainous	11	10	10	9	9	8	8

SOURCE: Based on *Green Book* Table 7-4.

Table 38. Maximum grades for rural and urban freeways (*4, 5*).

Type of terrain	Maximum grade (%) for specified design speed						
	50 mph	55 mph	60 mph	65 mph	70 mph	75 mph	80 mph
Level	4	4	3	3	3	3	3
Rolling	5	5	4	4	4	4	4
Mountainous	6	6	6	5	5	-	-

SOURCE: Based on *Green Book* Table 8-1.

Traffic Safety Effects

Chapter 12 (Urban and Suburban Arterials) of the HSM does not include a CMF for grade on urban and suburban arterials.

2.8.4 Freeways

Design Criteria

Chapter 8 of the *Green Book* provides the following specific guidance for urban freeways. Grades on urban freeways should generally be comparable to those in rural areas. Steeper grades can be tolerated in urban areas, but because interchanges may be closely spaced in urban areas, flatter grades are desirable when practical. Table 38 provides recommended maximum grades for rural and urban freeways.

Traffic Operational Effects

Chapter 11 (Basic Freeway Segments) of the HCM provides a methodology for determining the effect of grades on operations of freeways. The procedure is very similar to the procedure described above for multilane highways.

The heavy vehicles adjustment factor, f_{HV}, adjusts the demand volume to account for the tendency of heavy vehicles to travel more slowly on grades than passenger cars. Table 39 provides passenger-car equivalence factors for trucks and buses (E_T) and RVs (E_R). For any segment with a grade between 2 and 3 percent for more than 0.5 mi or with a grade steeper than 3 percent for more than 0.25 mi, the procedures for calculating E_T and E_R rely on the more extensive Tables 40, 41, and 42. A larger value of E_T or E_R results in a larger demand flow rate. The value of f_{HV} is determined with HCM Equation 11-3, the demand flow rate is determined with HCM Equation 11-2, and the service measure for multilane highways is determined with HCM Equation 11-4.

Traffic Safety Effects

The HSM safety prediction methodology for freeways developed in NCHRP Project 17-45 does not include any safety effects for grades on freeways (*25*).

2.8.5 Mitigation Strategies

The strategies for mitigating steep grades include the following (*7*):

- Providing drivers with advance warning signs for steep grades
- Providing climbing lanes and downgrade lanes
- Providing emergency escape ramps for trucks

Table 39. Passenger-car equivalents on extended freeway segments (*13*).

Passenger-car equivalent	Type of terrain		
	Level	Rolling	Mountainous
E_T (trucks and buses)	1.5	2.5	4.5
E_R (RVs)	1.2	2.0	4.0

SOURCE: Based on HCM Exhibit 11-10.

Table 40. Passenger-car equivalents for trucks and buses on upgrades for specific grades on freeways (*13*).

Upgrade (%)	Length (mi)	E_T Percentage of trucks and buses								
		2%	4%	5%	6%	8%	10%	15%	20%	25%
< 2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
≥ 2 to 3	0.00 to 0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25 to 0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.50 to 0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.75 to 1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5

SOURCE: Based on HCM Exhibit 11-11 (abridged).

Table 41. Passenger-car equivalents for RVs on upgrades for specific grade segments on freeways (*13*).

Upgrade (%)	Length (mi)	E_R								
		Percentage of RVs								
		2%	4%	5%	6%	8%	10%	15%	20%	25%
≤ 2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
> 2 to 3	0.00 to 0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
> 3 to 4	0.00 to 0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.25 to 0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5

SOURCE: Based on HCM Exhibit 11-12 (abridged).

Table 42. Passenger-car equivalents for trucks and buses on downgrades on specific grade segments on freeways (*13*).

Downgrade (%)	Length (mi)	E_T			
		Percentage of trucks			
		5%	10%	15%	20%
< 4	All	1.5	1.5	1.5	1.5
4 to 5	≤ 4	1.5	1.5	1.5	1.5
4 to 5	> 4	2.0	2.0	2.0	1.5
> 5 to 6	≤ 4	1.5	1.5	1.5	1.5

SOURCE: Based on HCM Exhibit 11-13 (abridged).

- Reducing the frequency or severity of lane-departure crashes (enhanced pavement markings; delineation; shoulder, painted edgeline, or centerline rumble strips; paved or partially paved shoulders; safety edge treatment; clear recovery area; traversable slopes; breakaway safety hardware; and barrier where appropriate).

The strategies for mitigating flat grades include the following (*7*):

- Adjusting the gutter profile
- Providing special drainage systems

2.9 Stopping Sight Distance

Stopping sight distance is the distance required for a driver to perceive or recognize a need to stop, react to that perception, and then decelerate to a stop. Horizontal and vertical curves limit available sight distance for drivers, requiring a careful analysis of stopping sight distance during the design process. Sight distance needs are based on the design speed of the roadway and the grade of the roadway, since cars traveling downhill require a greater distance to stop than cars traveling uphill or on the level. The minimum stopping sight distance is calculated using equations provided in the *Green Book* based on design speed and grade and assumed values of perception-reaction time and deceleration rate. Table 43 provides minimum stopping sight distances for various roadway design speeds and grades. The stopping sight distance criteria shown in Table 43 apply to all roadway types, including ramps and turning roadways. A design exception is required where stopping sight distances less than those shown in Table 43 are provided or retained.

Stopping sight distance generally provides drivers with enough distance to make a hurried stop, but these distances may not be adequate for a driver to interpret complex information or make a complex decision. In some cases, a maneuver other than a quick stop would be preferable, but would require more time for the driver to make that decision. For these reasons, the *Green Book* also provides decision sight distance guidelines for several different avoidance maneuver conditions that each assumes a different perception and reaction time. The decision sight distance criteria are presented in *Green Book* Table 3-3 (not shown here). Decision sight distance is not part

Table 43. Design criteria for stopping sight distance (*4, 5*).

Design speed (mph)	Stopping sight distance (ft)						
	Level	Downgrade			Upgrade		
	0%	3%	6%	9%	3%	6%	9%
15	80	80	82	85	75	74	73
20	115	116	120	126	109	107	104
25	155	158	165	173	147	143	140
30	200	205	215	227	200	184	179
35	250	257	271	287	237	229	222
40	305	315	333	354	289	278	269
45	360	378	400	427	344	331	320
50	425	446	474	507	405	388	375
55	495	520	553	593	469	450	433
60	570	598	638	686	538	515	495
65	645	682	728	785	612	584	561
70	730	771	825	891	690	658	631
75	820	866	927	1003	772	736	704
80	910	965	1035	1121	859	817	782

SOURCE: Based on AASHTO *Green Book* Tables 3-1 and 3-2.

of the controlling criteria; no design exceptions are required for decision sight distances less than the *Green Book* criteria.

The HCM does not include any effect of stopping sight distance on LOS for any roadway type. *Green Book* criteria for stopping sight distance assume that vehicles on a crest vertical curve, or in a region of restricted horizontal sight distance, are traveling at the design speed. There does not appear to be any basis on which to presume that limited stopping sight distance, especially marginal limitations, affects vehicle speeds or other traffic operational performance measures.

Research by Fambro et al. (*36*) found very few collisions on highways with objects smaller than another vehicle, even in areas of limited stopping sight distance. This led to the change in stopping sight distance from a 6-in. object to a 2-ft object (equivalent to the height of vehicle taillights) that was made in the 2001 edition of the *Green Book* (*3*). Thus, available research suggests that at most places on the highway with limited stopping sight distance there is unlikely to be anything in the roadway that a driver might strike. Safety is unlikely to be affected by limited stopping sight distance in such cases. However, when the limited sight distance restricts the driver's view of a location where other vehicles may be slowing or stopping (e.g., intersections, driveways, horizontal curves, entrance or exit ramps, or locations with daily congestion), improving limited sight distance may be very important to safety.

Neither the HSM nor the FHWA CMF Clearinghouse includes any CMFs indicating an effect of stopping sight distance on safety. Research conducted under NCHRP Project 17-53 (see Section 4.7) investigated the relationship between stopping sight distance and crash frequency. The research team compared the crash frequencies for crest vertical curves on rural two-lane highways with stopping sight distance less than AASHTO stopping sight distance criteria to crest vertical curves with stopping sight distance equal to or more than AASHTO stopping sight distance criteria. A statistical analysis found no differences in crash frequency (either for total crashes or fatal-and-injury crashes) between the crest vertical curves with differing stopping sight distance values, but there was a statistically significant difference in crash frequency (for both total crashes and fatal-and-injury crashes) between sites with and without horizontal curves, intersections, or driveways hidden by the presence of the crest vertical curve. The observed effect on crash frequency of the presence of a hidden horizontal curve, intersection, or driveway was 0.36 crashes per mi per year for total crashes and 0.48 crashes per mi per year for fatal-and-injury crashes.

Mitigation strategies for limited stopping sight distance include the following (*7*):

- Signing for crest vertical curves
- Lighting for intersections, sag vertical curves, or merge/diverge areas
- Lower height barriers to reduce sight distance limitations due to presence of the barrier
- Adjustment of lane placement within the roadway cross section on horizontal curves
- Selection of cross-sectional elements to manage speed
- Wider shoulders and wider clear zones
- Static or dynamic warning of intersections or entering traffic
- Repositioning, adding, or enhancing intersection signs

2.10 Cross Slope

The controlling criterion for cross slope addresses the traverse slope of the pavement surface on tangent sections or on horizontal curves where superelevation is not used. Superelevation on horizontal curves is addressed in Section 2.11.

The cross-slope design criterion is important because cross slope facilitates runoff of water from rain, snow, or ice from the pavement surface. In general, the steeper the cross slope, the more efficiently water flows to the edge of the lanes and off the roadway. Flat cross slopes can lead to water ponding on the lanes, especially where a curb is used. At the same time, a steep cross slope can affect steering and can make vehicles more susceptible to cross winds; drivers may tend toward the lower edge of the traveled way, and lateral skidding can become more likely when braking on wet or icy pavement. On roadways with a center crown, vehicles making passing maneuvers experience double the change in cross slope as they move over the crown, reversing the direction of lateral acceleration, and potentially causing trucks to sway from side to side. For these reasons, a balance must be struck between a steeper cross slope that efficiently moves water to the edge of the roadway and a shallow cross slope that is imperceptible to drivers during lane changes. The *Green Book* recommends a normal cross slope of 1.5 to 2 percent, although when two or more lanes are inclined in the same direction, each successive lane may be given a greater cross slope by 0.5 to 1.0 percent, not to exceed 4 percent in the outermost lanes. In areas of intense rainfall, a slope of 2.5 percent may be used. The National Transportation Safety Board (NTSB) has asked FHWA and AASHTO to investigate the appropriateness of design criteria for cross-slope breaks at the outside edge of the traveled way on horizontal curves for current passenger cars and trucks, especially trucks with high centers of gravity (*37*). The research underlying the current 8-percent design criterion for cross-slope breaks was completed in 1982 using an older vehicle dynamics simulation model (HVOSM) that simulated cross-slope break traversals by a 1971 Dodge Coronet passenger car (*38*). Research for a current passenger car and larger trucks, including trucks with high centers of gravity, would clearly be desirable.

Neither the HCM nor the HSM shows any qualitative effect of cross-slope or cross-slope breaks on traffic operations or safety. There are also no safety effects found in the FHWA CMF Clearinghouse.

The primary concern for locations with insufficient cross slope is inadequate drainage and ponding of water on the travel lanes. Mitigation strategies for inadequate cross slope include the following (*7*):

- SLIPPERY WHEN WET signing
- Grooved, textured, or open-graded pavements to improve surface friction
- Slope inside lanes toward the median and outside lanes toward the outside of the roadway (on multilane divided facilities)

Mitigation strategies for large pavement/shoulder cross slope breaks include the following:

- Adjustment of the high-side shoulder cross slope, including sloping the shoulder toward the traveled way
- Rounding of the cross-slope break (feasible for hot-mix asphalt pavements)

2.11 Superelevation

The *Green Book* provides equations and tables for determining the appropriate superelevation rate for specific horizontal curves based on the design speed, curve radius, and assumed maximum values of superelevation rate and friction demand. Maximum superelevation rates (e_{max}) are selected by highway agency policies; *Green Book* Chapter 3 permits highway agencies to choose e_{max} in the range of 4 to 12 percent. Where snow and ice are factors, the *Green Book* recommends that superelevation should not exceed 8 percent. For lower speed urban arterials, the *Green Book* recommends that little or no superelevation be used. *Green Book* Chapter 8 recommends that superelevation should not exceed 6 percent on freeways with viaducts where snow and ice are factors.

Neither the HCM nor any other available source indicates that superelevation has a quantifiable effect on traffic operations. It seems unlikely that minor variations in superelevation from the AASHTO design values would have much effect on traffic operations.

HSM Chapter 10 (Rural Two-Lane Highways) presents a CMF for superelevation on rural two-lane highways that is shown in the following equations:

$$CMF = 1.00 \text{ for } SV < 0.01 \quad (36)$$

$$CMF = 1.00 + 6 \times (SV - 0.01) \text{ for } 0.01 \le SV < 0.02 \quad (37)$$

$$CMF = 1.06 + 3 \times (SV - 0.02) \text{ for } SV \ge 0.02 \quad (38)$$

where

CMF = crash modification factor for the effect of superelevation variance on total crashes
SV = superelevation variance (ft/ft), which represents the superelevation rate contained in the *Green Book* minus the actual superelevation of the curve

The CMF applies to total roadway segment crashes for roadway segments located on horizontal curves. No CMFs are available and no trends are known for the safety effects of superelevation on roadway types other than rural two-lane highways.

The mitigation strategies for superelevation lower than *Green Book* criteria are the same as those described for horizontal alignment in Section 2.6.5 of this report.

2.12 Vertical Clearance

In general, vertical clearance does not affect operations on the roadway other than for those vehicles that are taller than the available vertical clearance allows for. When overpasses or other structures do not allow for taller vehicles to pass underneath, these vehicles use an alternate route, potentially increasing travel time. Guidance for vertical clearance is provided in the *Green Book* as follows:

- For rural arterials, the recommended minimum vertical clearance is 16 ft
- The preferred vertical clearance on urban arterials is 16 ft; however, when existing structures offer at least 14 ft of clearance, these structures may be retained as long as an alternate route with 16 ft of clearance is provided
- The recommended minimum vertical clearance on freeways is 16 ft; however, in highly developed areas, where replacement of structures would be costly, a minimum clearance of 14 ft is permitted, provided an alternate route with 16 ft of clearance is available. Sign trusses and pedestrian overpasses should be built with a minimum clearance of 17 ft.

There are no operational or safety effects of insufficient vertical clearance except for increased travel times for vehicles taller than the available vertical clearance.

Vertical clearance guidelines do not directly impact safety for the majority of vehicles, although in cases where the recommended vertical clearance is not provided, advanced warning and alternate route designation become important mitigation strategies for avoiding possible crashes involving tall vehicles. Vertical clearance crashes can have severe impacts on operations by damaging overpasses or other structures that result in extended road closures.

Special attention is given to vertical clearance on Interstate freeways to maintain the integrity of the system for national defense purposes. On rural Interstate freeways, vertical clearance at structures of at least 16 ft is maintained. In urban areas, 16 ft of clearance is maintained for at least one Interstate routing through the urban area, with other urban Interstate routes having vertical clearance of at least 14 ft. The 16-ft vertical clearance for Interstate freeways in rural areas and for the single routing in urban areas applies to the entire roadway width, including the usable shoulder width and the ramps and collector-distributor roadways at Interstate-to-Interstate interchanges.

2.13 Horizontal Clearance/ Lateral Offset

The controlling criterion known in current FHWA policy as horizontal clearance has been renamed lateral offset in the 2011 edition of the *Green Book* (*5*) to avoid confusion about the definition of this criterion. Lateral offset deals with the distance from the edge of the traveled way, face of curb, shoulder, or other designated point to a vertical roadside element or obstruction (*7*). Lateral offset can be thought of as an operational offset; vertical roadside elements are offset (1) so that they do not affect a driver's speed or lane position and (2) so that adequate clearance to vertical roadside elements is provided for overhangs or mirrors of trucks and buses and for opening curbside doors where on-street parking is provided.

Lateral offset as a controlling criterion is primarily of interest for roads with curb-and-gutter sections, such as urban and suburban arterials. For roads without curbs, the minimum shoulder widths generally take care of providing a minimum lateral offset from the traveled way.

Design criteria in the 2004 *Green Book* (*4*) specify a minimum lateral offset of 1.5 ft to address operational concerns for all roadway conditions and classifications. The 2011 *Green Book* (*5*) does not state an explicit lateral offset, but makes reference to the AASHTO *Roadside Design Guide* (RDG) (*39*). The 2006 edition of the RDG (*39*), as well as previous editions, incorporated the same 1.5-ft lateral offset as the 2004 *Green Book* (*4*). The 2011 edition of the RDG (*40*) encourages wider lateral offsets, particularly on urban and suburban arterials (see Section 2.13.3 below).

A design exception is required when the specified minimum lateral offset is not provided. It is important to note that the controlling criterion for lateral offset does not include the provision of clear recovery zones. Lateral offset is an operational criterion and, as explicitly stated by FHWA policy, does not address clear-zone width (*2*).

2.13.1 Rural Two-Lane Highways

Design Criteria

Relatively few rural two-lane highways have curb-and-gutter sections, so the minimum shoulder-width criteria generally provide the minimum lateral offset needed for operational reasons.

Traffic Operational Effects

Chapter 15 (Two-Lane Highways) of the HCM provides guidance for estimating the free-flow speed for two-lane highways. Although the LOS boundaries are not directly adjusted for lateral clearance, Table 5 provides an adjustment to free-flow speed based on lane and shoulder widths. As shown in Table 5, a 6-ft shoulder on a rural two-lane highway provides sufficient lateral clearance that there is no effect on vehicle speeds.

Traffic Safety Effects

Chapter 10 (Rural Two-Lane Highways) of the HSM does not contain any CMF for lateral offset. However, the CMF for shoulder width on two-lane highway segments presented in Table 13 and Figure 4 implicitly reflects, at least in part, the safety effects of lateral offset.

2.13.2 Rural Multilane Highways

Design Criteria

Relatively few rural multilane highways have curb-and-gutter sections, so the minimum shoulder-width criteria generally provide the minimum lateral offset needed for operational reasons.

Traffic Operational Effects

Chapter 14 (Multilane Highways) of the HCM provides guidance for estimating free-flow speed for multilane highways. Although the LOS boundaries are not directly adjusted for lateral clearance, Table 16 provides an adjustment to free-flow speed based on the sum of the lateral clearance on the left side of the roadway (maximum of 6 ft) and the right side of the roadway (maximum 6 ft).

Traffic Safety Effects

Chapter 11 (Rural Multilane Highways) of the HSM does not contain any CMF for lateral offset. However, the CMF for shoulder width in Table 13 and Figure 4 for undivided roadways and in Table 17 for divided roadways implicitly reflects, at least in part, the safety effects of lateral offset.

2.13.3 Urban and Suburban Arterials

Design Criteria

The design criterion for lateral offset on urban and suburban arterials in the 2006 RDG (*39*), and previous editions, is 1.5 ft. The 2011 RDG (*40*), which is referred to explicitly in Chapter 7 (Arterials) of the 2011 *Green Book* (*5*), states that a lateral offset of 3 ft from the face of the curb to obstructions should be provided at intersections and driveway openings, while a minimum lateral offset of 1.5 ft should be used elsewhere. However, the new RDG also presents a targeted design approach for high-risk urban roadside corridors:

- For locations with vertical curbs, provide a 6-ft offset from the face of curb to obstacles on the outside of curves, because obstacles on the outside of curves are hit more often, and provide a 4-ft offset elsewhere
- For locations without a vertical curb, 12-ft offsets to obstacles on the outside of curves and 8-ft offsets on tangent sections are recommended as reasonable goals where the clear-zone widths in RDG Chapter 3 cannot be achieved.

Traffic Operational Effects

Chapter 17 (Urban Street Segments) of the HCM includes a procedure for estimating free-flow speeds, but neither lateral offset nor shoulder width is considered as part of that procedure.

Traffic Safety Effects

Chapter 12 (Urban and Suburban Arterials) of the HSM does not include a CMF for either lateral offset or shoulder width. There is currently no quantifiable safety effect for these design elements.

2.13.4 Freeways

Design Criteria

Lateral offset is not generally relevant on freeways because minimum shoulder widths should always provide the minimum lateral offset from the traveled way.

Traffic Operational Effects

Chapter 11 (Basic Freeway Segments) of the HCM includes criteria for estimating the effect of shoulder width on free-flow speed (see Table 19).

Traffic Safety Effects

There are no CMFs for lateral offset on freeways, as freeway shoulders are usually wide enough to provide the minimum lateral offset. The results of NCHRP Project 17-45 include a CMF for right (outside) clearance (*25*). This is essentially a CMF for clear-zone width on freeways, which incorporates an adjustment for right (outside) shoulder width. The NCHRP Project 17-45 methodology also includes CMFs for right (outside) roadside barriers on freeways. Neither of these CMFs appears applicable to lateral offset on freeways because the shoulder-width CMFs from NCHRP Project 17-45, presented in Equations 8 through 11, should account for the effect of lateral offset on safety.

2.13.5 Mitigation Strategies

The primary mitigation strategy for lateral obstructions within the minimum lateral offset that cannot practically be removed is to delineate such obstacles with reflectors or reflective sheeting so that they become more visible, particularly at night (*7*).

2.14 Summary of Traffic Operational Effects

Table 44 summarizes which traffic operational effects for the 13 controlling criteria have been quantified and where in this report the information concerning each of those known effects can be found.

2.15 Summary of Traffic Safety Effects

Table 45 summarizes which traffic safety effects for the 13 controlling criteria have been quantified and where in this report the information covering each of those known effects can be found.

Table 44. Summary of traffic operational effects of the 13 controlling criteria for design.

Design criterion	Roadway type	Traffic operational effects
Design speed	All	No direct effects.[a]
Lane width	Rural two-lane highways	See Table 5 (based on HCM Exhibit 15-7) and Equation 1.
	Rural multilane highways	See Table 7 (based on HCM Exhibit 14-8) and Equation 3.
	Urban and suburban arterials	No quantified effects.
	Freeways	See Table 10 (based on HCM Exhibit 11-8) and Equation 4.
Shoulder width	Rural two-lane highways	See Table 5 (based on HCM Exhibit 15-7) and Equation 1.
	Rural multilane highways	See Table 16 (based on HCM Exhibit 14-9) and Equation 3.
	Urban and suburban arterials	No quantified effects.
	Freeways	See Table 19 (based on HCM Exhibit 11-9) and Equation 4.
Bridge width	Rural two-lane highways	Bridge roadway widths less than the approach roadway width do not appear to increase crash frequency or severity.
	Rural multilane highways	No quantified effects directly applicable to bridge width; related effects for lane and shoulder width are known (see Sections 2.2.2 and 2.3.2).
	Urban and suburban arterials	No quantified effects.
	Freeways	No quantified effects directly applicable to bridge width; related effects for lane and shoulder width are known (see Sections 2.2.4 and 2.3.4).
Structural capacity	All	No relationship to traffic operations; controlling criterion is based on risk of structural failure.
Horizontal alignment	Rural two-lane highways	See Table 21.
	Rural multilane highways	See Equation 18.
	Urban and suburban arterials	See Equation 21.
	Freeways	No quantified effects.
Vertical alignment (sag vertical curves)	Rural two-lane highways	No quantified effects.
	Rural multilane highways	No quantified effects.
	Urban and suburban arterials	No quantified effects.
	Freeways	No quantified effects.
Grade	Rural two-lane highways	See Tables 23 through 31 (based on HCM Exhibits 15-9, 15-10, 15-11, 15-12, 15-13, 15-16, 15-17, 15-18, 15-19) and Equation 34.
	Rural multilane highways	See Tables 33 through 36 (based on HCM Exhibits 14-12, 14-13, 14-14, 14-15) and HCM Equation 14-4.
	Urban and suburban arterials	No quantified effects.
	Freeways	See Tables 39 through 42 (based on HCM Exhibits 11-10, 11-11, 11-12, 11-13) and HCM Equations 11-2, 11-3, and 11-4.
Stopping sight distance	All	No quantified effects.
Cross slope	All	No quantified effects.
Superelevation	All	No quantified effects.
Vertical clearance	All	No quantified effects.
Horizontal clearance/lateral offset	Rural two-lane highways	Effect discussed in shoulder-width section (see Section 2.3.1).
	Rural multilane highways	Effect discussed in shoulder-width section (see Section 2.3.2).
	Urban and suburban arterials	No quantified effects.
	Freeways	Effect discussed in shoulder-width section (see Section 2.3.4)

[a] For indirect effects, see lane width, horizontal alignment, vertical alignment, and stopping sight distance.

Table 45. Summary of traffic safety effects for the 13 controlling criteria for design.

Design criterion	Roadway type	Traffic safety effects
Design speed	All roadway types	No direct effects.[a]
Lane width	Rural two-lane highways	See Equation 2 and Table 6 (based on HSM Equation10-11 and Table 10-8).
	Rural multilane highways	For undivided sections, see Equation 2 and Table 8 (based on HSM Equation 11-13 and Table 11-11); for divided sections, see Equation 2 and Table 9 (based on HSM Equation 11-16 and Table 11-16).
	Urban and suburban arterials	Lane width does not appear to affect crash frequency or severity. Lanes narrower than 12 ft may not be desirable on streets where substantial volumes of bicycles, trucks, or buses are present.
	Rural freeways	See Equations 5 and 6.
Shoulder width	Rural two-lane highways	See Equation 7 and Tables 13 and 14 (based on HSM Equation10-12 and Table 10-9 and 10-10).
	Rural multilane highways	For undivided sections, see Equation 7 and Tables 13 and 14 (based on HSM Equation10-12 and Table 10-9 and 10-10); for divided sections, see Table 17 (based on HSM Table 11-17).
	Urban and suburban arterials	No quantified effects.
	Freeways	See Equations 8 through 13.
Bridge width	Rural two-lane highways	No quantified effects directly applicable to bridge width; related effects for lane and shoulder width are known (see Sections 2.2.1 and 2.3.1).
	Rural multilane highways	No quantified effects directly applicable to bridge width; related effects for lane and shoulder width are known (see Sections 2.2.2 and 2.3.2).
	Urban and suburban arterials	No quantified effects.
	Freeways	No quantified effects directly applicable to bridge width; related effects for lane and shoulder width are known (see Sections 2.2.4 and 2.3.4).
Structural capacity	All roadway types	No relationship to traffic safety; controlling criterion is based on risk of structural failure.
Horizontal alignment	Rural two-lane highways	See Equation 15 (based on HSM Equation 10-13); potential updated effects are presented in Equations 16 and 17.
	Rural multilane highways	See Equations19 and 20.
	Urban and suburban arterials	No quantified effects.
	Freeways	See Equations 22 through 25.
Vertical alignment (sag vertical curves)	Rural two-lane highways	See Equations 30 through 33.
	Rural multilane highways	No quantified effects.
	Urban and suburban arterials	No quantified effects.
	Freeways	No quantified effects.
Grade	Rural two-lane highways	See Table 32 (based on HSM Table 10-11) and Equation 35; potential updated effects are presented in Equations 16 and 17.
	Rural multilane highways	No quantified effects.
	Urban and suburban arterials	No quantified effects.
	Freeways	No quantified effects.
Stopping sight distance	Rural two-lane highways	No effect on safety unless a hidden horizontal curve, intersection, or driveway is present.
	Rural multiline highways	No quantified effects.
	Urban and suburban arterials	No quantified effects.
	Freeways	No quantified effects.
Cross slope	All roadway types	No quantified effects.
Superelevation	Rural two-lane highways	See Equations 36 through 38 (based on HSM Equations 10-14 through 10-16).
	Rural multilane highways	No quantified effects.
	Urban and suburban arterials	No quantified effects.
	Freeways	No quantified effects.
Vertical clearance	All roadway types	No quantified effects.
Horizontal clearance	Rural two-lane highways	Only known effects are based on shoulder width (See Section 2.3.1).
	Rural multilane highways	Only known effects are based on shoulder width (See Section 2.3.2).
	Urban and suburban arterials	No quantified effects.
	Freeways	Only known effects are based on shoulder width (See Section 2.3.4).

[a] For indirect effects, see lane width, horizontal alignment, vertical alignment, and stopping sight distance.

SECTION 8

Conclusions and Recommendations

This section presents the conclusions and recommendations of the research.

8.1 Conclusions

The conclusions of the research are presented below.

For rural two-lane highways:

- Quantitative relationships between traffic speed and roadway geometric design criteria have been established in the HCM (*13*) or previous research for lane width, shoulder width, horizontal curve radius, and grade. These relationships are documented in Section 2 of this report. The effects on traffic speed of other roadway geometric design criteria are understood in a qualitative sense.
- Quantitative relationships between crash frequency or severity and roadway geometric design criteria have been established in the HSM (*12*) or previous research for lane width, shoulder width, horizontal curve radius, superelevation, and grade. These relationships are documented in Section 2 of this report. The effects on crash frequency of other roadway geometric design criteria are understood in a qualitative sense.
- Analysis of traffic crash data for bridges on two-lane rural highways as part of this research found no evidence of increased crash frequencies or severities for bridges with roadway widths (lane width plus shoulder width) narrower than the roadway width on the approach roadway.
- Analysis of crash data as part of this research found no increase of crash frequencies by crash severity level on crest vertical curves as a function of stopping sight distance for a range of stopping sight distance levels above and below the AASHTO stopping sight distance criteria. Crash frequencies increased on a crest vertical curve only when a horizontal curve, intersection, or driveway hidden from the view of approaching drivers by the crest vertical curve was present.

For rural multilane highways:

- Quantitative relationships between traffic speed and roadway geometric design criteria have been established in the HCM (*13*) or previous research for lane width, shoulder width, and grade. These relationships are documented in Section 2 of this report. The effects on traffic speed of other roadway geometric design criteria are understood in a qualitative sense.
- Quantitative relationships between crash frequency or severity and roadway geometric design criteria have been established in the HSM (*12*) or previous research for lane width and shoulder width. These relationships are documented in Section 2 of this report. The effects on crash frequency of other roadway geometric design criteria are understood in a qualitative sense.
- Analysis of traffic speed data collected upstream of and within horizontal curves on rural multilane highways as part of this research developed a model to predict the reduction in traffic speed on horizontal curves, in comparison to the traffic speed upstream of the curve, as a function of curve radius.
- Analysis of crash data as part of this research developed models to predict the crash frequency by crash severity level on horizontal curves as a function of curve length and radius.

For freeways:

- Quantitative relationships between traffic speed and roadway geometric design criteria have been established in the HCM (*13*) or previous research for lane width, shoulder width, and grade. These relationships are documented in Section 2 of this report. The effects on traffic speed of other roadway geometric design criteria are understood in a qualitative sense.

- Quantitative relationships between crash frequency or severity and roadway geometric design criteria have been established in the HSM (*12*) or previous research for lane width, shoulder width, and horizontal curve radius. These relationships are documented in Section 2 of this report. The effects on crash frequency of other roadway geometric design criteria are understood in a qualitative sense.

For urban and suburban arterials:

- There are no quantitative relationships between traffic speed, crash frequency, or crash severity and roadway geometric design criteria that have been established for urban and suburban arterials in the HCM (*13*) or the HSM (*12*). Previous research by Potts et al. (*23*, *24*) found, with limited exceptions, no statistically significant effect of lane width on crash frequency for urban and suburban arterials in the range of lane widths from 10 to 12 ft. Some effects of roadway geometric design criteria for urban and suburban arterials are understood in a qualitative sense, but, in general, roadway geometric design features appear to be less important in the traffic operational and safety performance of urban and suburban arterials than intersection features and access management strategies.
- Analysis of traffic speed data collected upstream and downstream of lane-width transitions on urban and suburban arterials as part of this research found no statistically significant effect of lane width on traffic speed.
- Analysis of traffic speed data collected upstream of and within horizontal curves on urban and suburban arterials as part of this research developed a model to predict the reduction in traffic speed on horizontal curves, in comparison to the traffic speed upstream of the curve, as a function of curve radius.

Priorities for the 13 controlling criteria by roadway type, based on traffic operational and safety effects of roadway geometric design criteria, are presented in Table 82.

8.2 Recommendations

The recommendations developed in the research are presented below. Ultimately, retaining, modifying, or dropping any of the 13 controlling criteria is a policy decision, and the portion of that decision that involves federal policy is beyond the scope of this research. However, recommendations concerning modification of the controlling criteria for application to non-federal projects are within the scope of this research. All recommendations given below concerning modification of the 13 controlling criteria should be read as referring to projects to which the controlling criteria are applied based on state policy, rather than federal policy. Recommendations presented here for changes in the controlling criteria represent simply potential changes in an administrative process that determines when a particular form of design review is needed. Except where explicitly stated, no changes to the design criteria presented in the *Green Book* or highway agency design manuals are contemplated. The primary focus of these recommendations is on design practice for reconstruction of existing roads; new construction projects appear much less likely than reconstruction projects to require design exceptions under both current and potential future procedures.

The recommendations are the following:

1. If all of the current controlling criteria are retained, it is recommended that they be renamed to minimize any potential confusion over which design features are, or are not, included as part of the controlling criteria. The recommended names for the current controlling criteria are the following:
   - Design speed
   - Lane width
   - Shoulder width
   - Bridge width
   - Structural capacity
   - Horizontal curve radius
   - Superelevation
   - Grade
   - Stopping sight distance
   - Sag vertical curve length
   - Cross slope
   - Vertical clearance
   - Lateral offset

   If these recommended names are used, the accompanying documentation should make clear that the stopping sight distance criterion includes stopping sight distance as limited by any roadway or roadside feature including crest vertical curves, sight obstructions on the inside of horizontal curves, and overpass structures. Thus, the controlling criterion for stopping sight distance directly influences the minimum crest vertical curve length for any given algebraic difference in grade and the offset to roadside sight obstructions for any curve radius on horizontal curves.
2. No need to add any new controlling criteria to the current 13 controlling criteria has been identified.
3. For rural two-lane highways, rural multilane highways, and rural and urban freeways, it is recommended that the following design criteria should be retained as controlling criteria and that design exceptions should be required: shoulder width, lane width (for lane widths less than 11 ft), horizontal curve radius, superelevation, grade, stopping sight distance (for locations where a hidden curve,

intersection, ramp, or driveway is present), and cross slope. The rationale for retention of these controlling criteria is presented in Section 7 of this report. There does not appear to be any need, based on their traffic operational and safety effects, for the following design criteria to be retained as controlling criteria: bridge width, sag vertical curve length, and horizontal clearance/lateral offset. This does not imply that bridge width, sag vertical curve length, and horizontal clearance/lateral offset are not important or that they do not need to be addressed in the *Green Book*, in highway agency design manuals, and during the design process. Rather, it means that the traffic operational and safety effects of these design criteria do not appear to rise to the level that requires an administrative control involving management review like the design exception process.

4. For rural two-lane highways, the *Green Book* and highway agency design policies for reconstruction projects should permit existing locations with limited stopping sight distance to remain in place unless there is a specific crash pattern present that indicates a need for such an improvement, or there is an approaching curve, intersection, or driveway that is hidden from the driver's view by the stopping sight distance limitation. This same guidance is likely applicable to rural multilane highways and to rural and urban freeways, but stopping sight distance limitations on these roadway types were not specifically investigated in the research.
5. For rural two-lane highways, the *Green Book* and highway agency design policies for reconstruction projects should permit existing bridges with roadway widths (lane width plus shoulder width) less than the approach width to remain in place if the bridge is in good structural condition (i.e., does not require replacement for structural reasons), and has no accompanying pattern of crashes (e.g., fixed-object, sideswipe, or head-on collisions) indicating a concern related to bridge width. This guidance is not applicable to one-lane bridges. This guidance is likely applicable to rural multilane highways and to rural and urban freeways, but narrow bridges on these roadway types were not specifically investigated in the research.
6. The implications for sag vertical curve design of the change in the target object height for crest vertical curve design to 2 ft (representing the taillight height of a vehicle), first implemented in the 2001 *Green Book* (*3*), need to be assessed in future research. If the target object for sag vertical curve design is another vehicle, the need for the current headlight sight distance criterion in sag vertical curve design appears to be moot because a vehicle's headlights are not needed to see a same-direction vehicle with illuminated taillights or an oncoming vehicle with illuminated headlights. It appears that sag vertical curve design could be based solely on considerations of drainage and driver comfort (except where an overpass structure is present). Until such research is completed, it may be premature to recommend a specific change in the *Green Book*, but there appears to be little rationale for retaining sag vertical curve length in the controlling criteria.
7. Horizontal clearance, renamed lateral offset in the 2011 *Green Book* (*5*) and the 2011 RDG (*40*), is not needed as a controlling criterion for rural two-lane highways, rural multilane highways, and rural and urban freeways because the controlling criterion for shoulder width ensures that there will be sufficient horizontal clearance/lateral offset. On urban and suburban arterials, any effect on traffic speed due to roadside objects less than 18 in behind the curb would be minimal. The primary function of the lateral offset design criterion is to ensure that mirrors or other appurtenances of heavy vehicles do not strike roadside objects and that passengers in parked cars are able to open their doors. While these considerations are important, they do not appear to rise to the level of importance that attaches to other design criteria that may address the likelihood of fatal-and-injury crashes and, therefore, horizontal clearance/lateral offset does not appear to need administrative control as a controlling criterion for design.
8. If Recommendation 7 is not acted upon and horizontal clearance is retained as a controlling criterion, it should be renamed lateral offset, with an accompanying clarification that this controlling criterion applies only to the 1.5-ft operational offset and not to wider lateral offsets now presented in the RDG (*40*) that are intended to reduce fixed-object collision for vehicles that run off the road. Alternatively, the RDG could be changed to use different terms for the 1.5-ft offset intended as an operational offset and the wider offsets intended to reduce fixed-object collision for vehicles that run off the road.
9. It is recommended that the concept of controlling criteria for roadway geometrics not be applied to urban and suburban arterials or that only a minimum set of controlling criteria be applied, including lane width (for lane widths less than 10 ft), stopping sight distance (for locations where a hidden curve, intersection, or driveway is present), and cross slope. The *Green Book* and existing highway agency design policies provide excellent guidance for the geometric design of urban and suburban arterials. More than other roadway types, the traffic operational and safety performance of urban and suburban arterials appears to depend on factors such as intersection design and access management, which are outside the scope of the 13 controlling criteria and outside the scope of this research. Well-reasoned and well-explained geometric design

criteria, with flexibility to adapt roadway cross sections to the specific needs of each corridor, along with appropriate intersection design and access management criteria, would appear to be of greater importance to design of urban and suburban arterials than the administrative controls provided by the 13 controlling criteria and the design exception process. A possible exception to this recommendation is for urban and suburban arterials with design speeds over 45 mph; such arterials are designed more like rural highways, and the same controlling criteria as for rural two-lane highways, rural multilane highways, and rural and urban freeways might be applied.

10. The established concept of the controlling criteria and the design exception process has served the profession well since 1985, given the lack of quantitative knowledge about the traffic operational and safety effects of geometric design criteria. As more knowledge has become available, it now appears appropriate to make some changes to the controlling criteria. Ultimately, the current design process itself might be replaced with a performance-based design process in which highway designers assess the traffic operational and safety effects of each design decision to develop an overall project design whose traffic operational and safety performance can be accurately estimated. The appropriate administrative controls to be incorporated into a performance-based process will need to be determined at a later date. Research is being conducted under NCHRP Project 15-47 to consider possible updates to the geometric design process, including performance-based approaches.
11. Future research on traffic operational effects of geometric design elements would be desirable for the following:
    - Shoulder width on urban and suburban arterials
    - Bridge width on rural two-lane highways, rural multilane highways, urban and suburban arterials, and freeways
    - Limited stopping sight distance on rural two-lane highways, rural multilane highways, urban and suburban arterials, and freeways
    - Lateral offset to roadside objects on urban and suburban arterials
12. Future research on safety effects of geometric design elements would be desirable for:
    - Shoulder width on urban and suburban arterials
    - Bridge width on rural multilane highways, urban and suburban arterials, and freeways
    - Horizontal curve radius on urban and suburban arterials
    - Horizontal curve superelevation on rural multilane highways, urban and suburban arterials, and freeways
    - Limited stopping sight distance on rural multilane highways, urban and suburban arterials, and freeways
    - Lateral offset to roadside objects on urban and suburban arterials

CODE SHEET

CRASH NUMBER: THE 9 DIGIT CRASH REPORT NUMBER

Y: THE "Y" THAT SOMETIMES APPEARS BETWEEN THE COLUMNS FOR CRASH NUMBER AND ROADWAY ID, IS A FLAG THAT IDENTIFIES CRASHES THAT ARE ON OTHER STATE ROADS OR ON NON-MAINTAINED SIDE ROADS. THESE CRASHES OCCUR WITH 50-250 FEET FEET OF THE QUERIED SR AND ARE CLASSIFIED AS INFLUENCED CRASHES. CRASHES LESS THAN 50 FEET FROM THE QUERIED SR WILL ALWAYS BE REPORTED, SINCE THEY AT THE INTERSECTION.

ROADWAY ID: THE 8 DIGIT NUMBER THAT IDENTIFIES THE PART OF THE STATE ROAD SYSTEM ON WHICH THE CRASH HAS OCCURRED

COUNTY: THE FIRST TWO DIGITS OF THE ROADWAY ID ARE THE NUMERIC D.O.T. CODE FOR COUNTY

SECTION: THE THIRD, FOURTH AND FIFTH DIGITS OF THE ROADWAY ID ARE THE SECTION OF THE STATE ROAD SYSTEM, WITHIN COUNTY, ON WHICH THE CRASH OCCURRED

SUBSECTION: THE SIXTH, SEVENTH AND EIGHTH DIGITS OF THE ROADWAY ID IDENTIFY THE SUBDIVISION OF THE PRIMARY SECTION ON WHICH THE CRASH OCCURRED

MILEPOST: THE MILEPOST IDENTIFIES THE EXACT POINT ON THE ROADWAY ID WHERE THE CRASH HAS OCCURRED

NEAREST NODE: THE NEAREST NODE IS THE CLOSEST NODE (A DEFINED POINT ON THE STATE ROAD SYSTEM) TO THE LOCATION OF THE CRASH

STATE ROAD: THE STATE ROAD IS THE ROUTE NUMBER ASSIGNED TO THE ROADWAY ID

AVERAGE DAILY TRAFFIC: THE AVERAGE NUMBER OF VECHICLES PER DAY PASSING THE MILE POINT WHERE CRASHES OCCURRED

YEAR: THE YEAR IN WHICH THE CRASH OCCURRED (FINAL TWO DIGITS)

MONTH: THE MONTH OF THE CRASH

DAY: THE DAY OF THE MONTH ON WHICH THE CRASH OCCURRED

HOUR: THE TIME AT WHICH THE CRASH OCCURRED, MILITARY TIME

CRASH RATE CLASS CATEGORY: THIS FIVE-LETTER/NUMBER CODE IS A COMBINATION OF RURAL/URBAN/ SUBURBAN CLASSIFICATION, NUMBER OF LANES, DIVIDED/ UNDIVIDED CODE, TYPE OF MEDIAN AND SUBSECTION TYPE. FOR THOSE NOT OTHERWISE DEFINED BELOW:

- A FIRST LETTER "U" MEANS "URBAN" (CURB & GUTTER), "S" MEANS "SUBURBAN", (OPEN DRAINAGE INSIDE CITY OR URBAN AREA), "R" MEANS RURAL (OPEN DRAINAGE OUTSIDE CITY OR URBAN AREA).
- AFTER THE HYPHEN (-) THE NUMBER GIVES THE NUMBER OF THRU LANES: "2" MEANS 2-3, "4" MEANS 4-5, "6" MEANS 6 OR MORE.
- THE LETTER IN THE 4TH POSITION DISTINGUISHES DIVIDED ("D") FROM UNDIVIDED ("UN")
- THE LETTER IN THE FINAL POSITION INDICATES THE TYPE OF MEDIAN: "R" FOR RAISED, "P" FOR PAINTED AND "UN" FOR NOT DIVIDED.
- "INT" MEANS INTERSTATE
- "TOL" MEANS TOLL ROAD
- "OLA" MEANS OTHER LIMITED ACCESS
- "RAMP" MEANS RAMP
- "1WAY" MEANS ONE WAY
- "UNKN" MEANS UNKNOWN

ALC INV: ALCOHOL INVOLVED CODE, COMBINED CRASH-LEVEL CODE FOR ALL OF DRIVERS AND PEDESTRIANS INVOLVED IN CRASH
- 0 - NONE
- 1 - ALCOHOL INVOLVED
- 2 - DRUGS INVOLVED
- 3 - ALCOHOL AND DRUGS
- 4 - UNDETERMINED

HARMFUL EVENT 1: FIRST HARMFUL EVENT OF CRASH, AS REPORTED BY OFFICER
- 00 - NOT CODED

NON-COLLISION
- 01 - OVERTURN/ROLLOVER
- 02 - FIRE/EXPLOSION
- 03 - IMMERSION
- 04 - JACKKNIFE
- 05 - CARGO/EQUIPMENT LOSS OR SHIFT
- 06 - FELL/JUMPED FROM MOTOR VEH
- 07 - THROWN OR FALLING OBJECT
- 08 - RAN INTO WATER/CANAL
- 09 - OTHER NON-COLLISION

COLLISION WITH NON-FIXED OBJ
- 10 - PEDESTRIAN
- 11 - PEDALCYCLE
- 12 - RAILWAY VEHICLE (TRAIN, ENGINE)
- 13 - ANIMAL
- 14 - MOTOR VEHICLE IN TRANSPORT
- 15 - PARKED MOTOR VEHICLE
- 16 - WORK ZONE/MAINTENANCE EQUIPMENT
- 17 - STRUCK BY FALLING/ SHIFTING CARGO
- 18 - OTHER NON-FIXED OBJECT

COLLISION WITH FIXED OBJECT
- 19 - IMPACT ATTENUATOR/ CRASH CUSHION
- 20 - BRIDGE OVERHEAD STRUCTURE
- 21 - BRIDGE PIER OR SUPPORT
- 22 - BRIDGE RAIL
- 23 - CULVERT
- 24 - CURB
- 25 - DITCH
- 26 - EMBANKMENT
- 27 - GUARDRAIL FACE
- 28 - GUARDRAIL END
- 29 - CABLE BARRIER
- 30 - CONCRETE TRAFFIC BARRIER
- 31 - OTHER TRAFFIC BARRIER
- 32 - TREE (STANDING)
- 33 - UTILITY POLE/LIGHT SUPPORT
- 34 - TRAFFIC SIGN SUPPORT
- 35 - TRAFFIC SIGNAL SUPPORT
- 36 - OTHER POST, POLE OR SUPPORT
- 37 - FENCE
- 38 - MAILBOX
- 39 - OTHER FIXED OBJECT (WALL, BUILDING, TUNNEL, ETC.)

MANNER OF COLL: MANNER OF COLLISION OR IMPACT CODE, AS REPORTED BY THE OFFICER:
- 00 - NOT CODED
- 01 - FRONT TO REAR
- 02 - FRONT TO FRONT
- 03 - ANGLE
- 04 - SIDESWIPE, SAME DIR
- 05 - SIDESWIPE, OPPOSITE DIR
- 06 - REAR TO SIDE
- 07 - REAR TO REAR
- 77 - OTHER, EXPLAIN IN NARRATIVE
- 88 - UNKNOWN

LIGHTING CONDTNS: LIGHTING CONDITIONS AT TIME OF CRASH, AS REPORTED BY OFFICER
- 00 - NOT CODED
- 01 - DAYLIGHT
- 02 - DUSK
- 03 - DAWN
- 04 - DARK - LIGHTED
- 05 - DARK - NOT LIGHTED
- 06 - DARK - LIGHTING UNKNOWN
- 77 - OTHER, EXPLAIN IN NARRATIVE
- 88 - UNKNOWN

WEATHER CONDTNS: WEATHER CONDITIONS AT TIME OF CRASH, AS REPORTED BY OFFICER
- 00 - NOTE CODED
- 01 - CLEAR
- 02 - CLOUDY
- 03 - RAIN
- 04 - FOG, SMOG, SMOKE
- 05 - SLEET/HAIL/FREEZING RAIN
- 06 - BLOWING SAND, SOIL, DIRT
- 07 - SEVERE CROSSWINDS
- 77 - OTHER, EXPLAIN IN NARRATIVE

RD SURF: ROAD SURFACE CONDITIONS AT TIME OF CRASH, AS REPORTED BY OFFICER
- 00 - NOT CODED
- 01 - DRY

02 - WET
04 - ICE/FROST
05 - OIL
06 - MUD, DIRT, GRAVEL
07 - SAND
08 - WATER (STANDING/ MOVING)
77 - OTHER, EXPLAIN IN NARRATIVE
88 - UNKNOWN

ROAD CONDTNS: CONTRIBUTING CIRCUMSTANCES ROAD, AS REPORTED BY OFFICER
00 - NOT CODED
01 - NONE
04 - WORK ZONE (CONSTRUCTION/ MAINTENANCE/ UTILITY)
06 - SHOULDERS (NON, LOW, SOFT, HIGH)
07 - RUT, HOLES, BUMPS
09 - WORN, TRAVEL-POLISHED SURFACE
10 - ROAD SURFACE CONDITION (WET, ICE, SNOW, SLUSH, ETC.)
11 - OBSTRUCTION IN ROADWAY
12 - DEBRIS
13 - TRAFFIC CONTROL DEVICE INOPERATIVE, MISSING OR OBSCURED
14 - NON-HIGHWAY WORK
77 - OTHER, EXPLAIN IN NARRATIVE
88 - UNKNOWN

DOT SITE LOCATION: D.O.T. SITE LOCATION AS CODED BY SAFETY OFFICE
01 - NOT AT INTERSECTION/ RRXING/BRIDGE
02 - AT INTERSECTION
03 - INFLUENCED BY INTERSECTION
04 - DRIVEWAY ACCESS
05 - RAILROAD CROSSING
06 - BRIDGE
07 - ENTRANCE RAMP
08 - EXIT RAMP
09 - PARKING LOT (PUBLIC)
10 - PARKING LOT (PRIVT)
11 - PRIVATE PROPERTY
12 - TOLL BOOTH
13 - PUBLIC BUS STOP ZONE

77 - ALL OTHER

ROAD SD: SIDE OF ROAD, AS REPORTED BY FLORIDA DEPT OF TRANSPORTATION SAFETY OFFICE FOR FIRST POINT OF IMPACT IN CRASH
E - END OF STATE ROAD
I - INTERSECTION
L - LEFT
M - MEDIAN
P - PARKING LOT/PRIV PROP
R - RIGHT
S - SIDE ROAD RIGHT
T - SIDE ROAD LEFT
U - UNKNOWN

ACC LN #: ACCIDENT LANE LOCATION, AS REPORTED BY FLORIDA DEPT OF TRANSPORTATION SAFETY OFFICE FOR FIRST POINT OF IMPACT IN CRASH
A - ACCEL/MERGE LANE
B - TOLL PLAZAS
C - CROSSWALK
D - DRIVEWAY
E - END OF STATE ROAD
H - ISLAND AREA
K - SERVICE/ACCESS ROAD
L - LEFT TURN LANE
M - MEDIAN
N - NOT APPLICABLE
P - PARKING LANE
R - RIGHT TURN LANE
S - SIDE OF THE ROAD
T - CONTINUOUS TURN LANE (CENTER)
U - UNKNOWN
V - BICYCLE LANE
X - RAMP
1 - 9 THROUGH-LANE (NUMBERED FROM CENTER)

V1 DIR OR V2 DIR: VEHCICLE DIRECTION FOR FIRST OR SECOND VEHICLE, AS REPORTED BY THE OFFICER; ASTERISK (*) IN V2 DIR INDICATES NON-MOTORIST RECORD
N - NORTH
S - SOUTH
E - EAST
W - WEST
O - OFF-ROAD
U - UNKNOWN

V1 BODY TYPE OR V2 BOD: VEHICLE TYPE FOR FIRST OR SECOND VEHICLE, AS REPORTED BY THE OFFICER
00 - NOT CODED
01 - PASSENGER CAR
02 - PASSENGER VAN
03 - PICKUP
07 - MOTOR HOME
08 - BUS
11 - MOTORCYCLE
12 - MOPED
13 - ALL TERRAIN VEHICLE (ATV)
15 - LOW SPEED VEHICLE
16 - (SPORT) UTILITY VEHICLE
17 - CARGO VAN (10,000 LBS (4,536 KG) OR LESS)
18 - MOTOR COACH
19 - OTHER LIGHT TRUCKS (10,000 LBS (4,536 KG) OR LESS)
20 - MEDIUM/HEAVY TRUCKS (MORE THAN 10,000 LBS (4,536 KG))
21 - FARM LABOR VEHICLE
77 - OTHER, EXPLAIN IN NARRATIVE
88 - UNKNOWN

V1 SPEC FUNC OR V2 FUNC: VEHICLE SPECIAL FUNCTION FOR FIRST OR SECOND VEHICLE, AS REPORTED BY THE OFFICER
00 - NOT CODED
01 - NO SPECIAL FUNCTION
02 - FARM VEHICLE
03 - POLICE
07 - TAXI
08 - MILITARY
09 - AMBULANCE
10 - FIRE TRUCK
11 - FARM LABOR TRANSPORT
12 - SCHOOL BUS
13 - TRANSIT/COMMUTER BUS
14 - INTERCITY BUS
15 - CHARTER/TOUR BUS
16 - LEAVING TRAFFIC LANE
17 - ENTERING TRAFFIC LANE
77 - OTHER, EXPLAIN IN NARRATIVE
88 - UNKNOWN

V1 MANEUVER OR V2 MNVR: VEHICLE MANEUVER ACTION FIRST OR SECOND VEHICLE, AS REPORT BY THE OFFICER
00 - NOT CODED
01 - STRAIGHT AHEAD
03 - TURNING LEFT
04 - BACKING
05 - TURNING RIGHT
06 - CHANGING LANES
08 - PARKED
10 - MAKING U-TURN
11 - OVERTAKING/PASSING
13 - STOPPED IN TRAFFIC
14 - SLOWING
15 - NEGOTIATING A CURVE
16 - LEAVING TRAFFIC LANE
17 - ENTERING TRAFFIC LANE
77 - OTHER, EXPLAIN IN NARRATIVE
88 - UNKNOWN

V1 DRIVR ACTION 1 OR V2 ACTN1: FIRST DRIVER'S ACTION AT TIME OF CRASH FOR FIRST OR SECOND VEHICLE DRIVER, AS REPORTED BY OFFICER
00 - NOT CODED
01 - NO CONTRIBUTING ACTION
02 - OPERATED MV IN CARELESS OR NEGLIGENT MANNER
03 - FAILED TO YIELD RIGHT-OF-WAY
04 - IMPROPER BACKING
06 - IMPROPER TURN
10 - FOLLOWED TOO CLOSELY
11 - RAN RED LIGHT
12 - DROVE TOO FAST FOR CONDITIONS
13 - RAN STOP SIGN
15 - IMPROPER PASSING
17 - EXCEED POSTED SPEED
21 - WRONG SIDE OR WRONG WAY
25 - FAILED TO KEEP IN PROPER LANE
26 - RAN OFF ROADWAY
27 - DISREGARDED OTHER TRAFFIC SIGN
28 - DISREGARDED OTHER ROAD MARKINGS
29 - OVER-CORRECTING/OVER-STEERING
30 - SWERVED OR AVOIDED: DUE TO WIND, SLIPPERY SURFACE, MV, OBJECT,

NON-MOTORIST IN ROADWAY, ETC.
31 - OPERATED MV IN ERRATIC, RECKLESS OR AGGRESSIVE MANNER
77 - OTHER CONTRIBUTING ACTION

V1 DRIVR AGE OR V2 DRAGE: AGE AT TIME OF CRASH FOR DRIVER OF VEHICLE 1 OR 2, BASED ON DATE OF BIRTH AS REPORTED BY THE OFFICER

NM DESC: NON-MOTORIST DESCRIPTION (WHEN ASTERISK (*) SHOWS IN V2 DIR COLUMN), AS REPORTED BY THE OFFICER
00 - NOT CODED
01 - PEDESTRIAN
02 - OTHER PEDESTRIAN (WHEELCHAIR, PERSON IN A BUILDING, SKATER, PEDESTRIAN CONVEYANCE, ETC.)
03 - BICYCLIST
04 - OTHER CYCLIST
05 - OCCUPANT OF MOTOR VEHICLE NOT IN TRANSPORT (PARKED, ETC.)
06 - OCCUPANT OF NON-MOTOR VEHICLE TRANSPORTATION DEVICE
07 - UNKNOWN TYPE OF NON-MOTORIST

NM LOC: NON-MOTORIST LOCATION AT TIME OF CRASH (WHEN ASTERISK (*) SHOWS IN V2 DIR COLUMN), AS REPORTED BY THE OFFICER
01 - INTERSECTION - MARKED CROSSWALK
02 - INTERSECTION - UNMARKED CROSSWALK
03 - INTERSECTION - OTHER
04 - MIDBLOCK - MARKED CROSSWALK
05 - TRAVEL LANE - OTHER LOCATION
06 - BICYCLE LANE
07 - SHOULDER/ROADSIDE
08 - SIDEWALK
09 - MEDIAN/CROSSING ISLAND
10 - DRIVEWAY ACCESS
11 - SHARED USE PATH OR TRAIL
12 - NON-TRAFFICWAY AREA
77 - OTHER, EXPLAIN IN NARRATIVE
88 - UNKNOWN

NM PRIOR: NON-MOTORIST ACTION PRIOR TO CRASH (WHEN ASTERISK (*) SHOWS IN V2 DIR COLUMN), AS REPORTED BY THE OFFICER
01 - CROSSING ROADWAY
02 - WAITING TO CROSS ROADWAY
03 - WALKING/CYCLING ALONG ROADWAY WITH TRAFFIC (IN OR ADJACENT TO TRAVEL LANE)
04 - WALKING/CYCLING ALONG ROADWAY AGAINST TRAFFIC (IN OR ADJACENT TO TRAVEL LANE)
05 - WALKING/CYCLING ON SIDEWALK
06 - IN ROADWAY - OTHER (WORKING, PLAYING, ETC.)
07 - ADJACENT TO ROADWAY (E.G. SHOULDER, MEDIAN)
08 - GOING TO OR FROM SCHOOL (K-12)
09 - WORKING IN TRAFFICWAY (INCIDENT RESPONSE)
10 - NONE
77 - OTHER, EXPLAIN IN NARRATIVE
88 - UNKNOWN

NM ACTN1: FIRST NON-MOTORIST ACTIONS/CIRCUMSTANCES (WHEN ASTERISK (*) SHOWS IN V2 DIR COLUMN), AS REPORTED BY THE OFFICER
00 - NOT CODED
01 - NO IMPROPER ACTION
02 - DART/DASH
03 - FAILURE TO YIELD RIGHT-OF-WAY
04 - FAILURE TO OBEY TRAFFIC SIGNS, SIGNALS, OR OFFICER
05 - IN ROADWAY IMPROPERLY (STANDING, LYING, WORKING, PLAYING)
06 - DISABLED VEHICLE RELATED (WORKING ON, PUSHING, LEAVING/ APPROACHING)
07 - ENTERING/EXITING PARKED/STANDING VEHICLE
08 - INATTENTIVE (TALKING, EATING, ETC.)
09 - NOT VISIBLE (DARK CLOTHING, NO LIGHTING, ETC.)
10 - IMPROPER TURN/MERGE
11 - IMPROPER PASSING
12 - WRONG-WAY RIDING OR WALKING
77 - OTHER, EXPLAIN IN NARRATIVE
88 - UNKNOWN

NM ACTN2: SECOND NON-MOTORIST ACTIONS/CIRCUMSTANCES (WHEN ASTERISK (*) SHOWS IN V2 DIR COLUMN), AS REPORTED BY THE OFFICER; SAME CODES AS ABOVE

VEHCLS: TOTAL NUMBER OF VEHICLES INVOLVED IN THE CRASH. IF THE NUMBER IS HIGHER THAN 9 THEN THIS FIELD WILL DISPLAY AN ASTERISK (*).

KILLED: TOTAL NUMBER OF FATALITIES AS A RESULT OF THE CRASH. IF THE NUMBER IS HIGHER THAN 9 THEN THIS FIELD WILL DISPLAY AN ASTERISK (*).

NUMBER INJURED: TOTAL NUMBER OF INJURIES AS A RESULT OF THE CRASH. IF THE NUMBER IS HIGHER THAN 99 THEN THIS FIELD WILL DISPLAY ASTERISKS(**).

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          CCCCCCCCCC      AAAAAAAAAA       RRRRRRRRR
        CCCCCCCCCCC     AAAAAAAAAAA       RRRRRRRRRRR
       CCC             AAA     AAA       RRR      RRR
      CCC             AAA     AAA       RRR      RRR
     CCC             AAAAAAAAAAA       RRRRRRRRRRRR
    CCC             AAAAAAAAAAA      RRRRRRRRRRRR
   CCC             AAA     AAA      RRR      RRR
  CCC             AAA     AAA      RRR       RRR
 CCCCCCCCCCC     AAA     AAA      RRR        RRRR
CCCCCCCCCCC     AAA     AAA      RRR         RRRRRR
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C R A S H   R E P O R T I N G   S Y S T E M

N O T I C E: THE INFORMATION CONTAINED IN THIS DOCUMENT (REPORT, SCHEDULE, LIST, OR DATA) HAS BEEN COMPILED FROM INFORMATION COLLECTED FOR THE PURPOSE OF IDENTIFYING, EVALUATING, OR PLANNING SAFETY ENHANCEMENTS. THIS PRODUCT IDENTIFIES INFORMATION USED FOR THE PURPOSE OF DEVELOPING HIGHWAY SAFETY CONSTRUCTION IMPROVEMENT PROJECTS WHICH MAY BE IMPLEMENTED UTILIZING FEDERAL-AID HIGHWAY FUNDS. ANY DOCUMENT DISPLAYING THIS NOTICE SHALL BE USED ONLY FOR THOSE PURPOSES DEEMED APPROPRIATE BY THE FLORIDA DEPARTMENT OF TRANSPORTATION. SEE TITLE 23, UNITED STATES CODE, SECTION 409.

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I/O NAME: ...............  CARI122
PROGRAM ID: .............  CARPJ122
REPORT NUMBER: ..........  01
RUN CLASS: ..............  A
MESSAGE CLASS: ..........  Q
PRINTER DEST: ...........  LOCAL
# COPIES: ...............  01
ACCOUNT #: ..............  5565945
SUBMIT W/HOLD? ..........  N
USERID: .................  RD960JF
DETAIL SORT ORDER: ......  1 - SORT BY ROADWAY, MILE POINT
PRINT SEGMENTS? .........  N
PRINT INTERSECTIONS? ....  N
SUMMARY FORMAT: .........  2 - TOP LINE ALL BREAKS
OVERRIDE VALUES:
 MAX # OF BREAKS: .......  06
 CRASH RATE CATEGORY: ...
 AVERAGE DAILY TRAFFIC:..
 # OF LEGS: .............
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COMMENT:                                        1 - SORT BY ROADWAY, MILE POINT
  FROM: 01/01/2014 TO 12/31/2015                                        RAMPS INCL
  FROM CO/SEC/SUB: 55 060 000                   MP: 006.100              INFL INCL
  TO   CO/SEC/SUB: 55 060 000                   MP: 008.400             CR/OS INCL

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  R N      C S   S     I      EN   TR   VAR   E  O  A  O  RALA  L AE AF IC EC D  OC OO O C 1 1  1U 1A 1C 1A 2 2N 2N 2M 2M  M 2N
  A U      O E   E     L      AO   AO   EIA   A  N  Y  U  ATAT  C RV N  GO AO    AO TC A C       N  N  T  G    M  M           M V K I
  S M      U C  SC     E      RD   TA   RLF   R  T     R  SESE    ME NC HN TN S  DN  A D   D B  SC  E DI DE D B  F  MP AA  A D  E I N
  H B      N T  UT     P      EE   ED   AYF      H        H SG  I FN EO TD HD U   D ST   L I OT P   U RO R  I OD UL NR CC  C RA H L J
    E      T I  BI     O      S         G I                  O  N UT RL IT ET R   T II S N R DY E   V IN I  R DE NO VI TT  T AG C L U
    R      Y O   O     S      T         E C                  R  V L   L NN RN F   N TO D     YP C   E V  V    /S CC RO 1N  N GE L E R
             N   N     T                                     Y     1    GS  S     S EN   #    E     R R1 R     C /  /R /1  2 E  S D D
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COMMENT:                                      1 - SORT BY ROADWAY, MILE POINT
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  FROM CO/SEC/SUB: 55 060 000                 MP: 006.100             INFL INCL
  TO   CO/SEC/SUB: 55 060 000                 MP: 008.400            CR/OS INCL

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  R N      C S   S     I      EN   TR   VAR   E  O  A  O  RALA  L AE AF IC EC D  OC OO O C 1 1  1U 1A 1C 1A 2 2N 2N 2M 2M  M 2N
  A U      O E   E     L      AO   AO   EIA   A  N  Y  U  ATAT  C RV N  GO AO    AO TC A C       N  N  T  G    M  M            M V K I
  S M      U C  SC     E      RD   TA   RLF   R  T     R  SESE    ME NC HN TN S  DN  A D    D B  SC  E DI DE D B  F  MP AA  A D  E I N
  H B      N T  UT     P      EE   ED   AYF      H        H SG  I FN EO TD HD U   D ST   L I OT P   U RO R  I OD UL NR CC  C RA H L J
    E      T I  BI     O      S         G I                  O  N UT RL IT ET R   T II S N R DY E   V IN I  R DE NO VI TT  T AG C L U
    R      Y O   O     S      T         E C                  R  V L   L NN RN F   N TO D     YP C   E V  V    /S CC RO 1N  N GE L E R
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REPORT...CARPJ122-01                             FLORIDA - DEPARTMENT OF TRANSPORTATION                                      PAGE NO:      8
  DATE...02/25/2016                               C A R - CRASH ANALYSIS REPORTING SYSTEM                                   USERID:  RD960JF
  TIME...08:49:53                        CRASH DATA DETAIL AND EXTRACT FOR STATE-MAINTAINED ROADS                           I/O....  CARO213

COMMENT:                                     1 - SORT BY ROADWAY, MILE POINT
  FROM: 01/01/2014 TO 12/31/2015                                      RAMPS INCL
  FROM CO/SEC/SUB: 55 060 000                MP: 006.100               INFL INCL
  TO   CO/SEC/SUB: 55 060 000                MP: 008.400              CR/OS INCL

   C       ROADWYID     M      N    S    ADT   Y  M  D  H  CRCC  A H  MO L  W  R  R  DL R A V V  VF VM VA V  V V  V  VN VN  N V  # # #
  R N      C S   S      I      EN   TR   VAR   E  O  A  O  RALA  L AE AF IC EC D  OC OO O C 1 1  1U 1A 1C 1A 2 2N 2N 2M 2M  M 2N
  A U      O E   E      L      AO   AO   EIA   A  N  Y  U  ATAT  C RV N  GO AO   AO TC A C     N  N  T  G    M  M            M V K I
  S M      U C  SC      E      RD   TA   RLF   R  T     R  SESE    ME NC HN TN S  DN  A D   D B  SC  E DI DE D B  F  MP AA  A D  E I N
  H B      N T  UT      P      EE   ED   AYF      H        H SG  I FN EO TD HD U   D ST   L I OT P   U RO R  I OD UL NR CC  C RA H L J
    E      T I  BI      O      S         G I                  O  N UT RL IT ET R   T II S N R DY E   V IN I  R DE NO VI TT  T AG C L U
    R      Y O   O      S      T         E C                  R  V L   L NN RN F   N TO D     YP C   E V  V    /S CC RO 1N  N GE L E R
             N   N      T                                     Y     1    GS  S    S EN   #    E    R R1 R    C /  /R /1  2 E  S D D
***************************************************************************************************************************************
848419880 55060000 08.148 0216   10 032500 14 08 08 12 U-6DP 0 14 05 01 01 01 01 02 R L W 08 01 01 77 49 E 77 01 13 01    45 2 0 00
845729230 55060000 08.152 0216   10 032500 14 02 16 16 U-6DP 0 14 01 01 01 01 01 02 R 1 W 01 01 01 10 43 E 02 01 14 01    61 2 0 00
845730230 55060000 08.152 0216   10 032500 14 02 21 09 U-6DP 0 14 04 01 02 02 88 02 L 3 0 88 88 88 00 00 W 01 01 01 01    21 2 0 00
850404750 55060000 08.161 0216   10 032500 14 10 21 15 U-6DP 0 14 04 01 01 01 01 02 L U W 08 14 01 77 47 W 01 01 01 01    43 2 0 00
847115150 55060000 08.166 0216   10 032500 14 05 08 17 U-6DP 0 14 01 01 01 01 01 03 L 2 W 16 01 01 10 23 W 16 01 14 01    32 2 0 01
845730140 55060000 08.171 0216   10 032500 14 02 21 11 U-6DP 0 14 04 01 03 02 01 03 R L W 16 01 01 77 51 W 16 88 77 01    45 2 0 00
848420640 55060000 08.191 0217   10 032500 14 08 12 09 U-6DP 0 14 04 01 01 01 01 03 R 3 E 16 01 06 15 30 E 08 13 13 01    42 2 0 00
850415420 55060000 08.191 0217   10 032500 14 12 01 06 U-6DP 0 14 04 04 01 01 01 03 R 3 E 08 13 01 25 42 E 20 01 01 01    41 2 0 00
845726030 55060000 08.229 0217   10 032500 14 02 04 14 U-6DP 0 14 03 01 01 01 01 02 R 3 E 01 01 01 11 35 S 01 01 01 01    28 2 0 02
845730040 55060000 08.229 0217   10 032500 14 02 20 19 U-6DP 0 14 03 04 01 01 01 02 R 3 W 01 01 03 77 23 E 01 01 01 77    18 2 0 00
845734950 55060000 08.229 0217   10 032500 14 03 13 10 U-6DP 0 14 04 01 01 01 01 02 I M 0 88 88 88    00 S 02 01 01 01    33 2 0 00
847121830 55060000 08.229 0217   10 032500 14 06 11 15 U-6DP 0 10 00 01 01 01 01 02 L C W 03 01 01 01 26 * 01 01 01 02 00 19 1 0 01
847121870 55060000 08.229 0217   10 032500 14 06 12 11 U-6DP 0 14 04 01 02 02 01 02 R 2 S 16 01 03 25 67 S 16 01 03 01    66 2 0 00
848414370 55060000 08.229 0217   10 032500 14 07 14 23 U-6DP 0 14 04 04 01 01 01 02 R 3 0 88 88 88    00 E 01 01 01 01    22 2 0 01
850399340 55060000 08.229 0217   10 032500 14 10 04 22 U-6DP 0 14 04 04 01 01 01 02 L 3 W 01 01 77 77 30 W 01 01 01 01    23 2 0 00
850402280 55060000 08.229 0217   10 032500 14 10 14 16 U-6DP 0 14 03 01 01 02 01 02 S 2 S 01 01 03 01 29 S 16 01 03 01    66 2 0 00
850415980 55060000 08.233 0217   10 032500 14 12 03 12 U-6DP 0 14 01 01 01 01 01 02 R 1 E 19 01 01 02 53 E 16 01 13 01    18 2 0 00
846760930 55060000 08.243 0217   10 032500 14 09 11 14 U-6DP 0 14 05 01 01 01 01 03 L L E 03 01 01 25 51 W 08 12 03 01    54 2 0 01
850404510 55060000 08.285 0218   10 032500 14 10 22 18 U-6DP 0 14 05 01 01 01 01 03 R 1 W 08 14 01 01 47 E 20 01 01 01    48 2 0 00
847114890 55060000 08.292 0218   10 032500 14 05 07 21 U-6DP 0 14 01 04 01 01 01 03 L 1 E 01 01 01 02 21 E 01 01 13 01    20 2 0 00
841992500 55060000 08.302 0218   10 032500 14 02 14 13 U-6DP 0 14 04 01 01 01 01 02 R 2 E 08 12 01 25 37 E 20 01 13 01    26 2 0 00
845737670Y55060000 08.304 0218   10 032500 14 03 26 15 U-6DP 0 14 01 01 01 01 01 01 S 1 0 88 88 88    00 N 01 01 14 01    20 2 0 00
847121250 55060000 08.304 0218   10 032500 14 06 09 13 U-6DP 0 14 03 01 01 01 01 02 R 3 E 16 01 01 11 17 N 19 01 01 01    56 2 0 00
848417090 55060000 08.304 0218   10 032500 14 07 26 02 U-6DP 0 14 05 04 01 01 01 02 S 1 0 88 88 88 00 00 N 01 01 01 01    60 2 0 01
848425000 55060000 08.304 0218   10 032500 14 08 31 00 U-6DP 0 14 03 04 01 01 01 02 L 3 W 01 01 01 11 26 N 01 01 01 01    23 2 0 04
846759960 55060000 08.304 0218   10 032500 14 09 29 17 U-6DP 0 14 01 02 03 02 10 02 S 3 N 01 01 14 02 34 N 01 01 13 01    54 2 0 00
850404530 55060000 08.304 0218   10 032500 14 10 22 20 U-6DP 0 14 04 04 01 01 01 02 S 3 0 88 88 88 00 00 S 01 01 01 01    55 2 0 00
845721330 55060000 08.313 0218   10 032500 14 01 15 18 U-6DP 0 14 04 01 01 01 01 02 L 2 0 88 88 88 00 00 W 01 01 01 01    22 2 0 00
845727120 55060000 08.313 0218   10 032500 14 02 08 07 U-6DP 0 14 01 03 03 02 01 02 L 3 0 88 88 88    00 W 16 01 13 01    75 2 0 00
856770660 55060000 08.319 0218   10 032500 14 12 22 18 U-6DP 0 14 04 04 02 02 01 03 L 1 W 16 01 16 02 51 W 01 01 01 01    20 2 0 00
845732030 55060000 08.367 0219   10 032500 14 03 01 04 U-6DP 0 14 77 04 01 01 01 02 L S W 01 01 01 02 26                   1 0 00
847113890 55060000 08.367 0219   10 032500 14 05 03 12 U-6DP 0 14 04 01 01 01 77 02 S 1 N 08 01 11 15 59 N 19 01 13 01    23 2 0 00
847117630 55060000 08.367 0219   10 032500 14 05 20 11 U-6DP 0 14 03 01 01 01 01 02 T C S 01 01 05 03 54 * 01 01 01 01 00 48 1 0 01
848417520 55060000 08.367 0219   10 032500 14 07 28 09 U-6DP 0 14 03 01 01 01 01 02 R 3 E 01 01 01 11 34 S 01 01 01 01    64 2 0 00
848422970 55060000 08.367 0219   10 032500 14 08 23 10 U-6DP 0 14 03 01 01 01 01 02 L 2 E 16 01 01 11 66 N 01 01 01 01    57 2 0 01
850405780 55060000 08.367 0219   10 032500 14 10 27 19 U-6DP 0 14 03 04 01 01 01 02 R 1 E 02 01 01 11 59 S 01 00 01 01    36 2 0 01
856767290Y55060000 08.367 0219   10 032500 14 12 09 08 U-6DP 0 14 04 01 02 01 01 04 S S S 08 14 05 26 50                   1 0 00
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FLORIDA TRAFFIC CRASH REPORT

LONG FORM 3 SHORT FORM (Shaded Areas) 3 UPDATE 3

TOTAL # OF VEHICLE SECTION(S) 4

TOTAL # OF PERSON SECTION(S) 5

TOTAL # OF NARRATIVE SECTION(S) 6

MAIL TO: DEPARTMENT OF HIGHWAY SAFETY & MOTOR VEHICLES
TRAFFIC CRASH RECORDS, NEIL KIRKMAN BUILDING
TALLAHASSEE, FL 32399-0537

CRASH DATE	TIME OF CRASH	DATE OF REPORT	REPORTING AGENCY CASE NUMBER	HSMV CRASH REPORT NUMBER
7	8	9	2	1

CRASH IDENTIFIERS

COUNTY CODE	CITY CODE	COUNTY OF CRASH	PLACE OR CITY OF CRASH	CHECK IF WITHIN CITY LIMITS	TIME REPORTED	TIME DISPATCHED
10	11	12	13	14	15	16

TIME ON SCENE	TIME CLEARED SCENE	CHECK IF COMPLETED	REASON (If Investigation NOT Complete)	Notified By: 1 Motorist 2 Law Enforcement
17	18	19	20	21

ROADWAY INFORMATION (CHOOSE ONLY 1 OF 4 OPTIONS)

CRASH OCCURRED ON STREET, ROAD, HIGHWAY	① AT STREET ADDRESS #	② AT LATITUDE AND LONGITUDE
22	23	24 / 25

AT FEET	MILES	N S E W	③ FROM INTERSECTION WITH STREET, ROAD, HIGHWAY	④ OR FROM MILEPOST #
26	27	28	29	30

Road System Identifier 31
1 Interstate
2 U.S.
3 State
4 County
5 Local
6 Turnpike/Toll
7 Forest Road
8 Private Roadway
9 Parking Lot
77 Other, Explain in Narrative

Type of Shoulder 32
1 Paved
2 Unpaved
3 Curb

Type of Intersection 33
1 Not at Intersection
2 Four-Way Intersection
3 T-Intersection
4 Y-Intersection
5 Traffic Circle
6 Roundabout
7 Five-Point, or More
77 Other, Explain in Narrative

CRASH INFORMATION (CHECK IF PICTURES TAKEN) 34

Light Condition 35
1 Daylight
2 Dusk
3 Dawn
4 Dark-Lighted
5 Dark-Not Lighted
6 Dark-Unknown Lighting
77 Other, Explain in Narrative
88 Unknown

Weather Condition 36
1 Clear
2 Cloudy
3 Rain
4 Fog, Smog, Smoke
5 Sleet/Hail/Freezing Rain
6 Blowing Sand, Soil, Dirt
7 Severe Crosswinds
77 Other, Explain in Narrative

Roadway Surface Condition 37
1 Dry
2 Wet
4 Ice/Frost
5 Oil
6 Mud, Dirt, Gravel
7 Sand
8 Water (standing/moving)
77 Other, Explain in Narrative
88 Unknown

School Bus Related 38
1 No
2 Yes, School Bus Directly Involved
3 Yes, School Bus Indirectly Involved

Manner of Collision/Impact 39
1 Front to Rear
2 Front to Front
3 Angle
4 Sideswipe, same direction
5 Sideswipe, Opposite Direction
6 Rear to Side
7 Rear to Rear
77 Other, Explain in Narrative
88 Unknown

First Harmful Event 40

First Harmful Event within Interchange 42
1 No
2 Yes
88 Unknown

Non-Collision
1 Overturn/Rollover
2 Fire/Explosion
3 Immersion
4 Jackknife
5 Cargo/Equipment Loss or Shift
6 Fell/Jumped From Motor Vehicle
7 Thrown or Falling Object
8 Ran into Water/Canal
9 Other Non-Collision

Collision Non-Fixed Object
10 Pedestrian
11 Pedalcycle
12 Railway Vehicle (train, engine)
13 Animal
14 Motor Vehicle in Transport
15 Parked Motor Vehicle
16 Work Zone/Maintenance Equipment
17 Struck By Falling, Shifting Cargo
18 Other Non-Fixed Object

Collision with Fixed Object
19 Impact Attenuator/Crash Cushion
20 Bridge Overhead Structure
21 Bridge Pier or Support
22 Bridge Rail
23 Culvert
24 Curb
25 Ditch
26 Embankment
27 Guardrail Face
28 Guardrail End
29 Cable Barrier
30 Concrete Traffic Barrier
31 Other Traffic Barrier
32 Tree (standing)
33 Utility Pole/Light Support
34 Traffic Sign Support
35 Traffic Signal Support
36 Other Post, Pole or Support
37 Fence
38 Mailbox
39 Other Fixed Object (wall, building, tunnel, etc.)

First Harmful Event Location 41
1 On Roadway
2 Off Roadway
3 Shoulder
4 Median
6 Gore
7 Separator
8 In Parking Lane or Zone
9 Outside Right-of-way
10 Roadside
88 Unknown

First Harmful Event Relation to Junction 43
1 Non-Junction
2 Intersection
3 Intersection-Related
4 Driveway/Alley Access Related
5 Railway Grade Crossing
14 Entrance/Exit Ramp
15 Crossover - Related
16 Shared-Use Path or Trail
17 Acceleration/Deceleration Lane
18 Through Roadway
77 Other, Explain in Narrative
88 Unknown

Contributing Circumstances: Road 44
1 None
4 Work Zone (construction/maintenance/utility)
6 Shoulders (none, low, soft, high)
7 Rut, Holes, Bumps
9 Worn, Travel-Polished Surface
10 Road Surface Condition (wet, icy, snow, slush, etc.)
11 Obstruction in Roadway
12 Debris
13 Traffic Control Device Inoperative, Missing or Obscured
14 Non-Highway Work
77 Other, Explain in Narrative
88 Unknown

Contributing Circumstances: Environment 45
1 None
2 Weather Conditions
3 Physical Obstruction(s)
4 Glare
5 Animal(s) in Roadway
77 Other, Explain in Narrative
88 Unknown

Work Zone Related 46
1 No
2 Yes
88 Unknown

Crash in Work Zone 47
1 Before the First Work Zone Warning Sign
2 Advance Warning Area
3 Transition Area
4 Activity Area
5 Termination Area

Type of Work Zone 48
1 Lane Closure
2 Lane Shift/Crossover
3 Work on Shoulder or Median
4 Intermittent or Moving Work
77 Other, Explain in Narrative

Workers in Work Zone 49
1 No
2 Yes
88 Unknown

Law Enforcement in Work Zone 50
1 No
2 Officer Present
3 Law Enforcement Vehicle Only Present

WITNESSES

NAME	ADDRESS	CITY & STATE	ZIP CODE
51, 52, 53, 54	55	56 57	58

NON VEHICLE PROPERTY DAMAGE

VEHICLE #	PERSON #	PROPERTY DAMAGE – OTHER THAN VEHICLE	EST. AMOUNT	OWNER'S NAME	(Check if Business)	ADDRESS	CITY & STATE	ZIP CODE
59	60	61	62	63, 64,65, 66	67	68	69 70	71

HSMV 90010 S

VEHICLE # 72	**Check if Commercial** 73	REPORTING AGENCY CASE NUMBER 2	HSMV CRASH REPORT NUMBER 1

1 Vehicle in Transport 2 Parked Motor Vehicle 3 Working Vehicle 74	VEHICLE LICENSE NUMBER 75	STATE 76	REGISTRATION EXPIRES 77	Check if Permanent Registration 78	VIN 79

Hit and Run 1 No 2 Yes 88 Unknown 80	YEAR 81	MAKE 82	MODEL 83	STYLE 84	COLOR 85	DAMAGE: 1 Disabling 4 Minor 2 Functional 88 Unknown 3 None 86	EST. AMOUNT 87

INSURANCE COMPANY (DRIVER) 88	INSURANCE POLICY NUMBER 89	Towed due to Damage: 1 No 2 Yes 90	VEHICLE REMOVED BY 91	1. Rotation 2. Owner Request 3. Driver 4. Other, Explain in Narrative 92

NAME OF VEHICLE OWNER 93,94,95,96	(Check if Business) 97	CURRENT ADDRESS 98	CITY & STATE 99 100	ZIP CODE 101

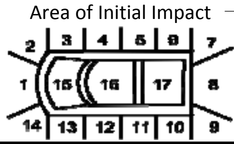
TRAILER #	LICENSE NUMBER	STATE	REGISTRATION EXPIRES	Check if Permanent Registration	VIN	YEAR	MAKE	LENGTH	AXLES
102	103	104	105	106	107	108	109	110	111
112	113	114	115	116	117	118	119	120	121

VEHICLE TRAVELING N S E W Off-Road Unknown 122	ON STREET, ROAD, HIGHWAY 123	AT EST. SPEED 124	POSTED SPEED 125	TOTAL LANES 126

HAZ. MAT. RELEASED 1 No 2 Yes 88 Unknown 127	HAZ. MAT PLACARD 1 No 2 Yes 88 Unknown 128	HAZ. MAT. NUMBER 129	HAZ. MAT. CLASS 130

MOTOR CARRIER NAME 133	US DOT NUMBER 134

Area of Initial Impact 131



18 Undercarriage 18
19 Overturn 19
20 Windshield 20
21 Trailer 21

132 Most Damaged Area

MOTOR CARRIER ADDRESS 135	CITY & STATE 136 137	ZIP CODE 138	PHONE NUMBER 139

Vehicle Body Type 140
1 Passenger Car
2 Passenger Van
3 Pickup
7 Motor Home
8 Bus
11 Motorcycle
12 Moped
13 All Terrain Vehicle (ATV)
15 Low Speed Vehicle
16 (Sport) Utility Vehicle
17 Cargo Van (10,000 lbs (4,536 kg) or less)
18 Motor Coach
19 Other Light Trucks (10,000 lbs (4,536 kg) or less)
20 Medium/Heavy Trucks (more than 10,000 lbs (4,536 kg))
21 Farm Labor Vehicle
77 Other, Explain in Narrative
88 Unknown

Trafficway 141
1 Two-Way, Not Divided
2 Two-Way, Not Divided, with a Continuous Left Turn Lane
3 Two-Way, Divided, Unprotected (painted >4 feet) Median
4 Two-Way, Divided, Positive Median Barrier
5 One-Way Trafficway
88 Unknown

Commercial Motor Vehicle Configuration 142
1 Vehicle 10,000 lbs or less Placarded for Hazardous Materials
2 Single-Unit Truck (2-axle and GVWR more than 10,000 lbs (4,536 kg))
3 Single-Unit Truck (3 or more axles)
4 Truck Pulling Trailer(s)
5 Truck Tractor (bobtail)
6 Truck Tractor/Semi-Trailer
7 Truck Tractor/Double Truck
8 Tractor/Triple
9 Truck more than 10,000 lbs (4,536 kg), Cannot Classify
10 Bus/Large Van (seats for 9-15 occupants, including driver)
11 Bus (seats for more than 15 occupants, including driver)
77 Other, Explain in Narrative
88 Unknown

Comm/Non-Commercial 143
1 Interstate Carrier
2 Intrastate Carrier
3 Not in Commerce/Government
4 Not in Commerce/Other Truck

Trailer Type
TRAILER 1 144 TRAILER 2 145
1 Single Semi Trailer
2 Tandem Semi Trailer
3 Tank Trailer
4 Saddle Mount/Trailer
5 Boat Trailer
6 Utility Trailer
7 House Trailer
8 Pole Trailer
9 Towed Vehicle
10 Auto Transport
77 Other, Explain in Narrative
88 Unknown

Cargo Body Type 146
1 No Cargo
2 Bus
3 Van/Enclosed Box
4 Hopper
5 Pole-Trailer
6 Cargo Tank
7 Flatbed
8 Dump
9 Concrete Mixer
10 Auto Transport
11 Garbage/Refuse
12 Log
13 Intermodal Container Chassis
14 Vehicle Towing Another Vehicle
15 Not Applicable (vehicle 10,000 lbs (4,536kg) or less not displaying HM placard)
77 Other, Explain in Narrative
88 Unknown

Comm GVWR/GCWR 147
1 10,000 lbs (4,536 kg) or less
2 10,001-26,000 lbs (4,536-11,793 kg)
3 More than 26,000 lbs (11,793 kg)
4 Not Applicable

Most Harmful Event 148

Sequence of Events
1st 149 2nd
3rd 4th

Non-Collision
1 Overturn/Rollover
2 Fire/Explosion
3 Immersion
4 Jackknife
5 Cargo/Equipment Loss or Shift
6 Fell/Jumped From Motor Vehicle
7 Thrown or Falling Object
8 Ran into Water/ Canal
9 Other Non-Collision

[*40-46 Sequence of Events only*]
40 Equipment Failure (blown tire, brake failure, etc.)
41 Separation of Units
42 Ran Off Roadway, Right
43 Ran Off Roadway, Left
44 Cross Median
45 Cross Centerline
46 Downhill Runaway

Collision with Non-Fixed Object
10 Pedestrian
11 Pedalcycle
12 Railway Vehicle (train, engine)
13 Animal
14 Motor Vehicle in Transport
15 Parked Motor Vehicle
16 Work Zone/Maintenance Equipment
17 Struck By Falling, Shifting Cargo or Anything Set in Motion by Motor Vehicle
18 Other Non-Fixed Object

Collision Fixed Object
19 Impact Attenuator/Crash Cushion
20 Bridge Overhead Structure
21 Bridge Pier or Support
22 Bridge Rail
23 Culvert
24 Curb
25 Ditch
26 Embankment
27 Guardrail Face
28 Guardrail End
29 Cable Barrier
30 Concrete Traffic Barrier
31 Other Traffic Barrier
32 Tree (standing)
33 Utility Pole/Light Support
34 Traffic Sign Support
35 Traffic Signal Support
36 Other Post, Pole, or Support
37 Fence
38 Mailbox
39 Other Fixed Object (wall, building, tunnel, etc.)

Emergency Vehicle Use 150
1 No
2 Yes
88 Unknown

Roadway Grade 151
1 Level
2 Hillcrest
3 Uphill
4 Downhill
5 Sag (bottom)

Roadway Alignment 152
1 Straight
2 Curve Right
3 Curve Left

Vehicle Maneuver Action 153
1 Straight Ahead
3 Turning Left
4 Backing
5 Turning Right
6 Changing Lanes
8 Parked
10 Making U-Turn
11 Overtaking/ Passing
13 Stopped in Traffic
14 Slowing
15 Negotiating a Curve
16 Leaving Traffic Lane
17 Entering Traffic Lane
77 Other, Explain in Narrative
88 Unknown

Traffic Control Device For This Vehicle 154
1 No Controls
4 School Zone Sign/ Device
5 Traffic Control Signal
6 Stop Sign
7 Yield Sign
8 Flashing Signal
9 Railway Crossing Device
10 Person (including Flagman, Officer, Guard, etc.)
13 Warning Sign
77 Other, Explain in Narrative
88 Unknown

Vehicle Defects 155
1 None
2 Brakes
3 Tires
4 Lights (head, signal, tail)
6 Steering
7 Wipers
9 Exhaust System
10 Body, Doors
11 Power Train
12 Suspension
13 Wheels
14 Windows/ Windshield
15 Mirrors
16 Truck Coupling/ Trailer Hitch/ Safety Chains
77 Other, Explain in Narrative
88 Unknown

Special Function of Motor Vehicle 156
1 No Special Function
2 Farm Vehicle
3 Police
7 Taxi
8 Military
9 Ambulance
10 Fire Truck
11 Farm Labor Transport
12 School Bus
13 Transit/Commuter Bus
14 Intercity Bus
15 Charter/Tour Bus
16 Shuttle Bus
17 Farm Labor Bus
88 Unknown

VIOLATIONS

PERSON #	NAME OF VIOLATOR	FL STATUTE NUMBER	CHARGE	CITATION NUMBER
157	158, 159, 160, 161	162	163	164
PERSON #	NAME OF VIOLATOR	FL STATUTE NUMBER	CHARGE	CITATION NUMBER
PERSON #	NAME OF VIOLATOR	FL STATUTE NUMBER	CHARGE	CITATION NUMBER

PERSON # 165

REPORTING AGENCY CASE NUMBER	HSMV CRASH REPORT NUMBER
2	1

1 Driver 2 Non-Motorist 3 Passenger 166	VEHICLE #	NAME	PHONE NUMBER	Check if 173 Recommend Driver Re-exam
	167	168, 169, 170, 171	172	

CURRENT ADDRESS (Number and Street)	CITY & STATE	ZIP CODE
174	175 176	177

DATE OF BIRTH	SEX: 179	DRIVER LICENSE NUMBER	STATE	EXPIRES	INJURY SEVERITY (INJ) 183
178	1 Male 2 Female 88 Unknown	180	181	182	1 None 2 Possible 3 Non-incapacitating 4 Incapacitating 5 Fatal (within 30 days) 6 Non-Traffic Fatality

DRIVER

DL Type
184
1 A 2 B 3 C
4 D/Chauffeur
5 E/Operator
6 E/Oper – Rest
7 None

Required Endorsements
185
1 Yes
2 No
3 No Req. Endorsement

Drivers Actions at Time of Crash
1st 186
2nd
3rd
4th

1 No Contributing Action
2 Operated MV in Careless or Negligent Manner
3 Failed to Yield Right-of- Way
4 Improper Backing
6 Improper Turn
10 Followed too Closely
11 Ran Red Light
12 Drove too Fast for Conditions
13 Ran Stop Sign
15 Improper Passing
17 Exceeded Posted Speed
21 Wrong Side of Wrong Way
25 Failed to Keep in Proper Lane
26 Ran off Roadway
27 Disregarded other Traffic Sign
28 Disregarded Other Road Markings
29 Over-Correcting/Over-Steering
30 Swerved or Avoided : Due to Wind, Slippery Surface, MV, Object, Non-Motorist in Roadway, etc.
31 Operated MV in Erratic, Reckless or Aggressive Manner
77 Other Contributing Action

Condition At Time of Crash
187
1 Apparently Normal
3 Asleep or Fatigued
5 Ill (sick) or Fainted
6 Seizure, Epilepsy, Blackout
7 Physically Impaired
8 Emotional (depression, angry, disturbed, etc.)
9 Under the Influence of Medications/Drugs/Alcohol
77 Other, Explain in Narrative
88 Unknown

Driver Distracted By
188
1 Not Distracted
2 Electronic Communication Devices (cell phone, etc.)
3 Other Electronic Device (navigation device, DVD player)
4 Other Inside the Vehicle (explain in narrative)
5 External Distraction (outside the vehicle, explain in narrative)
6 Texting
7 Inattentive
88 Unknown

Driver Vision Obstructions
189
1 Vision Not Obscured
2 Inclement Weather
3 Parked/Stopped Vehicle
4 Trees/Crops/Bushes
5 Load on Vehicle
6 Building/Fixed Object
7 Signs/Billboards
8 Fog
9 Smoke
10 Glare
77 All Other, Explain in Narrative

DRIVER OR PASSENGER

Helmet Use (HU)
193
1 DOT-Compliant Motorcycle Helmet
2 Other Helmet
3 No Helmet

Eye Protection (EP)
194
1 Yes
2 No
3 Not Applicable

Restraint Systems (RS)
195
1 Not Applicable (non-motorist)
2 None Used - Motor Vehicle Occupant
3 Shoulder and Lap Belt Used
4 Shoulder Belt Only Used
5 Lap Belt Only Used
6 Restraint Used - Type Unknown
7 Child Restraint System - Forward Facing
8 Child Restraint System - Rear Facing
9 Booster Seat
10 Child Restraint Type Unknown
77 Other, Explain in Narrative

DRIVER OR PASSENGER

Motor Vehicle Seating Position:
LOCATION: SEAT ROW OTHER (LOC)

Seat 190
1 Left
2 Middle
3 Right
77 Other (explain in narrative)
88 Unknown

Row 191
1 Front
2 Second
3 Third
4 Fourth
77 Other Row
88 Unknown

Other 192
1 Not Applicable
2 Sleeper Section of Truck Cab
3 Other Enclosed Cargo Area
4 Unenclosed Cargo Area
5 Trailing Unit
6 Riding on Motor Vehicle Exterior (non-trailing unit)
88 Unknown

Ejection (EJECT)
196
1 Not Ejected
2 Ejected, Totally
3 Ejected, Partially
4 Not Applicable
88 Unknown

Air Bag Deployed (ABD)
197
1 Not Applicable
2 Not Deployed
3 Deployed-Front
4 Deployed-Side
5 Deployed-Other (knee, air belt, etc.)
6 Deployed-Combination
7 Deployed-Curtain
88 Deployment Unknown

NON-MOTORIST

Non-Motorist Description
198
1 Pedestrian
2 Other Pedestrian (wheelchair, person in a building, skater, pedestrian conveyance, etc.)
3 Bicyclist
4 Other Cyclist
5 Occupant of Motor Vehicle Not in Transport (parked, etc.)
6 Occupant of a Non-Motor Vehicle Transportation Device
7 Unknown Type of Non-Motorist

Non-Motorist Location At Time of Crash
199
1 Intersection - Marked Crosswalk
2 Intersection - Unmarked Crosswalk
3 Intersection – Other
4 Midblock - Marked Crosswalk
5 Travel Lane - Other Location
6 Bicycle Lane
7 Shoulder/Roadside
8 Sidewalk
9 Median/Crossing Island
10 Driveway Access
11 Shared-Use Path or Trail
12 Non-Trafficway Area
77 Other, Explain in Narrative
88 Unknown

Action Prior to Crash
200
1 Crossing Roadway
2 Waiting to Cross Roadway
3 Walking/Cycling Along Roadway with Traffic (in or adjacent to travel lane)
4 Walking/Cycling Along Roadway Against Traffic (in or adjacent to travel lane)
5 Walking/Cycling on Sidewalk
6 In Roadway -- Other (working, playing, etc.)
7 Adjacent to Roadway (e.g., shoulder, median)
8 Going to or from School (K-12)
9 Working in Trafficway (incident response)
10 None
77 Other, Explain in Narrative
88 Unknown

Non-Motorist Actions/Circumstances
202
1 No Improper Action
2 Dart/Dash
3 Failure to Yield Right-of-Way
4 Failure to Obey Traffic Signs, Signals, or Officer
5 In Roadway Improperly (standing, lying, working, playing)
6 Disabled Vehicle Related (working on, pushing, leaving/approaching)
7 Entering/Exiting Parked/Standing Vehicle
8 Inattentive (talking, eating, etc)
9 Not Visible (dark clothing, no lighting, etc.)
10 Improper Turn/Merge
11 Improper Passing
12 Wrong-Way Riding or Walking
77 Other, Explain in Narrative
88 Unknown

Safety Equipment
201
1 None
2 Helmet
3 Protective Pads Used (elbows, knees, shins, etc.)
4 Reflective Clothing (jacket, backpack, etc.)
5 Lighting
6 Not Applicable
77 Other, Explain in Narrative
88 Unknown

ALCOHOL/DRUG/EMS

SUSPECTED ALCOHOL USE: 203	ALCOHOL TESTED:	ALCOHOL TEST TYPE:	ALCOHOL TEST RESULT:	BAC	SUSPECTED DRUG USE:	DRUG TESTED:	DRUG TEST TYPE:	DRUG TEST RESULT:
1 No 2 Yes 88 Unknown	1 Test Not Given 2 Test Refused 3 Test Given 88 Unknown, if Tested 204	1 Blood 2 Breath 3 Urine 77 Other, Explain in Narrative 205	1 Pending 2 Completed 88 Unknown 206	207	1 No 2 Yes 88 Unknown 208	1 Test Not Given 2 Test Refused 3 Test Given 88 Unknown, if Tested 209	1 Blood 3 Urine 77 Other, Explain in Narrative 300	1 Positive 2 Negative 3 Pending 88 Unknown 301

SOURCE OF TRANSPORT TO MEDICAL FACILITY	EMS AGENCY NAME OR ID	EMS RUN NUMBER	MEDICAL FACILITY TRANSPORTED TO
1 Not Transported 302 2 EMS 3 Law Enforcement 77 Other, Explain in Narrative 88 Unknown	303	304	305

ADDITIONAL PASSENGERS

VEHICLE #	PASS #	NAME	DATE OF BIRTH	INJ	SEX	LOC: S	R	O	EJECT	HU	EP	ABD	RS
167	165	168, 169, 170, 171	178	183	179	190	191	192	196	193	194	197	195

CURRENT ADDRESS (Number and Street)	CITY & STATE	ZIP CODE
174	175 176	177

SOURCE OF TRANSPORT TO MEDICAL FACILITY	EMS AGENCY NAME OR ID	EMS RUN NUMBER	MEDICAL FACILITY TRANSPORTED TO
1 Not Transported 302 2 EMS 3 Law Enforcement 77 Other, Explain in Narrative 88 Unknown	303	304	305

VEHICLE #	PASS #	NAME	DATE OF BIRTH	INJ	SEX	LOC: S	R	O	EJECT	HU	EP	ABD	RS

CURRENT ADDRESS (Number and Street)	CITY & STATE	ZIP CODE

SOURCE OF TRANSPORT TO MEDICAL FACILITY	EMS AGENCY NAME OR ID	EMS RUN NUMBER	MEDICAL FACILITY TRANSPORTED TO
1 Not Transported 2 EMS 3 Law Enforcement 77 Other, Explain in Narrative 88 Unknown			

NARRATIVE	REPORTING AGENCY CASE NUMBER 2	HSMV CRASH REPORT NUMBER 1

306

ADDITIONAL PASSENGERS

VEHICLE #	PASS #	NAME	DATE OF BIRTH	INJ	SEX	LOC: S	R	O	EJECT	HU	EP	ABD	RS
167	165	168,169,170,171	178	183	179								

CURRENT ADDRESS (Number and Street)	CITY & STATE	ZIP CODE

SOURCE OF TRANSPORT TO MEDICAL FACILITY 1 Not Transported 2 EMS 3 Law Enforcement 77 Other, Explain in Narrative 88 Unknown	EMS AGENCY NAME OR ID	EMS RUN NUMBER	MEDICAL FACILITY TRANSPORTED TO

VEHICLE #	PASS #	NAME	DATE OF BIRTH	INJ	SEX	LOC: S	R	O	EJECT	HU	EP	ABD	RS

CURRENT ADDRESS (Number and Street)	CITY & STATE	ZIP CODE

SOURCE OF TRANSPORT TO MEDICAL FACILITY 1 Not Transported 2 EMS 3 Law Enforcement 77 Other, Explain in Narrative 88 Unknown	EMS AGENCY NAME OR ID	EMS RUN NUMBER	MEDICAL FACILITY TRANSPORTED TO

ADDITIONAL VIOLATIONS

PERSON #	NAME OF VIOLATOR	FL STATUTE NUMBER	CHARGE	CITATION NUMBER
PERSON #	NAME OF VIOLATOR	FL STATUTE NUMBER	CHARGE	CITATION NUMBER

REPORTING OFFICER

ID/BADGE NUMBER	RANK & NAME	DEPARTMENT	FHP	SO	PD	OTHER
307	308 309, 310, 311, 312	313 314				

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Index Table for Florida Traffic Crash Report (HSMV 90010 S)

No.	Data Element	Data Table	Description
1	CRSH_NUM	CART001_CRSH_EVNT	Crash report number.
2	INVSTGT_RPT_ID	CART001_CRSH_EVNT	Case number used by the reporting agency.
3	EVNT_FORM_TYP_CD	CART001_CRSH_EVNT	Type of form.
4	TOT_OF_VHCL_NUM	CART001_CRSH_EVNT	Total number of vehicle sections of the report.
5	TOT_OF_PERS_NUM	CART001_CRSH_EVNT	Total number of person sections of the report.
6	TOT_NARR_SECT_CNT	CART001_CRSH_EVNT	Total number of narrative sections of the report.
7	EVNT_CRSH_TMS	CART001_CRSH_EVNT	Crash date and time.
8	EVNT_CRSH_TMS	CART001_CRSH_EVNT	Crash date and time.
9	RPT_TMS	CART001_CRSH_EVNT	Report date and time.
10	CONTYDMV	CART001_CRSH_EVNT	FLHSMV county code.
11	DHSCTYNO	CART001_CRSH_EVNT	FLHSMV city code.
12	EVNT_CNTY_NM	CART001_CRSH_EVNT	Name of the county in which the crash occurred.
13	EVNT_CTY_PLCE_NM	CART001_CRSH_EVNT	Name of the city or place in which the crash occurred.
14	EVNT_CTY_LMT_CD	CART001_CRSH_EVNT	Code indicating if the crash occurred within city limits.
15	NOTF_TMS	CART001_CRSH_EVNT	Date and time of crash notification.
16	DSPCH_TMS	CART001_CRSH_EVNT	Date and time of law enforcement dispatch.
17	ARR_TMS	CART001_CRSH_EVNT	Date and time that law enforcement arrived on the scene.
18	CLR_TMS	CART001_CRSH_EVNT	Date and time that law enforcement cleared the scene.
19	INVCOMCD	CART001_CRSH_EVNT	Code indicating if the crash report is complete.
20	INCMPLT_RSN_TXT	CART001_CRSH_EVNT	Reason for an incomplete report.
21	NOTF_BY_CD	CART001_CRSH_EVNT	Code indicating whether a motorist or law enforcement sent notification.
22	EVNT_ON_RD_NM	CART001_CRSH_EVNT	Name of the road on which the crash occurred.
23	STR_ADDR_NM_ID	CART001_CRSH_EVNT	Street address number.
24	EVNT_LAT_NUM	CART001_CRSH_EVNT	Latitude.
25	EVNT_LONG_NUM	CART001_CRSH_EVNT	Longitude.
26	FT_INTCT_DSTNC	CART001_CRSH_EVNT	Number of feet from the intersecting road.
27	MI_INTCT_DSTNC	CART001_CRSH_EVNT	Number of miles from the intersecting road.
28	DIRINTCD	CART001_CRSH_EVNT	Direction of the crash from the intersecting road or milepost.
29	EVNT_INTCT_RD_NM	CART001_CRSH_EVNT	Name of the intersecting road from which the crash occurred.
30	FROM_MIPST_NUM_ID	CART001_CRSH_EVNT	Milepost number from which the crash occurred.
31	DHSRDSYS	CART001_CRSH_EVNT	Road system identifier code.
32	TYPESHLD	CART001_CRSH_EVNT	Road shoulder type code.
33	INTCT_TYP_CD	CART001_CRSH_EVNT	Intersection type code.

Index Table for Florida Traffic Crash Report (HSMV 90010 S)

No.	Data Element	Data Table	Description
34	PHTCD	CART001_CRSH_EVNT	Code indicating if the investigator took photographs.
35	LGHT_COND_CD	CART001_CRSH_EVNT	Light condition code.
36	EVNT_WTHR_COND_CD	CART001_CRSH_EVNT	Weather condition code.
37	RD_SRFC_COND_CD	CART001_CRSH_EVNT	Road surface condition code.
38	SCHL_BUS_REL_CD	CART001_CRSH_EVNT	Code indicating school bus involvement.
39	IMPCT_TYP_CD	CART001_CRSH_EVNT	Manner of collision or impact code.
40	FRST_HARM_EVNT_CD	CART001_CRSH_EVNT	First harmful event code.
41	FRST_HARM_LOC_CD	CART001_CRSH_EVNT	Location code of the first harmful event.
42	INTCHG_CD	CART001_CRSH_EVNT	Code indicating if the first harmful event occurred within an interchange.
43	JCT_CD	CART001_CRSH_EVNT	Relation to junction code for the first harmful event for the crash.
44	FRST_RD_COND_CD SCND_RD_COND_CD THRD_RD_COND_CD	CART001_CRSH_EVNT	Road-related contributing causes code of first harmful event.
45	FRST_ENVRN_COND_CD SCND_ENVRN_COND_CD THRD_ENVRN_COND_CD	CART001_CRSH_EVNT	Environmental contributing causes code of first harmful event.
46	WRK_ZONE_REL_CD	CART001_CRSH_EVNT	Code indicating if the crash is work zone related.
47	LOC_WTHN-ZONE_CD	CART001_CRSH_EVNT	Location code within the work zone.
48	WRK_ZONE_TYP_CD	CART001_CRSH_EVNT	Work zone type code.
49	WRK_PRSNT_CD	CART001_CRSH_EVNT	Code for the presence of workers in the work zone.
50	LAW_ENFRC_PRSNT_CD	CART001_CRSH_EVNT	Code for the presence of law enforcement in the work zone.
51	Not applicable	Not applicable	Not applicable.
52	Not applicable	Not applicable	Not applicable.
53	Not applicable	Not applicable	Not applicable.
54	Not applicable	Not applicable	Not applicable.
55	Not applicable	Not applicable	Not applicable.
56	Not applicable	Not applicable	Not applicable.
57	Not applicable	Not applicable	Not applicable.
58	Not applicable	Not applicable	Not applicable.
59	VEH_SQ	CART008_PROP_DMG	Vehicle sequence number.
60	PERS_SQ	CART008_PROP_DMG	Person sequence number.
61	DMG_DS	CART008_PROP_DMG	Property damage other than vehicular.
62	PROP_DMG_ESTM_AMT	CART008_PROP_DMG	Amount of property damage excluding vehicles.
63	OWN_FRST_NM	CART008_PROP_DMG	First name of the owner.
64	OWN_MID_NM	CART008_PROP_DMG	Middle name of the owner.
65	OWN_LAST_NM	CART008_PROP_DMG	Last name of the owner.
66	SUFFIX_01	CART008_PROP_DMG	Suffix to the owner’s name.
67	BUS_CD	CART008_PROP_DMG	Code indicating a business.
68	OWN_STR_ADR_TXT	CART008_PROP_DMG	Street address of the owner.
69	OWN_CTY_TXT	CART008_PROP_DMG	City of the owner.

No.	Data Element	Data Table	Description
70	STATEID	CART008_PROP_DMG	State.
71	ZIPCODE9	CART008_PROP_DMG	Zip code.
72	VEH_SQ	CART002_VHCL	Vehicle sequence number.
73	VHCL_CMRC_CD	CART002_VHCL	Code indicating a commercial vehicle.
74	MOTN_CD	CART002_VHCL	Code indicating the vehicle is in transport, parked, or working.
75	TAG_ID	CART002_VHCL	State license/tag number.
76	REGST	CART002_VHCL	State of license plate/tag.
77	RGST_EXP_DT	CART002_VHCL	Expiration date for vehicle registration.
78	PERM_RGST_CD	CART002_VHCL	Code indicating is the vehicle registration is permanent.
79	VEHIDNO	CART002_VHCL	Vehicle Identification Number (VIN).
80	HAR_CD	CART002_VHCL	Code indicating a hit and run.
81	VEHYEAR	CART002_VHCL	Vehicle year.
82	VHCL_MAKE_TXT	CART002_VHCL	Vehicle make or manufacturer.
83	VHCL_MODL_TXT	CART002_VHCL	Vehicle model.
84	VHCL_STYL_TXT	CART002_VHCL	Vehicle style.
85	VHCL_COLOR_TXT	CART002_VHCL	Vehicle color.
86	DSABL_FNC_DMG_CD	CART002_VHCL	Code indicating the functional level of damage.
87	ESTVEHDM	CART002_VHCL	Estimated amount of vehicle damage.
88	INSUR_CO_NM	CART006_DRIVER	Name of the driver's insurance company.
89	INSUR_IN	CART006_DRIVER	Driver's insurance policy number.
90	TOW_DMG_CD	CART002_VHCL	Code indicating if vehicle is towed or not towed.
91	TOW_CO_NM	CART002_VHCL	Name of the towing business.
92	REMCD	CART002_VHCL	Code indicating who authorized removal of the vehicle.
93	OWN_FRST_NM	CART002_VHCL	First name of the person.
94	OWN_MID_NM	CART002_VHCL	Middle name of the person.
95	OWN_LAST_NM	CART002_VHCL	Last name of the person.
96	SUFFIX_01	CART002_VHCL	Suffix of the person.
97	BUS_CD	CART002_VHCL	Code indicating a business.
98	OWN_STR_ADR_TXT	CART002_VHCL	Street address of the owner.
99	OWN_CTY_TXT	CART002_VHCL	Name of the owner's address city.
100	STATEID	CART002_VHCL	State.
101	ZIPCODE9	CART002_VHCL	Zip code.
102	TRLR_SQ	CART003_TRLR	Number identifying the trailer of a vehicle.
103	TOW_VHCL_TAG_ID	CART003_TRLR	License/tag number of towing vehicle.
104	TOW_VHCL_TAG__ST_ID	CART003_TRLR	State of license plate/tag of towing vehicle.
105	RGST_EXP_DT	CART003_TRLR	Expiration date for vehicle registration.
106	PERM_RGST_CD	CART003_TRLR	Code indicating is the vehicle registration is permanent.

No.	Data Element	Data Table	Description
107	TOW_VHCL_ID	CART003_TRLR	Vehicle Identification Number (VIN) of towing vehicle.
108	TOW_VHCL_YR	CART003_TRLR	Year of towing vehicle.
109	TOW_VHCL_MAKE_ID	CART003_TRLR	Make or manufacturer of towing vehicle.
110	TRLR_LNGTH	CART003_TRLR	Trailer length.
111	TRLR_TOT_AXL_CNT	CART003_TRLR	Total number of axles on vehicle.
112	TRLR_SQ	CART003_TRLR	Number identifying the trailer of a vehicle.
113	TOW_VHCL_TAG_ID	CART003_TRLR	License/tag number of towing vehicle.
114	TOW_VHCL_TAG__ST_ID	CART003_TRLR	State of license plate/tag of towing vehicle.
115	RGST_EXP_DT	CART003_TRLR	Expiration date for vehicle registration.
116	PERM_RGST_CD	CART003_TRLR	Code indicating is the vehicle registration is permanent.
117	TOW_VHCL_ID	CART003_TRLR	Vehicle Identification Number (VIN) of towing vehicle.
118	TOW_VHCL_YR	CART003_TRLR	Year of towing vehicle.
119	TOW_VHCL_MAKE_ID	CART003_TRLR	Make or manufacturer of towing vehicle.
120	TRLR_LNGTH	CART003_TRLR	Trailer length.
121	TRLR_TOT_AXL_CNT	CART003_TRLR	Total number of axles on vehicle.
122	TRAVDIR	CART002_VHCL	Direction in which the vehicle traveled.
123	VHCL_ON_RD_NM	CART002_VHCL	Name of the road on which the vehicle traveled.
124	VEHSPEED	CART002_VHCL	Estimated speed of the vehicle.
125	SPDLIMIT	CART002_VHCL	Posted speed limit of the road on which the vehicle traveled.
126	TOT_LN_CNT	CART002_VHCL	Total lanes on the road on which the vehicle traveled.
127	HAZMAT_RLS_CD	CART002_VHCL	Code indicating the release of hazardous materials.
128	HAZMAT_PLCRD_CD	CART002_VHCL	Code indicating the presence of hazardous material placards.
129	HAZMAT_PLCRD_ID	CART002_VHCL	Hazardous material number on a placard.
130	HAZMAT_CLS_CD	CART002_VHCL	Class of hazardous materials.
131	POINTIMP	CART002_VHCL	Area of initial impact or collision.
132	MOST_DMG_AREA_CD	CART002_VHCL	Most damaged area of the vehicle.
133	CARY_CO_NM	CART004_MOTOR_CARY	Name of the motor carrier or business.
134	CARY_ID	CART004_MOTOR_CARY	US Department of Transportation (DOT) number.
135	CARY_STR_ADR_TXT	CART004_MOTOR_CARY	Street address of the motor carrier or business.
136	CARY_CTY_NM	CART004_MOTOR_CARY	City of the motor carrier or business.
137	CARY_ST_CD	CART004_MOTOR_CARY	State of the motor carrier or business.

No.	Data Element	Data Table	Description
138	CARY_ZIP_CD	CART004_MOTOR_CARY	Zip code of the motor carrier or business.
139	CNTCT_PH	CART002_VHCL	Phone number of the motor carrier or business.
140	VHCL_BDY_TYP_CD	CART002_VHCL	Body type of the vehicle.
141	TRAF_WAY_CD	CART002_VHCL	Traffic way
142	CMRC_VEH_CNFIG_CD	CART002_VHCL	Commercial vehicle configuration.
143	CMRC_USE_CD	CART002_VHCL	Commercial or non-commercial use.
144	TRLR_TYP_CD	CART003_TRLR	Type of trailer (1).
145	TRLR_TYP_CD	CART003_TRLR	Type of trailer (2).
146	CARY_BDY_TYP_CD	CART002_VHCL	Cargo body type.
147	CMRC_VEH_WT_CD	CART002_VHCL	Vehicle weight.
148	MOST_HARM_EVNT_CD	CART002_VHCL	Most harmful event.
149	HARM_EVNT_SQ01_CD HARM_EVNT_SQ02_CD HARM_EVNT_SQ03_CD HARM_EVNT_SQ04_CD	CART002_VHCL	First harmful event. Second harmful event. Third harmful event. Fourth harmful event.
150	EMER_VEH_USE_CD	CART002_VHCL	Code indicating an emergency vehicle.
151	RDWY_GRDE_CD	CART002_VHCL	Grade of the roadway.
152	RDWY_ALIGN_CD	CART002_VHCL	Alignment of the roadway.
153	VHCL_MOVE_CD	CART002_VHCL	Maneuver or action of the vehicle.
154	TRAF_CTRL_CD	CART002_VHCL	Traffic control devices for the vehicle.
155	FRST_VHCL_DFECT_CD SCND_VHCL_DFECT_CD	CART002_VHCL	Vehicle defects (first and second).
156	VHCL_SPCL_FNC_CD	CART002_VHCL	Special function of the vehicle.
157	PERS_SQ	CART009_VIOL	Person sequence number.
158	FRST_NM	CART009_VIOL	First name of the violator.
159	MID_NM	CART009_VIOL	Middle name of the violator.
160	LAST_NM	CART009_VIOL	Last name of the violator.
161	SUFFIX_01	CART009_VIOL	Suffix of the violator.
162	STATU_ID	CART009_VIOL	Florida statute number.
163	CITE_CHRG_DS	CART009_VIOL	Citation charge description.
164	CITE_ID	CART009_VIOL	Citation number.
165	PERS_SQ	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Person sequence number.
166	PERTYPCD		Code indicating a driver, non-motorist, or passenger.
167	VEH_SQ	CART006_DRIVER CART007_PASSENGER	Vehicle sequence number.
168	FRST_NM	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	First name of the person (non-motorist, driver, or passenger).
169	MID_NM	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Middle name of the person (non-motorist, driver, or passenger).
170	LAST_NM	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Last name of the person (non-motorist, driver, or passenger).

No.	Data Element	Data Table	Description
171	SUFFIX_01	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Suffix of the person (non-motorist, driver, or passenger).
172	CNTCT_PH	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Phone number of the person (non-motorist, driver, or passenger).
173	RECOEXD	CART006_DRIVER	Code indicating if a driver re-examination is recommended.
174	PERS_STR_ADR_TXT	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Street address of the person (non-motorist, driver, or passenger).
175	CTY_TXT	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	City of the person (non-motorist, driver, or passenger).
176	STATEID	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	State of the person (non-motorist, driver, or passenger).
177	ZIPCODE9	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Zip code (non-motorist, driver, or passenger).
178	BRTHDTE	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Birth date of the person (non-motorist, driver, or passenger).
179	PERS_SEX_CD	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Gender of the person (non-motorist, driver, or passenger).
180	DL_ID	CART006_DRIVER	Driver license number or identification.
181	LICST	CART006_DRIVER	State of the driver license.
182	DL_EXP_DT	CART006_DRIVER	Expiration date of the driver license.
183	INJSEVER	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Severity of the person’s injury (non-motorist, driver, or passenger).
184	DRLICTYP	CART006_DRIVER	Type of driver license.
185	RQIR_ENDRS_CD	CART006_DRIVER	Code indicating required endorsements.
186	FRST_DR_ACTION_CD SCND_DR_ACTION_CD THRD_DR_ACTION_CD FOUR_DR_ACTION_CD	CART006_DRIVER	First action of the driver at the time of the crash. Second action of the driver at the time of the crash. Third action of the driver at the time of the crash. Fourth action of the driver at the time of the crash.
187	DR_COND_CD	CART006_DRIVER	Condition of the driver at the time of the crash.
188	DR_DSTR_CD	CART006_DRIVER	Distractions to the driver at the time of the crash.
189	VISN_OBST_CD	CART006_DRIVER	Obstructions to the vision of the driver.
190	SEAT_POS_CD	CART006_DRIVER CART007_PASSENGER	Seating side of the person (driver or passenger).

Index Table for Florida Traffic Crash Report (HSMV 90010 S)

No.	Data Element	Data Table	Description
191	ROW_POS_CD	CART006_DRIVER CART007_PASSENGER	Seating row of the person (driver or passenger).
192	OTH_POS_CD	CART006_DRIVER CART007_PASSENGER	Other seating locations of the person (driver or passenger).
193	HLMT_USE_CD	CART006_DRIVER	Code indicating helmet use.
194	EYE_PRTCT_CD	CART006_DRIVER	Eye protection used by the person.
195	RSTRM_SYS_CD	CART006_DRIVER	Restraint systems used by the person.
196	EJCT_CD	CART006_DRIVER	Code indicating ejection of the person.
197	AIR_BAG_DPLOY_CD	CART006_DRIVER	Air bag deployment.
198	NON_MOTR_TYP_CD	CART005_NONMOTORST	Description of the non-motorist.
199	NON_MOTR_LOC_CD	CART005_NONMOTORST	Location of the non-motorist at the time of the crash.
200	ACTN_BFR_CRSH_CD	CART005_NONMOTORST	Action of the non-motorist prior to the crash.
201	FRST_SAF_EQUIP_CD SCND_SAF_EQUIP_CD	CART005_NONMOTORST	Safety equipment (1). Safety equipment (2).
202	NONMOTR_ACTN_01_CD NONMOTR_ACTN_02_CD	CART005_NONMOTORST	Actions or circumstances of the non-motorist (1). Actions or circumstances of the non-motorist (2).
203	SUSP_ALC_USE_CD	CART005_NONMOTORST CART006_DRIVER	Code indicating suspicion of alcohol use for a person (non-motorist or driver).
204	ALC_TST_CD	CART005_NONMOTORST CART006_DRIVER	Code indicating if a test for alcohol was given to a non-motorist or driver.
205	ALC_TST_TYP_CD	CART005_NONMOTORST CART006_DRIVER	Type of alcohol test for a person (non-motorist or driver).
206	ALC_TST_RSLT_CD	CART005_NONMOTORST CART006_DRIVER	Result of alcohol test for a person (non-motorist or driver).
207	BAC_NUM	CART005_NONMOTORST CART006_DRIVER	Blood alcohol level of a person (non-motorist or driver).
208	SUSP_DRUG_USE_CD	CART005_NONMOTORST CART006_DRIVER	Code indicating suspicion of drug use for a person (non-motorist or driver).
209	DRUG_TST_CD	CART005_NONMOTORST CART006_DRIVER	Code indicating if a drug test was given to a non-motorist or driver.
300	DRUG_TST_TYP_CD	CART005_NONMOTORST CART006_DRIVER	Type of drug test for a person (non-motorist or driver).
301	DRUG_TST_RSLT_CD	CART005_NONMOTORST CART006_DRIVER	Result of drug test for a person (non-motorist or driver).
302	TRNSP_SRCE_CD	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Method of transportation to the medical facility (non-motorist, driver, or passenger).
303	EMS_AGCY_NM	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Name of the emergency medical service provider for a person (non-motorist, driver, or passenger).
304	EMS_RUN_NUM_ID	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Number identifying the emergency medical service provider to a person (non-motorist, driver, or passenger).

No.	Data Element	Data Table	Description
305	INJR_TK_LOC_NM	CART005_NONMOTRST CART006_DRIVER CART007_PASSENGER	Name of the medical facility to which a person (non-motorist, driver, or passenger) was transported.
306			Narrative for the crash.
307	INVSTGT_BDGE_ID	CART001_CRSH_EVNT	Badge number / ID of investigator.
308	INVSTGT_RANK_ID	CART001_CRSH_EVNT	Rank of the investigator.
309	INVSTGT_FRST_NM	CART001_CRSH_EVNT	First name of the investigator.
310	INVSTGT_MID_NM	CART001_CRSH_EVNT	Middle name of the investigator.
311	INVSTGT_LAST_NM	CART001_CRSH_EVNT	Last name of the investigator.
312	INVSTGT_SUF_TXT	CART001_CRSH_EVNT	Suffix of the investigator.
313	INVSTGT_AGCY_NM	CART001_CRSH_EVNT	Name of the investigating agency.
314	INVSTGT_AGCY_CD	CART001_CRSH_EVNT	Code for the investigating agency.

District	Crash Rate Category	Average Crash Rate	Influence Area Crashes	Crash Count	Millions Entering Vehicles	Total Centerline Miles	Average Economic Loss Per Crash	Average Economic Loss Per Injury	Total Property Damage Only Crashes	Total Crashes With Highest Injury Possible	Total Crashes With Highest Injury Non Incapacitating	Total Crashes With Highest Injury Incapacitating	Total Crashes Involving Traffic Fatality	Total Crashes With Only Injury Non Traffic Fatality	Total Non Injured Persons	Total Persons With Possible Injury	Total Persons With Non Incapacitating Injury	Total Persons With Incapacitating Injury	Total Traffic Fatalities	Total Non Traffic Fatalities
Statewide	Interstate Urban	0.7908	855	103810	132352	3981	$ 148,682	$ 153,963	62186	22221	14430	5009	757	62	204629	40909	20755	6741	853	73
Statewide	Interstate Rural	0.38857	24	16890	43529	3498	$ 302,015	$ 341,754	9468	2903	2741	1454	340	8	30096	6079	4467	2186	416	13
Statewide	Toll Road Urban	0.65684	433	29207	45124	2312	$ 127,481	$ 130,641	17961	6506	3852	1141	170	10	55042	11802	5370	1478	193	11
Statewide	Toll Road Rural	0.36673	17	3351	9184	906	$ 216,945	$ 245,627	1834	681	607	198	43	5	5978	1523	1065	301	50	6
Statewide	Urban Other Limited Access	1.66801	3298	20327	14164	661	$ 94,131	$ 93,026	15207	5363	2347	614	84	10	49199	9493	3234	788	90	12
Statewide	Rural Other Limited Access	0.53203	22	12	64	20	$ 666,398	$ 639,511	23	4	3	2	2	0	79	11	9	3	2	0
Statewide	Ramp Urban	0	49866	14957	3614	1045	$ 100,326	$ 96,160	40860	14131	7400	2182	233	17	126432	23622	9823	2671	249	21
Statewide	Ramp Rural	0	48152	30336	7493	4277	$ 126,061	$ 125,381	46522	17815	10310	3405	411	25	156097	30613	14300	4312	451	33
Statewide	Urban 2-3Ln 2Wy Divd Rasd	5.18691	1901	2219	794	197	$ 102,876	$ 97,428	2468	934	538	166	13	1	9086	1589	715	203	13	1
Statewide	Urban 2-3Ln 2Wy Divd Pavd	4.16541	2768	7935	2569	616	$ 119,452	$ 114,405	6248	2442	1523	434	49	7	23015	3979	2076	538	51	7
Statewide	Urban 2-3Ln 2Wy Undivd	2.77556	1722	4901	2386	957	$ 133,473	$ 125,974	3951	1312	1015	306	38	1	13977	2120	1317	349	41	1
Statewide	Suburban 2-3Ln 2Wy Divd Rasd	2.63475	682	1874	970	239	$ 172,891	$ 186,560	1429	592	352	160	22	1	5564	1089	535	202	27	1
Statewide	Suburban 2-3Ln 2Wy Divd Pavd	2.24948	3751	15715	8654	1989	$ 180,880	$ 188,178	10255	4525	3271	1236	173	6	41219	8766	4841	1658	190	7
Statewide	Suburban 2-3Ln 2Wy Undivd	0.93205	1511	14227	16885	5722	$ 241,539	$ 245,281	7895	3437	2913	1272	216	5	30895	6739	4338	1719	229	8
Statewide	Rural 2-3Ln 2Wy Divd Rasd	1.10697	174	605	704	181	$ 253,240	$ 242,671	417	145	146	59	12	0	1599	294	209	74	12	0
Statewide	Rural 2-3Ln 2Wy Divd Pavd	1.79533	917	4151	2823	1027	$ 334,773	$ 358,031	2373	1126	976	482	111	0	9370	2442	1566	722	123	3
Statewide	Rural 2-3Ln 2Wy Undivd	0.64711	1229	16646	27623	19125	$ 486,090	$ 526,887	8180	3364	3511	2172	634	14	26534	6810	5606	3274	735	17
Statewide	Urban 4-5Ln 2Wy Divd Rasd	2.84759	17191	81712	34732	4250	$ 136,002	$ 131,445	55959	23317	14576	4438	575	38	216115	39903	19986	5474	596	50
Statewide	Urban 4-5Ln 2Wy Divd Pavd	4.72752	18997	74848	19851	2437	$ 110,752	$ 106,033	59093	19442	11600	3266	423	21	211320	32990	15597	3985	445	37
Statewide	Urban 4-5Ln 2Wy Undivd	5.2225	2054	12502	2787	475	$ 113,069	$ 107,908	9069	3001	1828	589	64	5	32408	5027	2517	708	67	7

Statewide	Suburban 4-5Ln 2Wy Divd Rasd	1.45912	4741	64897	47726	5477	$ 217,645	$ 222,214	34989	16955	12041	4772	838	43	145065	31909	17652	6377	905	57
Statewide	Suburban 4-5Ln 2Wy Divd Pavd	1.9715	863	8484	4741	509	$ 173,076	$ 171,684	5183	2181	1403	492	84	4	20864	3937	1973	653	88	5
Statewide	Suburban 4-5Ln 2Wy Undivd	1.34569	33	318	261	49	$ 170,708	$ 161,173	156	87	75	31	2	0	776	157	104	34	2	0
Statewide	Rural 4-5Ln 2Wy Divd Rasd	0.59578	356	10290	17869	4532	$ 431,701	$ 467,769	4815	2101	2198	1196	324	12	16716	4341	3575	1721	376	16
Statewide	Rural 4-5Ln 2Wy Divd Pavd	0.49792	6	545	1107	298	$ 415,313	$ 409,486	255	118	100	62	16	0	785	220	141	81	17	0
Statewide	Rural 4-5Ln 2Wy Undivd	1.42227	0	10	7	2	$ 82,539	$ 115,320	3	5	2	0	0	0	10	14	2	0	0	0
Statewide	Urban 6+Ln 2Wy Divd Rasd	3.74574	36764	221439	68932	4525	$ 119,647	$ 115,750	154124	59570	32980	10207	1251	71	582505	102122	45198	12734	1300	87
Statewide	Urban 6+Ln 2Wy Divd Pavd	4.12556	2502	16139	4518	323	$ 150,866	$ 147,197	10748	4166	2670	919	134	4	42341	7356	3672	1142	141	6
Statewide	Urban 6+Ln 2Wy Undivd	53.42096	42	275	6	1	$ 78,301	$ 62,606	244	33	31	8	1	0	736	44	34	8	1	0
Statewide	Suburban 6+Ln 2Wy Divd Rasd	2.21871	4623	51680	25376	1565	$ 151,414	$ 153,733	29826	14805	8061	3226	363	22	125097	26673	11498	4261	390	31
Statewide	Suburban 6+Ln 2Wy Divd Pavd	1.23379	48	1256	1057	55	$ 166,348	$ 163,648	785	274	173	59	12	1	2803	485	227	75	13	2
Statewide	Suburban 6+Ln 2Wy Undivd	0	0	0	1	1	$ -	$ -	0	0	0	0	0	0	0	0	0	0	0	0
Statewide	Rural 6+Ln 2Wy Divd Rasd	1.08617	18	305	297	45	$ 230,535	$ 235,465	148	75	71	24	4	1	751	180	110	31	4	1
Statewide	Rural 6+Ln 2Wy Divd Pavd	0.25316	0	19	75	29	$ 1,197,507	$ 1,636,800	7	3	5	2	2	0	16	5	9	4	3	0
Statewide	Rural 6+Ln 2Wy Undivd	0	0	0	0	0	$ -	$ -	0	0	0	0	0	0	0	0	0	0	0	0
Statewide	Urban One Way	8.56758	8265	23199	3672	957	$ 84,949	$ 78,091	21746	5586	3117	915	92	8	72451	8972	4193	1081	95	15
Statewide	Suburban One Way	2.44993	1760	4082	2385	459	$ 96,981	$ 89,360	3916	1104	638	161	23	0	13339	1833	827	199	23	0
Statewide	Rural One Way	5.5757	481	226	127	100	$ 158,245	$ 148,839	427	150	93	31	6	0	1473	259	118	41	6	0
Statewide	Undefined	0	7710	2487	0	0	$ 111,634	$ 109,739	6253	2216	1300	379	44	5	21007	3803	1795	466	48	7
Statewide	Totals	1.59728	23753	861876	554459	72840	$ 155,695	$ 156,457	511004	198685	125088	43693	6802	357	1863995	352374	176253	56966	7407	461

U.S. Department of Transportation
Federal Highway Administration
1200 New Jersey Avenue, SE
Washington, DC 20590
202-366-4000

Safety

Roadway Departure Safety: A Manual for Local Rural Road Owners

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Appendix C: Crash Rate Calculations

The crash rate for roadway departure crashes on a roadway is calculated as:

$$R = \frac{C \times 100{,}000{,}000}{V \times 365 \times N \times L}$$

The variables in this equation are:

R = Roadway Departure crash rate for the road segment expressed as crashes per 100 million vehicle-miles of travel,
C = Total number of roadway departure crashes in the study period
V = Traffic volumes using Average Annual Daily Traffic (AADT) volumes
N = Number of years of data
L = Length of the roadway segment in miles

This equation relies on having traffic volume information To determine how to obtain actual and estimated traffic volumes for a particular roadway, a local agency can contact its State highway agency, LTAP representative, or other state agencies.

Example 1. Crash Rate by Vehicle Miles Traveled

In this example, two roadways have the same number of crashes but different traffic volumes. By factoring in exposure, the calculation indicates that Route B may be more susceptible to future crashes. However, before any decision is made, other factors such as roadway geometrics, cross section, and other potential differentiating factors should be considered. There could be other issues not related to traffic volume that affect crash rates.

Table 3. Example of Roadway Departure Crash Rate Calculation by Vehicle Miles Traveled

Roadway	RD Crashes (C)	Traffic Volume (V)	Years of Data (N)	Length of segment (L)	Crash Rate (L)
Route A	15	4,000	5	12 miles	0.98

Route B	15	2,500	5	12 miles	1.85

Route A has experienced 0.98 crashes per 100 million vehicle-miles traveled on that roadway. Route B has experienced 1.85 crashes per 100 million vehicle-miles traveled. This data can be used to compare the two roadways. In this case, even though both routes had the same number of crashes, Route B is more susceptible to crashes based on the level of exposure. The practitioner could consider Route B a more promising candidate for a safety treatment than Route A due to its higher crash rate.

Example 2. Crash Rate by Route Length

In this example, two roadways have the same number of crashes but different roadway lengths. Traffic volume data is not available.

A "crashes per mile" rate for road segments is calculated as:

$$R = \frac{C}{N \times L}$$

Where:

R = Crashes per mile for the road segment expressed as crashes per each 1 mile of roadway per year.
C = Total number of crashes in the study period.
N = Number of years of data.
L = Length of the roadway segment in miles.

Table 4. Example of Roadway Departure Crash Rate Calculation by Route Length

Roadway	RD Crashes (C)	Years of Data (N)	Length of Segment (L)	Crashes per Mile (R)
Route A	12	5	17 miles	0.71
Route B	12	5	26 miles	0.46

In this example, Route A has experienced 0.71 crashes per roadway mile. Route B has experienced 0.46 crashes per mile of roadway. In this case, even though both routes have the same number of crashes, Route A may be more susceptible to future crashes. Therefore Route A may be a more promising candidate for safety treatments.

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Page last modified on June 28, 2011.

Safe Roads for a Safer Future
Investment in roadway safety saves lives

Harmful Events from the Crash Analysis Reporting (CAR) System associated with Controlling Elements

Code	Harmful Event (Crash Type)	DS	LW	SW	BW	HA	SE	VA	G	SSD	CS	VC	LO	SC
00	Unknown/Not Coded	X	X	X	X	X	X	X	X	X	X	X	X	X
01	Rear-End	X		X	X			X	X	X	X	X		
02	Head-On		X	X	X	X	X	X	X	X				
03	Angle					X		X		X				
04	Left-Turn	X	X					X		X				
05	Right-Turn	X	X					X		X				
06	Sideswipe		X	X	X	X	X				X			
07	Backed Into							X	X					
08	Collision with Parked Car		X	X	X		X				X		X	
09	Collision with Moving Vehicle on Roadway	X	X	X	X	X	X	X		X	X			
10	Collision with Pedestrian	X	X	X	X	X	X	X		X	X			
11	Collision with Bicycle	X	X	X	X	X	X	X		X	X			
12	Collision with Bicycle (Bike Lane)	X	X	X	X	X	X	X		X	X			
13	Collision with Moped	X	X	X	X	X	X	X		X	X			
14	Collision with Train									X				X
15	Collision with Animal	X						X		X				
16	Hit Sign/ Sign Post		X	X		X	X				X	X	X	
17	Utility/ Light Pole		X	X		X	X				X		X	
18	Hit Guardrail		X	X	X	X	X		X		X		X	
19	Hit Fence		X	X	X	X	X		X		X		X	
20	Hit Concrete Barrier Wall		X	X	X	X	X		X		X	X	X	X
21	Hit Bridge/ Pier/ Abutment / Rail		X	X	X	X	X				X	X	X	X
22	Hit Tree/ Shrubbery		X	X		X	X				X		X	
23	Collision with Construction Barricade Sign	X	X	X									X	
24	Collision with Traffic Gate												X	
25	Collision with Crash Attenuaters	X	X	X									X	
26	Collision with Fixed Object Above Road											X		
27	Hit Other Fixed Object		X	X	X	X	X				X		X	X
28	Collision with Moveable Object on Road				X			X		X				
29	Ran in Ditch Culvert		X	X		X	X						X	
30	Ran Off Road into Water			X		X	X						X	
31	Overturned	X		X		X	X		X					
32	Occupant Fell from Vehicle													
33	Jackknifed	X		X					X					
34	Fire											X		
35	Explosion											X		X
36	Downhill Runaway	X						X	X					
37	Cargo Loss or Shift					X	X	X	X			X		X
38	Separation of Units					X	X	X	X			X		
39	Median Crossover		X	X	X	X	X	X						
77	All other (Explain)	X	X	X	X	X	X	X	X	X	X	X	X	X

Legend:

DS = Design Speed
LW = Lane Width
SW = Shoulder Width
BW = Bridge Width
HA = Horizontal Alignment
SE = Superelevation
VA = Vertical Alignment
G = Grade
SSD = Stopping Sight Distance
CS = Cross Slope
VC = Vertical Clearance
LO = Lateral Offset
SC = Structural Capacity

SAFETY ANALYSIS TOOLS FOR DESIGN EXCEPTIONS AND VARIATIONS (MAY 2013)

13 Controlling Design Elements	2-lane Undivided			4-lane Undivided			4-lane Divided			Urban & Suburban Arterials			Freeways			Speed-Change Lanes			Ramps			All Facilities		Reference ID for State Safety Office CRFs or CRF Recommended Range
	Highway Safety Manual		FHWA Clearinghouse CMFs	Highway Safety Manual		FHWA Clearinghouse CMFs	Highway Safety Manual		FHWA Clearinghouse CMFs	Highway Safety Manual		FHWA Clearinghouse CMFs	Highway Safety Manual		FHWA Clearinghouse CMFs	Highway Safety Manual		FHWA Clearinghouse CMFs	Highway Safety Manual		FHWA Clearinghouse CMFs	Roadside Safety Analysis Program (RSAP)	Historical Crash Method (HCM)	
	Part C	Part D		Part C	Part D		Part C	Part D		Part C	Part D		Part C	Part D		Part C	Part D		Part C	Part D				
Design Speed			5-Star (5)			5-Star (5)			5-Star (5)		✓	3-Star (6) 4-Star (1) 5-Star (6)			5-Star (5)								✓	45, 116
Lane Width	✓	✓	3-Star (4) 4-Star (6) 5-Star (12) Unrated (7)	✓	✓	3-Star (4) 4-Star (6) 5-Star (10) Unrated (5)	✓	✓	3-Star (4) 4-Star (6) 5-Star (8) Unrated (5)	✓	✓	3-Star (3) 4-Star (8) 5-Star (17)) Unrated (5)	✓	✓	3-Star (5) 4-Star (1) 5-Star (1)	✓	✓		✓	✓			✓	18-22, 30-34, 43, 90, 95, 106, 118, 120-122, 126
Shoulder Width	✓	✓	3-Star (4) 4-Star (6) 5-Star (15) Unrated (7)	✓	✓	3-Star (4) 4-Star (6) 5-Star (10) Unrated (5)	✓	✓	3-Star (4) 4-Star (6) 5-Star (8) Unrated (5)		✓	3-Star (3) 4-Star (8) 5-Star (20) Unrated (5)	✓	✓	3-Star (5) 4-Star (1) 5-Star (1)	✓	✓		✓			✓	✓	18-22, 30-34, 43, 91, 92, 95, 106, 117, 118, 120-123, 126
Bridge Width																							✓	94
Horizontal Alignment	✓	✓										5-Star (3)	✓			✓			✓				✓	84, 96
Superelevation	✓	✓																					✓	85, 95, 96
Vertical Alignment		✓	3-Star (1) Unrated (1)																				✓	
Grade	✓	✓	3-Star (1) Unrated (1)																				✓	95
Stopping Sight Distance																							✓	104
Cross Slope																							✓	Recommended CRF Range 0.30 - 0.33
Vertical Clearance																							✓	
Horizontal Clearance (lateral offset to obstruction)	✓	✓	3-Star (4) 4-Star (2) 5-Star (7) Unrated (32)		✓	3-Star (3) 4-Star (2) 5-Star (3)		✓	3-Star (3) 4-Star (6) 5-Star (4)		✓	3-Star (3) 4-Star (2) 5-Star (1)		✓	3-Star (3) 4-Star (2) 5-Star (1)		✓		✓	✓		✓	✓	23-29, 35-38, 78-83, 101, 107, 114, 125, 127
Structural Capacity	Provide Load Rating Calculations and Maintenance Office Recommendation for Inventory Ratings less than 1.0. See FDOT Structures Design Guide Sections 1.7, 3.15.14, 4.6.10, & 7.1.1 and FDOT Bridge Load Rating Manual (http://www.dot.state.fl.us/statemaintenanceoffice/LRManual82012.pdf)																							105

NOTES:
1. The interactive version of this spreadsheet will be coming soon.
2. 1-Star (#) - Numbers in parenthesis indicate number of available FHWA Clearinghouse CMFs with its corresponding Star Rating as of May 2013. This table will be updated on an as-needed basis using the latest FHWA Clearinghouse CMFs which are updated quarterly.
3. CMF - measures the percentage of change in number of crashes as a result of implementing one or more countermeasures; typically are applied in HSM Predictive Analyses.
4. CRF - measures the percent reduction in number of crashes as a result of implementing one or more countermeasures; typically are applied in Historical Crash Method Analyses.
5. CMF & CRF - multiplicative factors that can help identify the safety impacts of implementing one or more countermeasures. Mathematically related: CMF = 1 - (CRF / 100).
6. FDOT State Safety Office CRFs with less than 3 Projects are not recommended for use. In any analysis, no more than 3 Cumulative CMFs/CRFs should be used. Non cumulative CRFs or CRFs shall not be used together. (e.g. a stop sign and a traffic signal)
7. FHWA CRFs can be used with the Historical Crash Method.
8. References used to produce this table include:

Reference	Website
Highway Safety Manual	www.highwaysafetymanual.org
FHWA Clearinghouse	www.clearinghouse.org
FDOT State Safety Office CRFs	www.dot.state.fl.us/rddesign/QA/Tools/CRF.pdf
FDOT Roadway Design Office	www.dot.state.fl.us/rddesign/default.shtm
FHWA Desktop Reference for Crash Reduction Factors	safety.fhwa.dot.gov/tools/crf/resources/fhwasa08011

Crash Reduction Factors (as of 02/14/2014)

Florida Department of Transportation

Note: Use of CRFs based on less than 5 projects (Column C) are not recommended for use in B/C analysis. Positive CRFs imply reduced crashes. Negative CRFs imply increased crashes.

ID	Improvement	Potential Controlling Criteria Application														Number of Projects	Total	Fatal	Injury	PDO	Urban	Rural	Night	Day	Rear-End	Angle	Left-Turn	Right-Turn	Sideswipe	Fixed-Object	Head-On	Pedestrian	Ran-Off-Road	Wet Surface
		DS	LW	SW	BW	HA	SE	VA	G	SSD	CS	VC	HC	SC	Other																			
1	**New signal at channelized intersection**									x						***31***	12	15	20	-1	13	7	4	16	-51	53	16	70	10	-40	53	-90	-90	20
2	**New signal at non-channelized intersection**									x						***11***	15	58	15	14	20	-27	21	13	-5	11	34	23	23	51	-46	13	26	11
3	**Add signal and channelization**									x						***19***	19	-8	25	13	17	21	-41	31	-8	40	50	26	-16	-3	48	58	51	34
4	**Modify signal at channelized intersection**									x						***7***	11		31	-18	11		-13	18	29	20	17	7	-4	-272	-272	7	-86	22
5	Modify signal at non-channelized intersection									x						2	-99	-23	-118	-85	38	-141	-126	-73	-48	-94	-188	100	-23	38				-48
6	**Modify both signal and channelization**									x						***15***	24	50	33	13	25	-20	7	29	6	30	66	-4	4	4	-59	34	-164	33
7	**Modify signal and add channelization**									x						***10***	28	-87	27	29	28	30	-1	35	11	37	49	25	-42	-20	-87		38	-17
8	Remove signal														x	0																		
9	Add flashing warning signal (signalization)					x		x		x						4	-2	100	-37	28		-2	59	-22	80	-30	-117	100	-63	100			100	46
10	Interconnect traffic signals	x														0																		
11	**New LT channelization w/ LT phase (signalized)**	x														***9***	17	59	36	-9	16	44	16	19	5	16	50	-42	12	-1	15	29	68	18
12	**New LT channelization w/o LT phase (signalized)**	x														***10***	31	79	35	26	31	39	33	30	18	46	61	42	39	-26	38	41	12	49
13	**New LT channelization (nonsignalized intersection)**	x														***46***	3	61	9	-6	-6	20	-26	9	-5	7	24	42	1	-19	-26	6	0	21
14	**Modify intersection at signalized intersection**					x				x			x			***28***	6	-24	13	0	5	78	1	8	7	10	28	11	3	21	-9	16	24	18
15	**Modify intersection at non-signalized intersection**					x				x			x			***5***	18	66	32	6	18	100	13	15	10	25	59	43	31	-53	39	-2	-2	17
16	Modify channelization and add signal		x	x												2	22		21	22	22		-131	18	11	16	39	33	-6	58	-68	16	-26	5
17	**Increase storage lane**														x	***8***	11	-76	15	9	20	-10	-9	17	0	8	15	-36	7	1	-68	17	-6	17
18	**Add turn bay**		**x**	**x**				x		x						***8***	10	52	16	-1	10	10	1	11	5	6	21	36	20	-222	-190		36	48
19	**Add right turn**	x	**x**	**x**												***8***	9	67	9	8	0	52	-6	3	11	16	37	1	-20	-39	-33	-49	100	16
20	Add LT (T-intersection)	x	**x**	**x**												3	42	9	56	31	42	43	-39	61	37	84	84	-81	55	-55	100		48	-81
21	Add LT (Y-intersection)	x	**x**	**x**												1	42	-118	53	31	42		24	56	52	48	84	46	17	32	69	-118	27	64
22	**Add 2nd LT lane in same direction as existing**		**x**	**x**											x	***15***	4	0	13	-3	1	92	0	2	1	22	30	45	-33	28	-135	-25	13	15
23	Guardrail at bridges end				x								**x**			0																		
24	Guardrail at steep embankments		x	x									**x**			3	-5	-3	3	-16	-2	-19	-63	2	3	-184	-55		74	-120	100		5	-9
25	Guardrail at steep embankments with curve		x	x			x						**x**			1	-256		-78			-256		-167					100					11
26	Guardrail at roadside obstacles (piers, sign posts, poles, etc.)		x	x									**x**			1	52		60	37	52		27	62	44	100			68	37	100	100		54
27	Guardrail end treatments		x	x									**x**			0																		
28	Guardrail relocation		x	x									**x**			0																		
29	Guardrail removal		x	x									**x**			0																		
30	Add painted median		**x**	**x**											x	2	43	78	43	40		43	-273	25	33	14	68	66	62	-72	57	83	-15	39
31	**Add raised median**		**x**	**x**											x	***18***	20	38	19	20	20		22	19	2	29	48	23	41	-2	45	22	-37	27
32	Increase median width		**x**	**x**									x			4	-2	-12	0	-3	-10	100	-19	3	3	-43	5	3	-28	30	-699	-224	60	45
33	**Add two-way LT lanes**	x	**x**	**x**												***12***	41	35	45	39	40	44	33	44	58	32	36	32	38	34	18	-24	27	24
34	Install concrete median barrier		**x**	**x**									x			1	-37	56	-27	-46	-37		-71	-36	-46	-407	56	94	29	-112	9	-58	-73	-48
35	**Install double sided guardrail on wider median**		x	x									**x**			***12***	-16	33	1	-38	-29	1	-15	-17	3	-4	2		19	-83	61	-96	28	-54
36	Install attenuator type (IBC) barrier			x	x								**x**			0																		
37	Upgrade to concrete median barrier			x	x								**x**			0																		
38	Upgrade to attenuator barrier			x	x								**x**			0																		
39	Pavement deslicking										x	x				4	-3	-30	-13	2	-2	-20	-34	3	17	-24	-7	8	-43	8	-399	35	-127	30
40	**Skid Hazard overlay**										x	x				***95***	-6	-53	-5	-6	-5	-19	-11	-3	2	-35	0	5	-11	-9	-19	-13	-7	18
41	Pavement grooving										x	x				0																		
42	Eliminate parking		x	x						x				x		4	12	100	11	12	12		8	13	2	29	32	46	25	14	13	63		26
43	Change two-way operation to one-way		**x**	**x**												0																		
44	Prohibit turns									x						2	-190	100	-99	-309	-190		-43	-360	-198	-138				-19	-19	-19		-99
45	Modify speed limit (increase or decrease)	**x**					x	x		x				x		1	52	56	50	53		52		54	-18	75	85		71	56			100	78
46	Delineation of right edge lines		x	x												0																		
47	Delineation of painted median edge lines		x	x												1	-76		-18	-155	-76		-65	-85	-85	7	-85		31	-410				
48	Centerline striping		x													0																		
49	Delineation of no passing stripes		x			x		x		x						0																		
50	Delineation of reflectorized guide markers		x	x		x										0																		
51	Delineation of reflectorized raised pavement markers (center line)		x			x										1	10	23	11	5		21	16	3	7	7	-62	100	81	-36	38	100	25	7
52	Delineation of general pavement markings (stop bar, ped. crossing, code 46-51)		x	x						x						0																		
53	Delineation of guide posts on curves					x	x									0																		
54	Intersection delineation		x			x				x						0																		

ID	Improvement	Potential Controlling Criteria Application														Number of Projects	Total	Fatal	Injury	PDO	Urban	Rural	Night	Day	Rear-End	Angle	Left-Turn	Right-Turn	Sideswipe	Fixed-Object	Head-On	Pedestrian	Ran-Off-Road	Wet Surface
		DS	LW	SW	BW	HA	SE	VA	G	SSD	CS	VC	HC	SC	Other																			
55	Curve warning Signing	x				x	x									2	35		6	49	44	-306	56	21	72	-2	32		49	49	-2			-19
56	Chevrons Signing	x				x	x									1	30		12	63		30	-120	78	-120		100		100	-65	100	100	45	-120
57	All-way stops Signing									x						0																		
58	Overhead directional (where to turn) Signing														x	3	-7	100	-9	-5	-7		-17	-4	-15	16	9	41	14	-13	-383	-45		-11
59	Roadside directional (where to turn) Signing														x	0																		
60	Overhead lane designation Signing														x	0																		
61	Minor leg stop control Signing					x				x						0																		
62	Yield sign					x				x						0																		
63	Advanced warning signs				x	x	x	x	x	x		x		x	x	1	60		60			60		60			100							
64	Intersection directional or warning signs					x									x	0																		
65	**New roadway segment lighting**							x		x			x			***58***	2	23	10	-9	2	26	14	-5	-2	-4	25	20	1	-16	-11	33	16	6
66	**Upgrade roadway segment lighting**							x		x			x			***7***	-12	15	-11	-14	-12	100	0	-18	-22	-27	23	57	-1	-8	-39	-1	12	0
67	**New lighting at intersection**							x		x			x			***9***	-2	5	-11	8	-4	-1	31	-15	-30	-15	9	41	12	24	-42	-279	41	-26
68	Upgrade lighting at intersection							x		x			x			0																		
70	Bridge approach lighting			x	x								x			1	9		-5	21		9		32	-42				62	37			-26	24
71	Underpass lighting											x				0																		
72	Intersection flashers four leg red-yellow					x				x						2	-59			100		-59		36		-91	52							
73	Intersection flashers three leg red-yellow					x				x						0																		
74	Intersection flashers four way red					x				x						0																		-105
76	Advanced warning flashers (curve & intersection)					x	x			x						1																		
77	**Install flashing warning signal (flashing beacon)**					x				x						***5***	-29		-65	-12	-52	23	-111	-11	-80	-55	6	48	11	-48	100		29	-46
78	**Obstacle Removal/Hazard Mitigation**												**x**			***5***	25	28	37	5	26	19	33	19	22	37	44	14	4	19	6	-38	61	28
79	Relocate obstacle 30 feet from road												**x**			0																		
80	Convert to breakaway												**x**			0																		
81	Cushion attenuators												**x**			0																		
82	**Install guardrail**			x	x								**x**			***9***	-38	43	-9	-77	-57	16	-44	-37	-19	-37	19	100	-32	-82	-49	27	-6	-67
83	Upgrade substandard bridgerail			x	x								**x**			1	25		100	-125	25		100	-12						-12				
84	Realignment					**x**		x		x						3	60	50	71	50	-50	100	33	60	57	100	100			-200				0
85	Superelevation					x	**x**									1																		
86	**Modify/Close median openings**	x								x						***27***	18	40	26	9	18	92	6	21	6	29	58	25	11	-18	-46	-25	45	20
87	Relocate drives						x			x					x	0																		
88	Curtail turning movements									x					x	0																		
89	Increase radii at intersection					x				x						2	38	100	16	58		57	21	44	-5	48	-5					100		-109
90	Widen travel way		**x**				x									2	-52	27	-31	-66		-2	-149	-40	7	-56	-136	-164	-27	-10	45	-10	-147	-65
91	Widen shoulder			**x**						x						1	-9	26	-11	-11		16	-845	-18	5	-178	-48	-233	72	-39	-48		-78	1
92	Add 4 foot shoulders (bike lane)			**x**												1	6		15	3	6		-95	17	-15	-37	57	59	51	-173			67	-18
93	Construct grade separation					x		x		x					x	0																		
94	**Widen bridge (min. of 6 feet)**		x	x	**x**											***5***	55	-39	19	73	-39	65	7	61	48	-109	54	100	69	51	30	30	79	25
95	**Reconstruct road & shoulders**		**x**	**x**			**x**		**x**							***10***	-11	-99	-13	-8	-23	66	-41	-2	-1	-51	-9	9	-10	-35	-43	-29	-73	12
96	Reconstruct curve					**x**	**x**									3	42	100	53	43	40	54	28	53	23	27	58	100	78	48	100	17	64	27
97	Construct interchange					x		x		x						1	-60	100	-188	-24		100	100	-99	-61				-13	-50			25	-126
98	Lengthen accel/decel lanes	x								x						1																		
99	Extend drop lane	x								x						0																		
100	**Install rumble strips**		x	x	x	x	x			x						***9***	22	50	19	22	4	23	38	7	0	14	17	-56	48	4	36	-56	46	20
101	Flatten side slopes			x									**x**			0																		
102	Install Accel/Decel lane	x								x						2	20	100	9	8		20	52	10	39	22	-7		46			100	57	-115
103	**Upgrade signal and add pedestrian feature**									x					x	***17***	-5	10	16	-20	-5		-7	-7	-20	-20	19	-9	0	19	-78	0	37	-2
104	Sight distance improvements					x				**x**						3	25	-93	38	10	24	25	61	4	13	49	81		52	100				4
105	Minor structures replaced or improved for safety												x	**x**		1	14		32	-23	14		23	5	3	22	45	56	-14	56	100	-17		-86
106	Lanes added to travel way		**x**	**x**												4	13	69	18	5	13		26	5	-2	35	72	6	-15	-26	-214	-183	53	6
107	Upgraded guardrail			x	x								**x**			1	-22	-46	-16	-33	2	-44	8	-44	-25	-7	-155	-292	29	-85	-370	74	-10	-1
108	**Sidewalk construction**														x	***15***	-11	-9	1	-29	-11		2	-19	-16	-11	14	3	-34	-2	43	15	-15	1
109	Over/Under passes for pedestrians and/or bicycles														x	2	37		7	67	37		31	35	20	100			57		13			48
110	Fencing or other pedestrian barriers												x		x	2	-4	100	11	-43	-4		-61	4	3	10	27	100	-107	-12	3	-45		1
111	Ramps on existing curbs														x	0																		
112	New bikeway/multi-use path construction														x	0																		
113	Bicycle non-construction improvements														x	0																		
114	Impact Attenuators			x	x								**x**			3	2		16	-27	2		-14	4	-3	-14	45	-36	26	-70	-2	-2	74	2

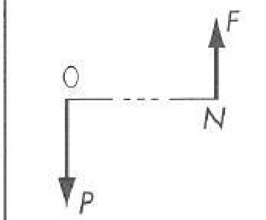
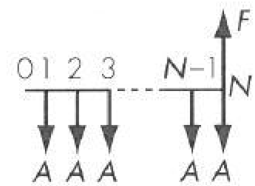
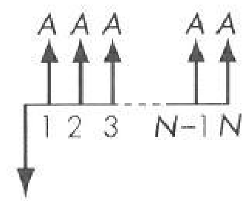
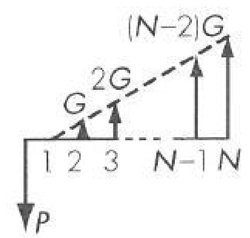
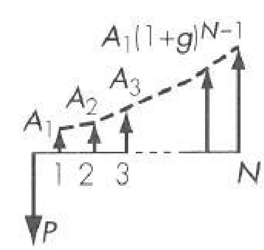
ID	Improvement	Potential Controlling Criteria Application														Number of Projects	Total	Fatal	Injury	PDO	Urban	Rural	Night	Day	Rear-End	Angle	Left-Turn	Right-Turn	Sideswipe	Fixed-Object	Head-On	Pedestrian	Ran-Off-Road	Wet Surface
		DS	LW	SW	BW	HA	SE	VA	G	SSD	CS	VC	HC	SC	Other																			
115	**Signing and Pavement Markings**		x	x	x		x				x					***11***	11	1	11	11	11	6	0	13	10	5	20	4	-21	13	23	-14	8	15
116	Install Traffic Calming Features	x														2	8	100	3	-16	8		13	20	42	36			42	-132	100		71	42
117	**Add paved shoulders**			x			x				x					***21***	5	-6	12	-9	8	2	9	2	-1	-5	22	40	11	-2	-2	24	4	19
118	**Add turn lane/s & pavement resurfacing**		x	x			x				x					***6***	35	3	47	21	35		45	31	49	20	53	51	-15	3	51	3	-46	33
119	Reconstruct bicycle/multi-use path														x	1	37	100	40	33	37		64	24	17	38	52	4	61	36	52			71
120	Construct median, add signal, & pavmnt.resurfacing		x	x			x				x					4	9	-104	34	-30	9		-6	13	31	4	22	-53	-55	-13	32		100	33
121	**Reconstruct median/median improvments**		x	x												***16***	-14	56	-6	-27	-25	40	0	-19	-31	-57	14	13	-27	-5	-10	-26	26	-23
122	**Construct LT and RT lanes**		x	x												***5***	-8	-7	-4	-12	-12	39	5	-8	-1	-76	11	-22	-107	5	-114	20	47	19
123	Paved shoulders & rumble strips		x	x			x				x					3	3	69	8	-17	-79	51	-1	11	-38	-57	62	65	-5	-10	25	100	5	24
124	Upgrade traffic signal									x		x			x	3	16		21	12	16		20	11	34	14	-27	-45	-31	30	-24	31		35
125	Traffic signals, guardrail, signing & lighting									x			x		x	0																		
126	Traffic signals, resurfacing, turn lanes, lighting		x	x				x					x			4	-51	100	-27	-87	-36	-158	-105	-48	-52	-32	-47	-67	-80	-128	-42	-24	29	-37
127	Resurface, guardrail, signing & pavt. markings		x	x			x				x		x			1	-23		25	-161	-23		-112	2	-71	16	76			100			-96	-96
128	Add Ped crossing mid-block with signals														x	3	-23	-93	-21	-24	-23		-25	-16	-60	-19		-286	4	4		52		-148
129	Add Ped crossing mid-block without signals														x	1	-52	-46	-27	-108	-52		-37	-58	-70	-22	19	-191	-154	-240	-122	-73	100	-37
130	Add roundabout to intersection	x			x					x						2	46	100	58	32	46		41	47	65	17	76	-90	44	5	-1607	-8	100	66
131	Convert shldr inverted rumble to audible edgeline			x												0																		
132	**New inverted AUDIBLE marking on CL or edgeline**		x	x		x	x				x					***12***	6	4	14	-6	-5	11	3	9	-19	18	35	21	55	15	17	15	40	4
133	Use of ITS safety system device(s)														x	1	-16		52	-42	-16		-3	-8	-267	31	-3	-106	-158	-3	83	100		-106
134	High friction surface treatment (tyregrip, etc.)					x	x		x		x					1																		
135	Modify signal timing and phasing	x													x	2	14		30	-1	14		-9	20	-22	31	66	-20	-17	33	100	-141		36

1. Source of Crash Data: The Department of Highway Safety and Motor Vehicles (DHSMV) is the official custodian of the crash reports. The numbers that DHSMV reports are the official numbers. The Florida Department of Transportation (FDOT) Safety Office maintains its own database with crash data obtained from DHSMV, and conducts analyses based on this data for internal FDOT purposes.

2. Use Restrictions: The information on the Traffic Safety Web Portal has been compiled from information collected for the purpose of identifying, evaluating or planning safety enhancements. It is used to develop highway safety construction improvements projects which may be implemented utilizing Federal Aid Highway funds. Any document displaying this notice shall be used only for the purposes deemed appropriate by the Florida Department of Transportation. See Title 23, United States Code, Section 409.

3. Crash Reduction Factors Parameters - ID: 465, From Year: Any Year, To Year: 2009, Before Month: 36, Min. Before Month: 12, After Month: 36, Min. After Month: 12

DS - Design Speed
LW - Lane Width
SW - Shoulder Width
BW - Bridge Width
HA - Horizontal Alignment
SE - Superelevation
VA - Vertical Alignment
G - Grade
SSD - Stopping Sight Distance
CS - Cross Slope
VC - Vertical Clearance
HC - Horizontal Clearance
SC - Structural Capacity

Flow Type	Factor Notation	Formula	Excel Command	Cash Flow Diagram
SINGLE	Compound amount $(F/P, i, N)$	$F = P(1+i)^N$	$=FV(i,N,P,,0)$	
	Present worth $(P/F, i, N)$	$P = F(1+i)^{-N}$	$=PV(i,N,F,,0)$	
EQUAL PAYMENT SERIES	Compound amount $(F/A,i,N)$	$F = A\left[\frac{(1+i)^N - 1}{i}\right]$	$=FV(i,N,A,,0)$	
	Sinking fund $(A/F,i,N)$	$A = F\left[\frac{i}{(1+i)^N - 1}\right]$	$=PMT(i,N,P,F,0)$	
	Present worth $(P/A,i,N)$	$P = A\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right]$	$=PV(i,N,A,,0)$	
	Capital recovery $(A/P,i,N)$	$A = P\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right]$	$=PMT(i,N,P)$	
GRADIENT SERIES	Linear gradient Present worth $(P/G,i,N)$	$P = G\left[\frac{(1+i)^N - iN - 1}{i^2(1+i)^N}\right]$		
	Geometric gradient Present worth $(P/A_1,g,i,N)$	$P = \begin{bmatrix} A_1\left[\frac{1-(1+g)^N(1+i)^{-N}}{i-g}\right] \\ \frac{NA_1}{1+i}(\text{if } i = g) \end{bmatrix}$		

U.S. Department
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**Federal Highway
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Mitigation Strategies for Design Exceptions

July 2007

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16. Abstract

Design criteria, established through years of practice and research, form the basis by which highway designers strive to balance cost, safety, mobility, social and environmental impacts, and the needs of a wide variety of roadway users. For many situations, there is sufficient flexibility within the design criteria to achieve a balanced design and still meet minimum values. On occasion, designers encounter situations in which the appropriate solution may suggest that using a design value or dimension outside the normal range of practice is necessary. In these cases, a design exception may be considered. A design exception is a documented decision to design a highway element or a segment of highway to design criteria that do no meet minimum values or ranges established for that highway or project.

This publication provides detailed information on design exceptions and mitigating the potential adverse impacts to highway safety and traffic operations.

- **Chapter 1 provides basic information on design exceptions. Also discussed are the concepts of nominal and substantive safety, which are fundamental to the topic of design exceptions, their mitigation, and decision making.**
- **Chapter 2 discusses the steps of an effective design exception process.**
- **Chapter 3 clarifies the 13 controlling criteria, including when design exceptions are required, how safety and operations are affected by the 13 controlling criteria, and what the potential adverse impacts are if design criteria are not met. Information on substantive safety is provided where available.**
- **Chapter 4 presents and illustrates potential mitigation strategies.**
- **Chapters 5 through 8 are case studies that illustrate how several States have effectively approached projects with difficult site constraints and design exceptions, including implementation of mitigation strategies.**

17. Key Words	18. Distribution Statement
Design exceptions, highway safety, design exception case studies, design exception mitigation, controlling criteria, nominal safety, substantive safety, highway safety strategies	**No restrictions.**

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CHAPTER 3

The 13 Controlling Criteria

As discussed in Chapter 1, FHWA has identified 13 design criteria as having substantial importance for the safe and efficient operation of highways. A formal design exception is required if these controlling criteria are not met on the NHS:

1. Design speed
2. Lane width
3. Shoulder width
4. Bridge width
5. Horizontal alignment
6. Superelevation
7. Vertical alignment
8. Grade
9. Stopping sight distance
10. Cross slope
11. Vertical clearance
12. Lateral offset to obstruction
13. Structural capacity

Exceptions to non-controlling criteria should also be identified, justified, and documented, taking into consideration the effect of any deviation from design criteria on safety. The project files should include this information.

Traffic Operational and Safety Effects

This chapter provides additional technical information on the 13 controlling criteria, including clarifications on when formal design exceptions are required and the potential impacts to traffic operations or substantive safety that a designer should consider when evaluating design exceptions and mitigation strategies.

Traffic operational effects may include the influence of a change in a design dimension on the facility's capacity, on speed, or on changes in speed or other operating behavior for either the overall traffic stream or certain critical vehicle types. Substantive safety effects may include expected or predicted changes in the crash frequency, severity, or both, associated with an incremental change in a design dimension. For both traffic operational and substantive safety effects, the information provided in this chapter represents a synthesis of research and technical literature.

With respect to substantive safety effects, effects will be described in two ways. *Safety performance functions (*SPFs*)* describe the expected crash frequency for a condition or element as a function of traffic volume and other fundamental values. SPFs are usually expressed as an equation or mathematical function. *Accident modification factors (*AMFs*)* describe the expected change in crash frequency (total or particular crash types) associated with an incremental change in a design dimension. AMFs may be shown in tabular form or in some cases as a simple function. They are expressed as a decimal, with an AMF less than 1.0 meaning the crash frequency would be lower and an AMF greater than 1.0 meaning the crash frequency would increase. So, for example, an AMF of 0.95 means a reduction in expected crash frequency of 1.0 – 0.95, or 5 percent.

Designers should be aware that traffic operational and substantive safety effects associated with incremental design dimensions will vary by facility type and context. For example, the change in capacity associated with a 1-foot change in lane width is different for a two-lane rural highway versus urban freeway versus signalized intersection approach. So, considering a design exception in each case will mean a different operational effect should be expected.

Designers should also be mindful of the fundamental concept of exposure. As discussed in Chapter 2, exposure to traffic volume, length of highway, and duration of the design exception are of primary importance. A 5 percent reduction in capacity or expected increase in crash frequency will in many cases be negligible when converted to an annualized value; but in other contexts (say, a high-volume urban freeway) a 5 percent reduction in performance may translate to significant annual impacts.

The information presented in each section is intended to provide the reader with a basic awareness and understanding of expected effects of design exceptions. At the end of the discussion of each criterion, a list of resources is provided for further consultation.

Design Speed

AASHTO defines design speed as follows:

> *Design speed is a selected speed used to determine the various geometric features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of the highway.*

Design speed is different from the other controlling criteria in that it is a design control, rather than a specific design element. In other words, the selected design speed establishes the range of design values for many of the other geometric elements of the highway (Figure 5). Because of its effect on so much of a highway's design, the design speed is a fundamental and very important choice that a designer makes. The selected design speed should be high enough so that an appropriate regulatory speed limit will be less than or equal to it. Desirably, the speed at which drivers are operating comfortably will be close to the posted speed limit.

In recognition of the wide range of site-specific conditions, constraints, and contexts that designers face, the adopted criteria allow a great deal of design flexibility by providing ranges of values for design speed (see Table 1) on page 26. For most cases, the ranges provide adequate flexibility for designers to choose an appropriate design speed without the need for a design exception. *A Guide for Achieving Flexibility in Highway Design* (AASHTO) provides additional information on how to apply this flexibility for selecting appropriate design speeds for various roadway types and contexts.

For projects on extended alignments, design exceptions will be rare primarily because, as shown in Table 1, the range for acceptable design speeds is broad. If a limited portion of an alignment must be designed to a lower speed, it may be more appropriate to evaluate specific geometric element(s) and treat those as design exceptions (instead of the design control).

In the rare instances where a design exception for design speed appears necessary over an extended alignment, it is best to evaluate the expected performance of the continuous alignment to refine the design, and highlight specific locations for mitigation.

FIGURE 5
Because it is a design control, design speed affects the curvature (radius), stopping sight distance, superelevation, and other features of this horizontal curve.

TABLE 1
Ranges for Design Speed

Type of Roadway	Terrain	Rural		Urban	
		US (mi/h)	Metric (km/h)	US (mi/h)	Metric (km/h)
Freeway	Level	70	110	50 min	80 min
	Rolling	70	110	50 min	80 min
	Mountainous	50–60	80–100	50 min	80 min
Arterial	Level	60–75	100–120	30–60	50–100
	Rolling	50–60	80–100	30–60	50–100
	Mountainous	40–50	60–80	30–60	50–100
Collector	Level	40–60	60–100	30+	50+
	Rolling	30–50	50–80	30+	50+
	Mountainous	20–40	30–60	30+	50+
Local	Level	30–50	50–80	20–30	30–50
	Rolling	20–40	30–60	20–30	30–50
	Mountainous	20–30	30–50	20–30	30–50

Source: A Policy on Geometric Design of Highways and Streets, AASHTO

Clarification: Ramp Design Speeds for Freeways and Interchanges

Exhibit 10-56 in the *Green Book* provides "guide values" for selection of ramp design speeds as a function of the highway design speed. According to the Policy, ramp design speeds should not be less than the low range presented in Exhibit 10-56, with other specific guidance offered for particular types of ramps (loops, direct and semi-direct connections). Some States have adopted design policies requiring the use of middle or higher range values for certain cases, such as system interchanges.

Designers are occasionally confronted with situations in which the appropriate ramp design speed per Exhibit 10-56 may not be achievable. Such cases are almost always associated with the inability to achieve minimum radius for the controlling curvature of the exit or entrance ramp. Not meeting the lower (50 percent) range per Exhibit 10-56 requires a design exception per FHWA policy. Where the design issue involves curvature, a design exception should be prepared for the non-standard horizontal curve rather than for the use of a lower design speed for the ramp.

Evaluating Reduced Design Speed

Research confirms that lower speeds are safer and lowering speed limits can decrease both crash frequency and severity. However, speeds cannot be reduced simply by changing the posted speed limit. Geometric and cross-sectional elements, in combination with the context, establish a driving environment where drivers choose speeds that feel reasonable and comfortable.

One tool that designers can use to determine where operating speeds may exceed the design speed on rural two-lane highways is the Design Consistency Module of the IHSDM (see Chapter 1). This module can identify speed discrepancies, both in terms of level of magnitude and length of highway affected. Mitigation strategies can then be targeted to the locations where speed discrepancies are expected.

Research suggests that crash risk increases with increasing differentials in speed (Table 2). Such differentials can be between adjoining highway sections (change in 85th percentile speeds due to changes in roadway geometry) or between speeds of vehicles in the same traffic stream (such as trucks and passenger vehicles). Exhibit 3-58 in the *Green Book* provides information on the crash rate of trucks as a function of the speed differential of trucks to the average running speed of all traffic.

TABLE 2
Relative Risk of Differential Speed Caused by Changes in Roadway Geometry

Speed Differential (ΔV)	Safety Risk
ΔV < 5 mi/hr	Low
5 mi/hr < ΔV < 15 mi/hr	Medium
ΔV > 15 mi/hr	High

Design Speed Resources

- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *A Guide for Achieving Flexibility in Highway Design*, AASHTO, 2004.
- *Design Speed, Operating Speed, and Posted Speed Practices*, NCHRP Report 504, Transportation Research Board, 2003.
- *A Guide to Best Practices for Achieving Context Sensitive Solutions*, NCHRP Report 480, Transportation Research Board, 2002.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *Highway Safety Design and Operations Guide*, AASHTO, 1997.

Lane Width

The adopted criteria describe design values for through travel lanes, auxiliary lanes, ramps, and turning roadways. There are also recommended widths for special-purpose lanes such as continuous two-way left-turn lanes. AASHTO also provides guidance for widening lanes through horizontal curves to provide for the off-tracking requirements of large trucks. Lane width does not include shoulders, curbs, and on-street parking areas. Table 3 summarizes the range of lane widths for travel lanes and ramps.

TABLE 3
Ranges for Lane Width

Type of Roadway	Rural		Urban	
	US (feet)	Metric (meters)	US (feet)	Metric (meters)
Freeway	12	3.6	12	3.6
Ramps (1-lane)	12–30	3.6–9.2	12–30	3.6–9.2
Arterial	11–12	3.3–3.6	10–12	3.0–3.6
Collector	10–12	3.0–3.6	10–12	3.0–3.6
Local	9–12	2.7–3.6	9–12	2.7–3.6

Source: A Policy on Geometric Design of Highways and Streets, AASHTO

It is FHWA policy that the requirement of a formal design exception for lane width is applicable for all travel lanes, including auxiliary lanes and ramps. With respect to the practice of widening lanes through horizontal curves, a formal design exception is not necessary for cases not providing additional lane width, but the decision should be documented in project records. Exhibit 7-3 in the *Green Book* describes minimum lane widths for two-lane rural highways for a range of design speeds and design-year traffic. The table entries show a 24-foot traveled way (12-foot lanes) for most conditions. Careful inspection of this table (see subnote [a]) shows that 11-foot lanes are acceptable and within policy for reconstruction projects in which an existing 22-foot dimension is operating in a satisfactory manner. For such cases, the designer should document this is the case, but retention of the 11-foot width would not require a design exception.

Safety

Speed is a primary consideration when evaluating potential adverse impacts of lane width on safety. On high-speed, rural two-lane highways, an increased risk of cross-centerline head-on or cross-centerline sideswipe crashes is a concern because drivers may have more difficulty staying within the travel lane. On any high-speed roadway, the primary safety concerns with reductions in lane width are crash types related to lane departure, including run-off-road crashes. The mitigation strategies for lane width presented in Chapter 4 focus on reducing the probability of these crashes.

In a reduced-speed urban environment, the effects of reduced lane width are different. On such facilities, the risk of lane-departure crashes is less. The design objective is often how to best distribute limited cross-sectional width to maximize safety for a wide variety of roadway users. Narrower lane widths may be chosen to manage or reduce speed and shorten crossing distances for pedestrians. Lane widths may be adjusted to incorporate other cross-sectional elements, such as medians for access control, bike lanes, on-street parking, transit stops, and landscaping. The adopted ranges for lane width in the urban, low-speed environment normally provide adequate flexibility to achieve a desirable urban cross section without a design exception.

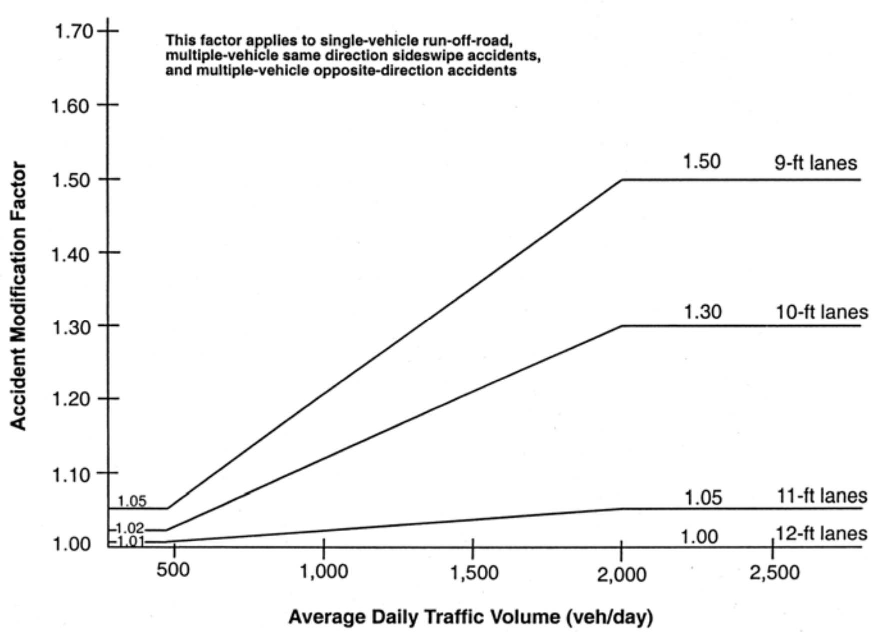
Designers should understand the interrelationships among lane width and other design elements. On high-speed roadways with narrow lanes that also have narrow shoulders, the risk of severe lane-departure crashes increases. Drivers on rural two-lane highways may shift even closer to the centerline as they become less comfortable next to a narrow shoulder. At other times, they may shift closer to the shoulder edge and are at greater risk of driving off the paved portion of the roadway (and over potential edge drop-offs) as they meet oncoming traffic.

Horizontal alignment is another factor that can influence the safety of lane width reductions. Curvilinear horizontal alignments increase the risk of lane departure crashes in general, and when combined with narrow lane widths, the risk will further increase for most high-speed roadways. In addition, trucks and other large vehicles can affect safety and operations by off-tracking into adjacent lanes or the shoulder. This affects the safety of other drivers, as well as non-motorized users such as bicyclists who may be using the adjacent lane or shoulder. It is important to understand this interaction of design elements when a design exception for lane with is being evaluated.

Substantive Safety

Figure 6 shows accident modification factors for variations in lane width on rural two-lane highways. Note that there is little difference between 11- and 12-foot lanes.

FIGURE 6
Accident Modification Factors for Lane Width on Rural Two-Lane Highways.
(Source: Prediction of the Expected Safety Performance of Rural Two-Lane Highways, FHWA)



For multilane urban arterials and multilane rural arterials, the expected difference in substantive safety for variations in lane width is much less—on the order of a few percentage points when comparing lane widths of 10 to 12 feet.

Traffic Operations

Lane width has an effect on traffic operations and highway capacity, particularly for high-speed roadways. The interaction of lane width with other geometric elements, primarily shoulder width, also affects operations.

When determining highway capacity, adjustments are made to reflect the effect of lane width on free-flow speeds. Lane widths of less than 12 feet (3.6 meters) reduce travel speeds on high-speed roadways, as summarized in Tables 4 and 5.

TABLE 4
Operational Effects of Freeway Lane Widths

Lane width (ft)	Reduction in Free-Flow Speed (mi/h)
12	0.0
11	1.9
10	6.6
Lane width (m)	**Reduction in Free-Flow Speed (km/h)**
3.6	0.0
3.5	1.0
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

Source: Highway Capacity Manual

TABLE 5
Operational Effects of Lane and Shoulder Width on Two-Lane Highways

Lane width (ft)	Reduction in Free-Flow Speed (mi/h)			
	Shoulder Width (ft)			
	≥0<2	≥2<4	≥4<6	≥6
9<10	6.4	4.8	3.5	2.2
≥10<11	5.3	3.7	2.4	1.1
≥11<12	4.7	3.0	1.7	0.4
≥12	4.2	2.6	1.3	0.0

TABLE 5 (CONTINUED)
Operational Effects of Lane and Shoulder Width on Two-Lane Highways

	Reduction in Free-Flow Speed (km/h)			
	Shoulder Width (m)			
Lane width (m)	≥0.0<0.6	≥0.6<1.2	≥1.2<8	≥1.8
2.7<3.0	10.3	7.7	5.6	3.5
≥3.0<3.3	8.5	5.9	3.8	1.7
≥3.3<3.6	7.5	4.9	2.8	0.7
≥3.6	6.8	4.2	2.1	0.0

Source: Highway Capacity Manual

Summary

Table 6 summarizes the potential adverse impacts to safety and operations for a design exception for lane width.

TABLE 6
Lane Width: Potential Adverse Impacts to Safety and Operations

Safety & Operational Issues	Freeway	Expressway	Rural Two-Lane	Urban Arterial
Run-off-road crashes	X	X	X	
Cross-median crashes	X	X		
Cross-centerline crashes			X	
Sideswipe (same direction) crashes	X	X		X
Rear-end crashes if operations deteriorate (abrupt speed reduction)	X	X	X	
Reduced free-flow speeds	X	X	X	X
Large vehicles off-tracking into adjacent lane or shoulder	X	X	X	X

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Lane Width Resources

- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Guide for the Planning, Design, and Operation of Pedestrian Facilities*, AASHTO, 2004.

- *A Guide for Reducing Collisions on Horizontal Curves*, NCHRP Report 500, Volume 7, Transportation Research Board, 2004.
- *A Guide for Reducing Collisions Involving Pedestrians*, NCHRP Report 500, Volume 10, Transportation Research Board, 2004.
- *A Guide for Reducing Collisions Involving Heavy Trucks*, NCHRP Report 500, Volume 13, Transportation Research Board, 2004.
- *A Guide for Addressing Head-On Collisions*, NCHRP Report 500, Volume 4, Transportation Research Board, 2003.
- *A Guide for Addressing Run-Off-Road Collisions*, NCHRP Report 500, Volume 6, Transportation Research Board, 2003.
- *Roadside Design Guide,* AASHTO, 2002.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *Highway Capacity Manual*, Transportation Research Board, 2000.
- *Guide for the Development of Bicycle Facilities*, AASHTO, 1999.
- *Highway Safety Design and Operations Guide*, AASHTO, 1997.
- *Use of Shoulders and Narrow Lanes to Increase Freeway Capacity*, NCHRP Report 369, Transportation Research Board, 1995.
- *Roadway Widths for Low-Traffic Volume Roads*, NCHRP Report 362, Transportation Research Board, 1994.
- *Effective Utilization of Street Width on Urban Arterials*, NCHRP Report 330, Transportation Research Board, 1990.
- *FHWA Roadside Hardware Web site* http://safety.fhwa.dot.gov/roadway_dept/road_hardware/index.htm

Shoulder Width

Shoulders provide a number of important functions. Safety and efficient traffic operations can be adversely affected if any of the following functions are compromised:

- Shoulders provide space for emergency storage of disabled vehicles (Figure 7). 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 and can prevent a lane from being closed, which can cause severe congestion and safety problems on these facilities.

- Shoulders provide space for enforcement activities (Figure 7). This is particularly important for the outside (right) shoulder because law enforcement personnel prefer to conduct enforcement activities in this location. Shoulder widths of approximately 8 feet or greater are normally required for this function.

- Shoulders provide space for maintenance activities (Figure 7). If routine maintenance work can be conducted without closing a travel lane, both safety and operations will be improved. Shoulder widths of approximately 8 feet or greater are normally required for this function. In northern regions, shoulders also provide space for storing snow that has been cleared from the travel lanes.

- Shoulders provide an area for drivers to maneuver to avoid crashes (Figure 7). This is particularly 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.
- Shoulders improve bicycle accommodation (Figure 8). For most highways, cyclists are legally allowed to ride on the travel lanes. A paved or partially paved shoulder offers cyclists an alternative to ride with some separation from vehicular traffic. This type of shoulder can also reduce risky passing maneuvers by drivers.
- Shoulders increase safety by providing a stable, clear recovery area for drivers who have left the travel lane. If a driver inadvertently leaves the lane or is attempting to avoid a crash or an object in the lane ahead, a firm, stable shoulder greatly increases the chance of safe recovery. However, areas with pavement edge drop-offs can be a significant safety risk. Edge drop-offs (Figure 9) 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.
- Shoulders improve stopping sight distance at horizontal curves by providing an offset to objects such as barrier and bridge piers (Figure 10).
- On highways with curb and enclosed drainage systems, shoulders store and carry water during storms, preventing water from spreading onto the travel lanes.
- On high-speed roadways, shoulders improve capacity by increasing driver comfort.

FIGURE 7
Shoulders on this urban freeway provide enough width for crash avoidance, storage of disabled vehicles, maintenance activities, and enforcement.

FIGURE 8
Partially-paved shoulders on this rural arterial improve bicycle accommodation and reduce risky passing maneuvers.

FIGURE 9
Pavement edge drop-off.

FIGURE 10
Comparison of how shoulder width affects stopping sight distance past concrete bridge rail along horizontal curves.

Table 7 summarizes the range of minimum shoulder widths for travel lanes and ramps.

TABLE 7
Ranges for Minimum Shoulder Width

Type of Roadway	Rural		Urban	
	US (feet)	Metric (meters)	US (feet)	Metric (meters)
Freeway	4–12	1.2–3.6	4–12	1.2–3.6
Ramps (1-lane)	1–10	0.3–3.0	1–10	0.3–3.0
Arterial	2–8	0.6–2.4	2–8	0.6–2.4
Collector	2–8	0.6–2.4	2–8	0.6–2.4
Local	2–8	0.6–2.4	—	—

Source: A Policy on Geometric Design of Highways and Streets, AASHTO

Clarification: Usable and Paved Shoulders

Design values in the adopted criteria refer to both usable and paved shoulders. A usable shoulder width is the actual width available for the driver to make an emergency or parking stop. This is measured from the edge of traveled way to the point of intersection of the shoulder slope and mild slope (for example, 1:4 or flatter) or to beginning of rounding to slopes steeper than 1:4.

Usable shoulders do not have to be paved. The adopted criteria note that rural arterial shoulders should be paved. FHWA policy does not require a design exception for shoulder type, but rather for the usable shoulder width dimension only.

Clarification: Minimum Shoulder Widths for Interstate Highways

One clarification for shoulder width design exceptions relates to the requirements for Interstates with six or more lanes. The adopted criteria for Interstates specify that the paved width of the right shoulder shall not be less than 10 feet (3.0 meters). Where truck traffic exceeds 250 DDHV (the design hourly volume for one direction), a paved shoulder width of 12 feet (3.6 meters) should be considered. On a four-lane section, the paved width of the left shoulder shall be at least 4 feet (1.2 meters). On sections with six or more lanes, a 10-foot (3.0-meter) paved width for the left shoulder should be provided. Where truck traffic exceeds 250 DDHV, a paved width of 12 feet (3.6 meters) should be considered.

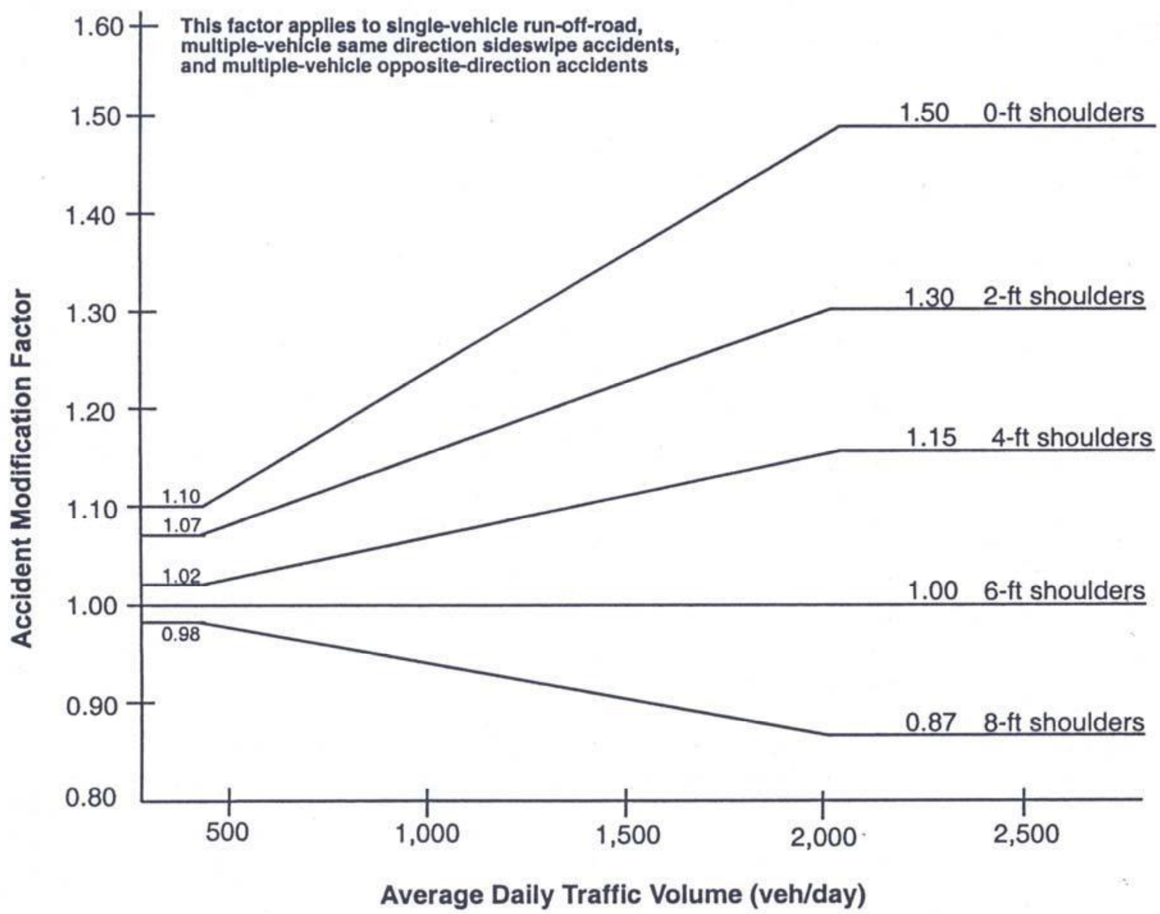
Regardless of the differences in language used in the adopted criteria ("shall," "should be considered," etc.) all of the shoulder widths described above have become standards for the Interstate System by virtue of their adoption by FHWA, and they are the minimum values for each condition described. Therefore, a project designed for the Interstate System that does not provide the applicable shoulder widths would require a formal design exception.

In addition, the incorporation of high-occupancy vehicle (HOV) lanes is now common practice on many urban freeways. Lower-cost design solutions have in many cases resulted in the conversion of an existing full-width (12-foot) shoulder to a designated HOV lane. Where conversion of a shoulder to HOV use is being considered and replacement or construction of a new shoulder is not proposed, a design exception is required (potentially for both shoulder width and lateral offset to obstruction).

Substantive Safety

Figure 11 illustrates how variations in shoulder width can affect safety on rural two-lane highways. Note that the substantive safety effects of incremental shoulder widths are less on multilane arterials and on lower-speed urban arterials.

FIGURE 11
Accident Modification Factors for Shoulder Width on Rural Two-Lane Highways.
(Source: Prediction of the Expected Safety Performance of Rural Two-Lane Highways, FHWA)



Traffic Operations

Shoulder width has a measurable effect on traffic operations and highway capacity, particularly for high-speed roadways. The interaction of shoulder width with other geometric elements, primarily lane width, also affects operations.

When determining highway capacity, adjustments are made to reflect the effect of shoulder width on free-flow speeds. Table 5 summarizes these effects for rural two-lane highways and Table 8 summarizes effects for freeways.

TABLE 8
Operational Effects of Freeway Shoulder Widths

Right-Shoulder Lateral Clearance (ft)	Reduction in Free-Flow Speed (mi/h)			
	Lanes in One Direction			
	2	3	4	≥5
≥6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6
Right-Shoulder Lateral Clearance (m)	**Reduction in Free-Flow Speed (km/h)**			
	Lanes in One Direction			
	2	3	4	≥5
≥1.8	0.0	0.0	0.0	0.0
1.5	1.0	0.7	0.3	0.2
1.2	1.9	1.3	0.7	0.4
0.9	2.9	1.9	1.0	0.6
0.6	3.9	2.6	1.3	0.8
0.3	4.8	3.2	1.6	1.1
0.0	5.8	3.9	1.9	1.3

Source: Highway Capacity Manual

Summary

Table 9 summarizes the potential adverse impacts to safety and operations of a design exception for shoulder width.

TABLE 9
Shoulder Width: Potential Adverse Impacts to Safety and Operations

Safety & Operational Issues	Freeway	Expressway	Rural Two-Lane	Urban Arterial
Run-off-road crashes	X	X	X	Assumed cross section with curb and gutter (no shoulders)
Cross-median crashes	X	X		
Cross-centerline crashes			X	
Pavement edge dropoffs	X	X	X	
Rear-end crashes if operations deteriorate (abrupt speed reduction)	X	X	X	
Lane blockage from incidents	X	X	X	
Reduced free-flow speeds	X	X	X	
Shying away from the edge of the roadway	X	X	X	
Inadequate space for enforcement activities and emergency response	X	X	X	
Inadequate space for emergency pullover	X	X	X	
Inadequate space to avoid crashes or objects on the travel lanes	X	X	X	
Lack of storage space for disabled vehicles	X	X	X	
Bicyclists forced onto the travel lanes.	X	X	X	
Inadequate space for maintenance activities	X	X	X	

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Shoulder Width Resources

- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *A Guide for Achieving Flexibility in Highway Design*, AASHTO, 2004.
- *A Guide for Addressing Head-On Collisions*, NCHRP Report 500, Volume 4, Transportation Research Board, 2003.
- *A Guide for Addressing Run-Off-Road Collisions*, NCHRP Report 500, Volume 6, Transportation Research Board, 2003.

- *Roadside Design Guide,* AASHTO, 2002.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *Highway Capacity Manual*, Transportation Research Board, 2000.
- *Guide for the Development of Bicycle Facilities*, AASHTO, 1999.
- *Highway Safety Design and Operations Guide*, AASHTO, 1997.
- *Use of Shoulders and Narrow Lanes to Increase Freeway Capacity*, NCHRP Report 369, Transportation Research Board, 1995.
- *Roadway Widths for Low-Traffic Volume Roads*, NCHRP Report 362, Transportation Research Board, 1994.
- FHWA Roadside Hardware Web site http://safety.fhwa.dot.gov/roadway_dept/road_hardware/index.htm

Bridge Width

Bridge width is the total width of all lanes and shoulders on the bridge, measured between the points on the bridge rail, curb, or other vertical elements that project the farthest onto the roadway (Figure 12). A bridge width that meets adopted criteria maintains the minimum acceptable lane and shoulder width for the particular design condition as defined by area, functional class, design speed, and traffic volume. A design exception is required when a bridge is proposed to be constructed with narrower lanes, shoulders, or both.

Potential problems associated with narrow bridges are twofold. Relatively short bridges represent a discontinuity that may affect driver behavior. The narrowed cross section can make some drivers uncomfortable and cause them to dramatically reduce speed, increasing the risk of rear-end crashes and degrading operations on high-speed, high-volume facilities. The bridge rail may be close enough to the travel lanes to cause drivers to shy towards the centerline or into adjacent lanes (Figure 13). The bridge infrastructure itself is closer to the edge of pavement and thus represents a roadside hazard. Even when properly designed and delineated, there is an increased risk of a roadside collision with a bridge end closer to the edge of traveled way.

A second set of concerns is evident for longer bridges (say, greater than 500 feet in length). The safety and operational concerns at narrow bridges are similar to those on roads with narrow shoulders. There may be inadequate space for storage of disabled vehicles, enforcement activities, emergency response, and maintenance work. The lack of shoulder width on the bridge may make it impossible to avoid a crash or object on the roadway ahead. In addition, options are limited for non-motorized users such as bicyclists, forcing them onto the traveled lanes or close to the bridge rail.

Narrow bridges on horizontal curves can have limited horizontal stopping sight distance past the bridge rail (Figure 10). Operations can be degraded, particularly on long bridges on high-speed roadways, because of speed reductions as drivers enter the narrowed cross section as well as a decrease in driver comfort on the bridge.

FIGURE 12
Bridge width.

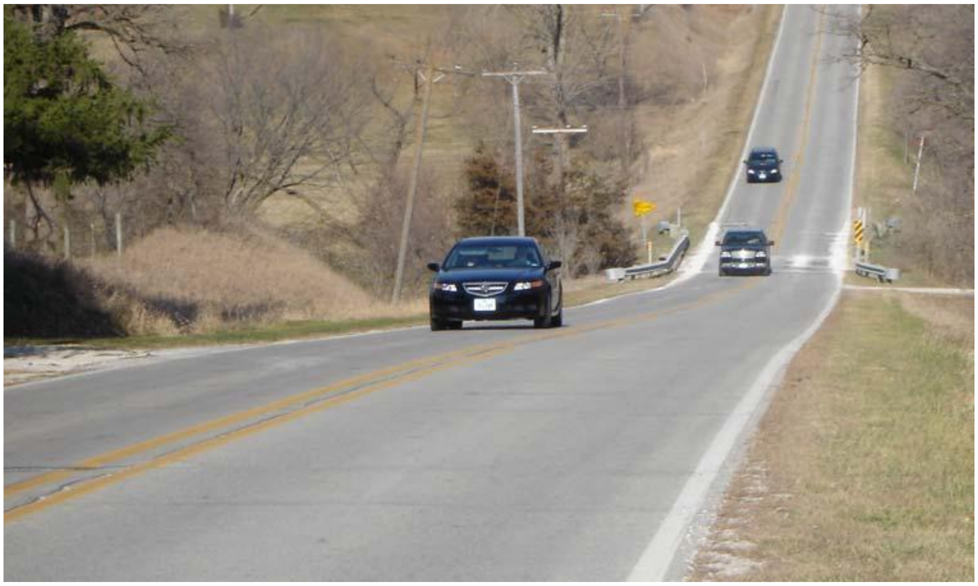


FIGURE 13
Vehicle shying towards the centerline on a narrow bridge.

Summary

Table 10 summarizes the potential adverse impacts to safety and operations of a design exception for bridge width.

TABLE 10
Bridge Width: Potential Adverse Impacts to Safety and Operations

Safety & Operational Issues	Freeway	Expressway	Rural Two-Lane	Urban Arterial
Collision with bridge rail or approach guardrail	X	X	X	X
Rear-end crashes (abrupt speed reduction)	X	X	X	
Cross-centerline crashes			X	X
Degraded operations because of abrupt speed reduction as drivers approach bridge	X	X		X
Reduced free-flow speeds	X	X	X	X
Inadequate space for enforcement activities and emergency response (long bridges)	X	X	X	X
Lane blockage from incidents (long bridges)	X	X	X	X
Shying away from the bridge rail	X	X	X	X
Inadequate space for bicyclists	X	X	X	X
Inadequate space for emergency pullover (long bridges)	X	X	X	X
Inadequate space to avoid crashes or objects on the travel lanes	X	X	X	X
Lack of storage space for disabled vehicles (long bridges)	X	X	X	X

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Substantive Safety

In evaluating the potential substantive safety of narrow bridges, the designer should consider the two types of conditions described above. For short bridges, the safety risk can be modeled by use of the Roadside Safety Analysis Program (see the AASHTO *Roadside Design Guide*). Based on traffic volumes and the widths in question, a designer can estimate the relative increased risk of the bridge end closer to the traveled way.

For longer bridges, the designer can reference information in the shoulder width section, such as Figure 11, to gain an understanding of the incremental increase in safety risk with a narrower dimension for the combination of lane and shoulder width.

Bridge Width Resources

- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *A Guide for Addressing Head-On Collisions*, NCHRP Report 500, Volume 4, Transportation Research Board, 2003.
- *Roadside Design Guide,* AASHTO, 2002.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *Highway Safety Design and Operations Guide*, AASHTO, 1997.
- *FHWA Roadside Hardware Web site* http://safety.fhwa.dot.gov/roadway_dept/road_hardware/index.htm

Horizontal Alignment

In terms of the 13 controlling criteria, the term horizontal alignment refers only to the horizontal curvature of the roadway (Figure 14). The adopted design criteria specify a minimum radius for the selected design speed, which is calculated from the maximum rate of superelevation (set by policy from a range of options) and the side friction factor (established by policy through research). Superelevation is considered a separate criterion and is discussed below. Horizontal alignment influences another primary controlling criterion, stopping sight distance.

Curve design policy published by AASHTO is based on a series of assumptions of driver behavior and operations. Drivers are assumed to track the curve in a passenger car at design speed. The combination of superelevation, side friction, and radius are established to provide for an acceptable level of comfort for the majority of drivers. The design model applies to the full range of highway types and conditions.

The radii of curves are one variable that affects the risk of lane-departure crashes on high-speed roadways. Other contributing factors may include the amount of superelevation, the surface friction of the pavement, and the horizontal and vertical alignments preceding the curve. Inadequate superelevation or pavement friction can contribute to vehicles skidding as they maneuver through a curve. The alignment preceding a curve influences approach speeds. The expected crash frequency increases as the speed differential from the approach tangent to the curve increases. This may occur if the curve is preceded by a long segment of tangent roadway (versus a continuously curvilinear alignment that encourages lower speeds), if the approach is on a significant downgrade, or if the curve is not visible to the driver on the approach.

At ramps and loops, a lack of deceleration length can contribute to drivers running off the first curve after exiting a freeway.

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. As discussed in the lane width section, 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.

The risk of lane-departure crashes at curves is significantly influenced by speed, which is why curves in reduced-speed urban environments generally present fewer safety and operational concerns for the horizontal alignment criterion.

FIGURE 14
Horizontal alignment.

Traffic Operations

Curves influence speed behavior. Curvilinear roads will have lower speeds, which can negatively affect highway capacity. However, for some highway types and contexts, lower speeds can be beneficial—for example, reduced-speed urban environments where lower speeds increase safety for pedestrians. On rural two-lane highways, curves will limit available passing zones and thereby influence capacity.

A curve that is nominally unsafe (has a radius less than the minimum for the selected design speed) may or may not present an unusual operational or safety risk. Such risk depends on the site conditions. One approach to characterizing this risk for two-lane rural highways is through use of the Design Consistency Module of FHWA's IHSDM (see Chapter 1). The design consistency module predicts the 85th percentile speed along an alignment as a function of grade, horizontal alignment, roadway width, and direction of travel.

Designers can estimate speeds produced on the approach to a sharp curve to determine the extent of concern over its use or acceptability. A designer can estimate both the 85th percentile speed through the curve, as well as the change in speeds produced by the alignment of both approaches. Marginal speed reductions and/or differences between operating and design speed (say, less than 10 mi/hr) may be considered acceptable.

Substantive Safety

The substantive safety performance of a roadway is influenced by the presence and design characteristics of horizontal curvature, including both the length of curve and radius. Other factors contributing to substantive safety of curves include the cross section and the character of the roadside through the curve. The following AMF can be used to predict how variations in horizontal alignment will affect the expected safety performance of rural two-lane highways:

$$AMF = \frac{(1.55L_c + 80.2/R - 0.012S)}{1.55L_c}$$

Where,

L_c = length of horizontal curve (mi)
R = radius of curvature (ft)
S = 1 if spiral transition curve is present
= 0 if spiral transition curve is not present

The difference in substantive safety between two designs can be estimated by comparing the result of exercising this function for the two cases and comparing the results. Note that at a given location the curve's central angle will be fixed, and hence a milder curve than the alternative will be longer. Note that the effect on total safety risk will vary with traffic volume as well. Designers may accept a design exception for curvature on a roadway with a design volume of 750 vehicles per day (vpd), but reach a different conclusion for a road with a design volume of 8,000 vpd.

Summary

Table 11 summarizes the potential adverse impacts to safety and operations of a design exception for horizontal alignment.

TABLE 11
Horizontal Alignment: Potential Adverse Impacts to Safety and Operations

Safety & Operational Issues	Freeway	Expressway	Rural Two-Lane	Urban Arterial
Run-off-road crashes	X	X	X	
Cross-median crashes	X	X		
Cross-centerline crashes			X	X
Large vehicle rollover crashes	X	X	X	
Large vehicles off-tracking into adjacent lane or shoulder	X	X	X	X
Skidding	X	X	X	X
Rear-end crashes if operations deteriorate (abrupt speed reduction)	X	X	X	
Reduced free-flow speeds	X	X	X	X

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Horizontal Alignment Resources

- Low-Cost Treatments for Horizontal Curve Safety, FHWA, 2006.
- *Communicating Changes in Horizontal Alignment*, NCHRP Report 559, Transportation Research Board, 2006.
- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *A Guide for Reducing Collisions on Horizontal Curves*, NCHRP Report 500, Volume 7, Transportation Research Board, 2004.
- *A Guide for Reducing Collisions Involving Heavy Trucks*, NCHRP Report 500, Volume 13, Transportation Research Board, 2004.
- *Review of Truck Characteristics as Factors in Roadway Design*, NCHRP Report 505, Transportation Research Board, 2003.
- *A Guide for Addressing Head-On Collisions*, NCHRP Report 500, Volume 4, Transportation Research Board, 2003.
- *A Guide for Addressing Run-Off-Road Collisions*, NCHRP Report 500, Volume 6, Transportation Research Board, 2003.
- *Roadside Design Guide,* AASHTO, 2002.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *FHWA Roadside Hardware Web site* http://safety.fhwa.dot.gov/roadway_dept/road_hardware/index.htm

Superelevation

Superelevation is the rotation of the pavement on the approach to and through a horizontal curve. Superelevation is intended to assist the driver by counteracting the lateral acceleration produced by tracking the curve. Superelevation is expressed as a decimal, representing the ratio of the pavement slope to width, ranging from 0 to 0.12 foot/feet. The adopted criteria allow for the use of maximum superelevation rates from 0.04 to 0.12. Maximum superelevation rates for design are established by policy by each State.

Selection of a maximum superelevation rate is based on several variables, such as climate, terrain, highway location (urban vs. rural), and frequency of very slow-moving vehicles. For example, northern States that experience ice and snow conditions may establish lower maximums for superelevation than States that do not experience these conditions. Use of lower maximum superelevation rates by policy is intended to address the perceived problem created by vehicles sliding transversely when traveling at very low speeds when weather conditions are poor.

The adopted criteria provide complete tables expressing the appropriate superelevation rate consistent with the established policy for all curves and all design speeds.

FIGURE 15
Superelevation

Clarifications

A formal design exception is required if the State's superelevation policy cannot be met in design of any curve on the NHS. Thus, if a State's maximum policy is set at 0.06 and a design is proposed that would use a superelevation rate greater than 0.06 (but within overall AASHTO guidance) this is considered an exception. A design exception is also required if a superelevation rate is proposed that is different from the published rate per the State's policy for that curve, regardless of whether the curve is a controlling one (minimum radius for a design speed) or not.

Note that no design exception is required for superelevation transition lengths. Also, some States employ spiral curves for high speed and sharper curves to help develop superelevation. For States that use spiral transitions, the inability or decision to not use a spiral does not require a design exception.

Safety and Operational Considerations

The safety and operational concerns related to inadequate superelevation are similar to those discussed in the horizontal alignment section. Inadequate superelevation can cause vehicles to skid as they travel through a curve, potentially resulting in a run-off-road crash. Trucks and other large vehicles with high centers of mass are more likely to roll over at curves with inadequate superelevation.

Substantive Safety

Table 12 reports how variations in superelevation affect safety on rural two-lane highways. A superelevation deficiency is one in which there is insufficient superelevation compared to that specified by the appropriate design policy and values.

TABLE 12
Accident Modification Factors for Superelevation on Rural Two-Lane Highways

Superelevation Deficiency	Accident Modification Factor
0.02	1.06
0.03	1.09
0.04	1.12
0.05	1.15

Source: Prediction of the Expected Safety Performance of Rural Two-Lane Highways, FHWA

Summary

Table 13 summarizes the potential adverse impacts to safety and operations of a design exception for superelevation.

TABLE 13
Superelevation: Potential Adverse Impacts to Safety and Operations

Safety & Operational Issues	Freeway	Expressway	Rural Two-Lane	Urban Arterial
Run-off-road crashes	X	X	X	
Cross-median crashes	X	X		
Cross-centerline crashes			X	
Skidding	X	X	X	X
Large vehicle rollover crashes	X	X	X	

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Superelevation Resources

- Low-Cost Treatments for Horizontal Curve Safety, FHWA, 2006.
- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *A Guide for Reducing Collisions Involving Heavy Trucks*, NCHRP Report 500, Volume 13, Transportation Research Board, 2004.

- *Review of Truck Characteristics as Factors in Roadway Design*, NCHRP Report 505, Transportation Research Board, 2003.
- *A Guide for Addressing Head-On Collisions*, NCHRP Report 500, Volume 4, Transportation Research Board, 2003.
- *A Guide for Addressing Run-Off-Road Collisions*, NCHRP Report 500, Volume 6, Transportation Research Board, 2003.
- *Roadside Design Guide,* AASHTO, 2002.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *FHWA Roadside Hardware Web site* http://safety.fhwa.dot.gov/roadway_dept/road_hardware/index.htm

Vertical Alignment

In terms of the 13 controlling criteria, vertical alignment includes grade as well as vertical curvature (both crest and sag); grade is considered separately and discussed below. Vertical curvature influences another primary controlling criterion, stopping sight distance. The geometric design basis for minimum length of crest vertical curvature is to provide the minimum stopping sight distance for the combination of grades and design speed. Sag vertical curves are normally designed so the curve does not restrict the distance of roadway illuminated by vehicle headlights, which would reduce stopping sight distance at night. The influence of and design considerations regarding design exceptions for vertical curvature are discussed below in the section on stopping sight distance.

Refer to the sections on grade and stopping sight distance for more information on vertical alignment.

Vertical Alignment Resources

- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.

Grade

Grade is the rate of change of the vertical alignment. Grade affects vehicle speed and vehicle control, particularly for large trucks. The adopted criteria express values for both maximum and minimum grade. The inability to meet either a maximum or minimum value may produce operational or safety problems.

A primary safety concern is the potential for drivers of heavy trucks to lose control as they descend steep grades. A design exception is required if the maximum grade is exceeded. Minimum grades to achieve proper drainage have also been established, and a design exception is required for highway segments that are flatter than the minimum grade.

Speed differential on highways with steep grades can contribute to safety and operational problems. Trucks and other heavy vehicles lose speed on steep, ascending grades and may be unable to reach full highway speed until they have passed the crest of the steep grade. Vehicles behind them are slowed, degrading operations at the least, and contributing to rear-end conflicts and in some cases risky passing maneuvers at the worst. 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.

Another potential safety concern is present when a horizontal curve lies at the bottom of a steep grade (Figure 16). This combination of alignments increases the risk of severe run-off-road crashes.

FIGURE 16
Horizontal curve at the base of a steep grade.

Clarification

The adopted criteria also include achieving a minimum grade. Grades of at least 0.30 percent are considered necessary to achieve appropriate drainage of the pavement. Where very mild grades are used for significant lengths of highway, care should be taken to assure the combination of cross slope (see discussion below) and grade are sufficient for good drainage. A design exception is required when either the maximum grade for a design condition is exceeded, or when the minimum grade cannot be achieved.

Traffic Operations

The combination of grades, including length of grade, and horizontal curvature can have a demonstrable influence on vehicle speeds. One tool for assessing this operational condition is the Design Consistency Module of FHWA's IHSDM (see Chapter 1). This module produces a speed profile for continuous alignment by direction of travel. It can be used to test alignment variations, and provide a direct operational measure of a design exception for maximum grade.

Substantive Safety

Table 14 illustrates how variations in grade may affect safety on rural two-lane highways.

TABLE 14
Accident Modification Factors for Grade on Rural Two-Lane Highways

Grade (%)	Accident Modification Factor
0	1.00
2	1.03
4	1.07
6	1.10
8	1.14

Source: Prediction of the Expected Safety Performance of Rural Two-Lane Highways, FHWA

Summary

Table 15 summarizes the potential adverse impacts to safety and operations of a design exception for grade.

TABLE 15
Grade: Potential Adverse Impacts to Safety and Operations

Safety and Operational Issues	Freeway	Expressway	Rural Two-Lane	Urban Arterial
Trucks losing control descending grade	X	X	X	
Risky passing maneuvers			X	X
Reduced speeds ascending grade	X	X	X	X
Reduced speeds descending grade	X	X	X	X
Run-off-road crashes, particularly where steep grades are combined with horizontal curves	X	X	X	
Rear-end crashes descending grade	X	X	X	
Slick pavement (flat grades)	X	X	X	X
Water ponding on the pavement surface (flat grades)	X	X	X	X
Water spreading onto the traveled lanes (flat grades)				X

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Grade Resources

- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *A Guide for Reducing Collisions on Horizontal Curves*, NCHRP Report 500, Volume 7, Transportation Research Board, 2004.
- *A Guide for Reducing Collisions Involving Heavy Trucks*, NCHRP Report 500, Volume 13, Transportation Research Board, 2004.
- *A Guide for Addressing Head-On Collisions*, NCHRP Report 500, Volume 4, Transportation Research Board, 2003.
- *A Guide for Addressing Run-Off-Road Collisions*, NCHRP Report 500, Volume 6, Transportation Research Board, 2003.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *Highway Drainage Guidelines,* AASHTO, 2000.

Stopping Sight Distance

Stopping sight distance is defined as the distance needed for drivers to see an object on the roadway ahead and bring their vehicles to safe stop before colliding with the object. The distances are derived for various design speeds based on assumptions for driver reaction time, the braking ability of most vehicles under wet pavement conditions, and the friction provided by most pavement surfaces, assuming good tires. A roadway designed to criteria employs a horizontal and vertical alignment and a cross section that provides at least the minimum stopping sight distance through the entire facility.

Stopping sight distance is influenced by both vertical and horizontal alignment. For vertical stopping sight distance, this includes sight distance at crest vertical curves (Figure 17), headlight sight distance at sag vertical curves (Figure 18), and sight distance at undercrossings (Figure 19).

For crest vertical curves, the alignment of the roadway limits stopping sight distance (Figure 17). Sag vertical curves provide greater stopping sight distance during daylight conditions, but very short sag vertical curves will limit the effective distance of the vehicle's headlights at night. If lighting is provided at sag vertical curves, a design to the driver comfort criteria may be adequate. The length of sag vertical curves to satisfy the comfort criteria over the typical design speed range results in minimum curve lengths of about half those based on headlight criteria.

For horizontal curves, physical obstructions can limit stopping sight distance (Figure 20). Examples include bridge piers, barrier, walls, backslopes, and vegetation.

FIGURE 17
Vertical stopping sight distance at a crest vertical curve.

FIGURE 18
Headlight sight distance at a sag vertical curve.

FIGURE 19
Sight distance at an undercrossing.

FIGURE 20
Horizontal stopping sight distance.

Clarifications

In addition to stopping sight distance, the *Green Book* provides design criteria for decision sight distance, passing sight distance (applies to two-lane roads only) and intersection sight distance. FHWA requires a formal design exception wherever stopping sight distance cannot be provided. Because stopping sight distance is influenced by both vertical and horizontal alignment, a design exception may be required, based on a range of geometric or roadside conditions limiting sight lines in three dimensions.

For sag vertical curves, formal design exceptions are required for curves that meet the comfort criteria but not the headlight criteria, unless lighting is provided.

Safety Effects

The adopted criteria for stopping sight distance apply to the entire length of a highway. Clearly though, the relative risk of limited sight distance can vary significantly, based on the circumstances. A simple 'model' for evaluating locations with limited sight distance involves the following questions:

- What roadway or other conditions or features are within the segment with limited sight distance?
- How significant is the deficiency in sight distance (as measured by length of highway as well as amount of deficiency relative to that required per adopted criteria)?
- What is the traffic volume through the location with limited sight distance?

For example, the risk associated with a crest vertical curve with non-standard sight distance is greater at a location with intersections or driveways or other roadway features (Figure 21) within the area of the sight restriction compared with a similar location with no such features. Table 16 summarizes the relative safety risk of combining various geometric elements and other roadway features with non-standard stopping sight distance.

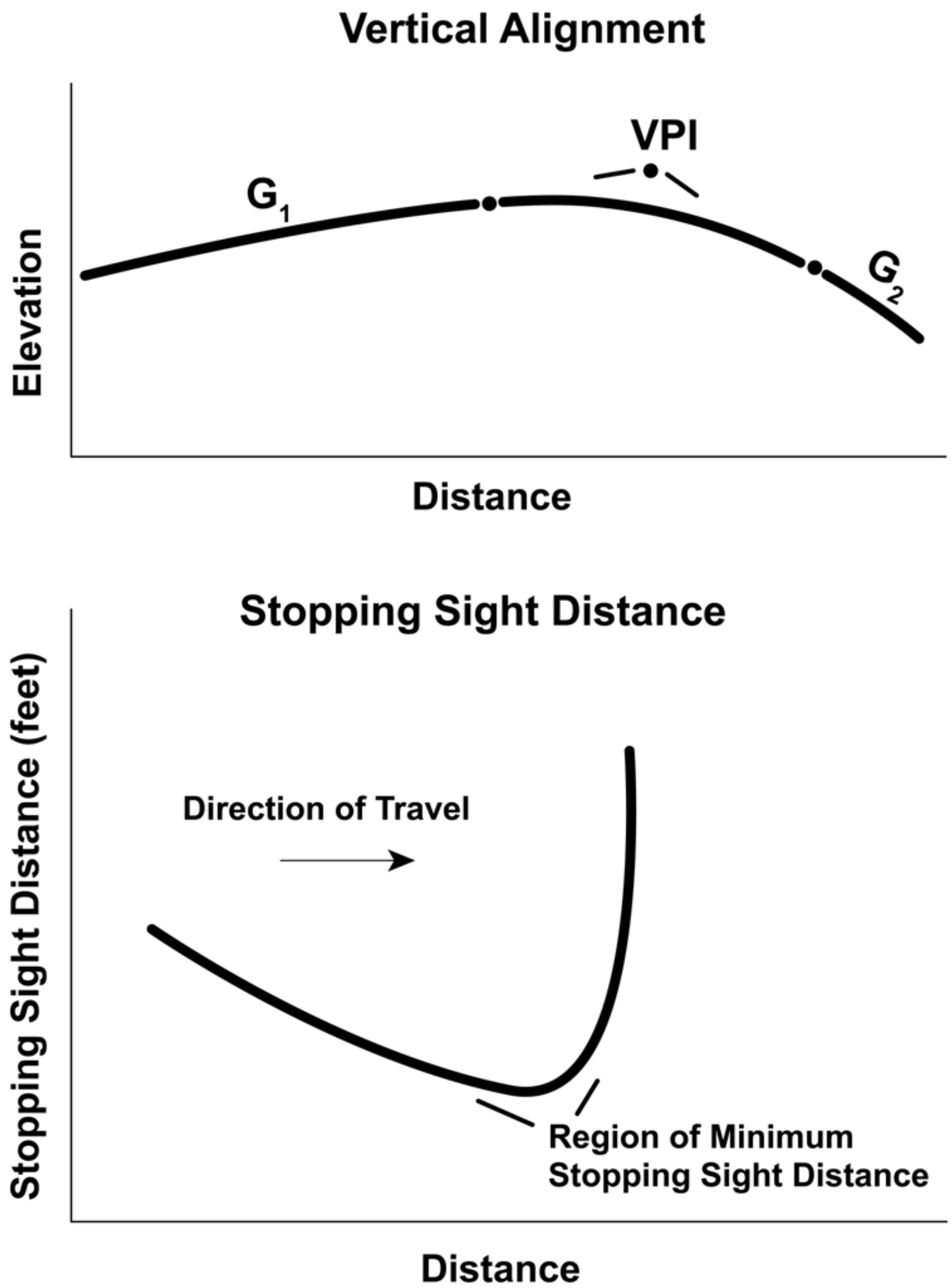
A stopping sight distance profile (see Figure 22) can be a useful tool for understanding location-based risk of limited stopping sight distance. The profile shows the amount of stopping sight distance at each location along the roadway, thereby illustrating the magnitude of sight distance restrictions and where they occur. This information can help designers understand the severity of a sight distance restriction, how the restriction may interact with other roadway conditions or features, and how/where to implement mitigation strategies. The IHSDM (see Chapter 1) creates stopping sight distance profiles for rural two-lane highways.

TABLE 16
Relative Safety Risk of Various Conditions in Combination with Non-Standard Stopping Sight Distance

Geometric Condition	Relative Safety Risk
Tangent horizontal alignment	Minor
Mild curvature >2000 ft (600m) radius	Minor
Mild downgrade (<3%)	Minor
Low-volume intersection	Significant
Intermediate curvature 1000 ft (300 m) to 2000 ft (600 m) radius	Significant
Moderate downgrade (3–5%)	Significant
Structure	Significant
High volume intersection	Major
Y-diverge on road	Major
Sharp curvature <1000 ft (300 m) radius	Major
Steep downgrade (>5%)	Major
Narrow bridge	Major
Narrow pavement	Major
Freeway lane drop	Major
Exit or entrance downstream along freeway	Major

FIGURE 21
Not all locations with limited stopping sight distance are the same in terms of safety risk. In this example, the intersecting roadway in the background creates the illusion of a straight alignment and may increase the risk of run-off-road crashes.

FIGURE 22
Stopping sight distance profile (Source: A Guide for Achieving Flexibility in Highway Design, AASHTO).



Summary

Table 17 summarizes the potential adverse impacts to safety and operations of a design exception for stopping sight distance.

TABLE 17
Stopping Sight Distance: Potential Adverse Impacts to Safety and Operations

Safety & Operational Issues	Freeway	Expressway	Rural Two-Lane	Urban Arterial
Collisions with vehicles stopped or slowed on the roadway	X	X	X	X
Collisions with objects on the roadway	X	X	X	X
Collisions with vehicles entering from intersecting roadways		X	X	X

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Stopping Sight Distance Resources

- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *A Guide for Reducing Collisions on Horizontal Curves*, NCHRP Report 500, Volume 7, Transportation Research Board, 2004.
- *A Guide for Addressing Run-Off-Road Collisions*, NCHRP Report 500, Volume 6, Transportation Research Board, 2003.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *Determination of Stopping Sight Distances*, NCHRP Report 400, Transportation Research Board, 1997.

Cross Slope

Pavement cross slope is an important cross-sectional design element. The cross slope drains water from the roadway laterally and helps minimize ponding of water on the pavement. This prevents maintenance problems and also minimizes icing from occurring on poorly drained 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. Cross slopes that are too steep can cause vehicles to drift, skid laterally when braking, and become unstable when crossing over the crown to change lanes. These conditions are exacerbated by icy, snowy, or windy conditions. Both maximum and minimum criteria exist for cross slope. A formal design exception is required wherever either cannot be met.

Clarifications

Cross slope criteria apply to typical tangent alignments. On high-speed roadways, normal cross slope is 1.5–2.0 percent, with the cross-slope break (the algebraic difference in slopes between the lanes) at the centerline not exceeding 4 percent. In areas of intense rainfall and where there are three or more lanes in each direction, additional cross slope may be necessary for adequate drainage. Accomplishing other design features (superelevation transitions, pavement warping at intersections, etc.) will inevitably require removal of cross slope in spot locations. These cases are routine and necessary in design and a design exception is not required.

In addition to the cross slope of the lanes, the cross-slope break on the high side of superelevated curves should not exceed 8 percent (Figure 23). A formal design exception is required when this condition is not met.

FIGURE 23
Cross-slope break on the high side of superelevated curve.

Summary

Table 18 summarizes the potential adverse impacts to safety and operations of a design exception for cross slope.

TABLE 18
Cross Slope: Potential Adverse Impacts to Safety and Operations

Safety & Operational Issues	Freeway	Expressway	Rural 2-Lane	Urban Arterial
Run-off-road crashes	X	X	X	
Slick pavement	X	X	X	X
Water ponding on the pavement surface	X	X	X	X
Water spreading onto the traveled lanes				X
Loss of control when crossing over a high cross-slope break	X	X	X	

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Cross Slope Resources

- *A Policy on Design Standards Interstate System*, AASHTO, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *A Guide for Reducing Collisions on Horizontal Curves*, NCHRP Report 500, Volume 7, Transportation Research Board, 2004.
- *A Guide for Reducing Collisions Involving Heavy Trucks*, NCHRP Report 500, Volume 13, Transportation Research Board, 2004.
- *A Guide for Addressing Run-Off-Road Collisions*, NCHRP Report 500, Volume 6, Transportation Research Board, 2003.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *Highway Drainage Guidelines,* AASHTO, 2000.

Vertical Clearance

The adopted criteria provide vertical clearance values for the various highway functional classifications (Table 19). These criteria are set to provide at least a 1-foot differential between the maximum legal vehicle height and the roadway, with additional allowances for future resurfacing. These clearances apply to the entire roadway width (traveled way and shoulders). A formal design exception is required whenever these criteria are not met for the applicable functional classification.

Clarifications

The specific standards for vertical clearance adopted for the Interstate System maintain its integrity for national defense purposes. On Interstates, the clear height of structures shall not be less than 16 feet (4.9 meters) over the entire roadway width, including the useable width of shoulder. In urban areas, the 16-foot (4.9-meter) clearance shall apply to at least a single routing. On other urban Interstate routes, the clear height shall not be less than 14 feet (4.3 meters). A design exception is required if this standard is not met. Exceptions on the Interstate must also be coordinated with the Military Surface Deployment and Distribution Command Transportation Engineering Agency of the Department of Defense.

TABLE 19
Ranges for Minimum Vertical Clearance

Type of Roadway	Rural		Urban	
	US (feet)	Metric (meters)	US (feet)	Metric (meters)
Freeway	14–16*	4.3–4.9*	14–16*	4.3–4.9*
Arterial	14–16	4.3–4.9	14–16	4.3–4.9
Collector	14	4.3	14	4.3
Local	14	4.3	14	4.3

*17 feet (5.1 meters) for sign trusses and pedestrian overpasses.
Source: A Policy on Geometric Design of Highways and Streets, AASHTO

Substantive Safety

The adverse effects of structures with insufficient vertical clearance are obvious (see Figure 24). Impacts to low bridges create risk for the driver of the vehicle, others on both roadways, and in extreme situations can result in closure of the bridge for lengthy periods and necessitating costly repairs.

FIGURE 24
Interstate closure after an impact with a bridge.

Summary

Table 20 summarizes the potential adverse impacts to safety and operations of a design exception for vertical clearance.

TABLE 20
Vertical Clearance: Potential Adverse Impacts to Safety and Operations

Safety & Operational Issues	Freeway	Expressway	Rural Two-Lane	Urban Arterial
Collision with overhead structure	X	X	X	X
Rear-end crashes (vehicles following the vehicle that collided with the structure)	X	X	X	X
Debris on the roadway	X	X	X	X
Long delays as a result of a closed roadway or lanes	X	X	X	X

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Vertical Clearance Resources

- *A Policy on Design Standards Interstate System*, AASHTO, 2005.

- *Federal Aid Policy Guide*, FHWA, 2005. http://www.fhwa.dot.gov/legsregs/directives/fapg/0625sup.htm
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.

Lateral Offset to Obstruction

The lateral offset to obstruction is defined as the distance from the edge of traveled way, shoulder, or other designated point to a vertical roadside element. Examples of these elements are curbs, walls, barriers, bridge piers, sign and signal supports, trees, and utility poles (Figure 25).

Lateral offset can be thought of as an operational offset—vertical roadside elements offset to the extent that they do not affect a driver's speed or lane position. Adequate clearance from these elements should be provided for mirrors on trucks and buses and for opening curbside doors where on-street parking is provided.

The adopted criteria specify a minimum operational offset for all roadway conditions and classifications of 1.5 feet.

Clarification

Lateral offset should not be confused with the clear zone—a clear recovery area, free of rigid obstacles and steep slopes, which allows vehicles that have run off the road to safely recover or come to a stop. While lateral offset can be thought of as an operational offset, the clear zone serves primarily a substantive safety function.

FIGURE 25
Lateral offset to obstruction is an operational offset and is not the same as clear zone.

Lateral offset to obstructions is one of the 13 controlling criteria that require a formal design exception per FHWA Policy. Clear zone is not.

Although clear zone is not one of the controlling criteria that require a formal design exception, its importance should still be recognized. The AASHTO *Roadside Design Guide* provides ranges for clear zone based on speed, traffic, and roadside slopes. The *Guide* states that "the values suggest only the approximate center of a range to be considered and not a precise distance to be held as absolute." Designers are expected to exercise judgment in selecting an appropriate clear zone, taking into account the variables listed above as well as the location (urban vs. rural), the type of construction (new construction/reconstruction/ 3R), and the context. Chapter 10 of the *Guide* provides guidance on roadside safety in urban and restricted environments and emphasizes the need to look at each location and its particular site characteristics individually.

According to FHWA, a clear zone should be established for projects or project segments based on a thorough review of site conditions, constraints, and safety considerations. Once a clear zone has been established, decisions to deviate from it for particular roadside obstacles should be identified, justified, and documented.

Summary

Table 21 summarizes the potential adverse impacts to safety and operations of a design exception for lateral offset.

TABLE 21
Lateral Offset to Obstruction: Potential Adverse Impacts to Safety and Operations

Safety and Operational Issues	Freeway	Expressway	Rural 2-Lane	Urban Arterial
Shying away from obstructions	X	X	X	X
Reduced free-flow speeds	X	X	X	X
Difficulty for parked vehicles				X

Freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

Lateral Offset to Obstruction Resources

- *Clear Zone and Horizontal Clearance, Frequently Asked Questions*, FHWA, 2005, http://www.fhwa.dot.gov/programadmin/clearzone.htm
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.
- *Highway Capacity Manual*, Transportation Research Board, 2000.

Structural Capacity

The 13th controlling criterion is structural capacity. This refers only to the load-carrying capacity of the bridge. Because it is not strictly an element of geometric design, structural capacity will not be covered in detail in this guide. Designers should be aware, however, that the inability to design for the designated structural capacity requires a design exception. There is also information in the *Green Book* on conditions under which existing bridges may remain in place.

Clarification

Bridge rail that is structurally sound and meets current crash test standards is an important safety consideration, and updating substandard barrier is an important safety improvement on 3R and other projects. However, the type or condition of bridge rail is not considered to be one of the 13 controlling criteria that require a formal design exception.

Summary

Each of the 13 controlling design criteria is established to reflect a desired operational and/or safety benefit. Designer understanding of the nature of the benefits and the design sensitivities will lead to good decisions regarding design exceptions.

Based on the topics discussed in this chapter, designers should appreciate that the inability to meet a minimum threshold criterion should not be made lightly, and that the expected performance for a lesser design may be based on many conditions. Designers should expect that to some extent adverse operational and/or safety effects may occur with a design exception. The next chapters of this Guide discuss how designers can mitigate potential adverse effects and deliver a design with acceptable performance.

CHAPTER 4

Mitigation Strategies

Table 22 lists potential mitigation strategies for FHWA's 13 controlling criteria. Additional information is provided on the following pages. The list is not meant to include every possible mitigation strategy for each criterion. Rather, it is intended to initiate a thought process by presenting some common as well as innovative mitigation strategies to consider. Every design exception location is unique, so the photos and examples presented in this chapter and the case studies that follow are not meant to imply a best solution for any particular location. The recommended approach is to consider the mitigation strategies presented in this chapter as well as other ideas and new approaches. If available, consult current research to gain additional information. Then customize one or more strategies to address the unique concerns and site conditions at the design exception location.

The known effectiveness of the mitigation strategies varies. Some, such as shoulder rumble strips, have been used for many years and are well proven. Others are new ideas that have been tried, but their effectiveness is still being studied. The body of knowledge on these strategies will continue to grow, so designers should consult the most recent research available to assess the effectiveness of particular strategies.

TABLE 22
Potential Mitigation Strategies

<table>
<tr><th>Design Element</th><th>Objective</th><th>Potential Mitigation Strategies</th></tr>
<tr><td>1. Design Speed</td><td>Reduce operating speeds to the design speed.</td><td>Cross-sectional elements to manage speed.</td></tr>
<tr><td rowspan="13">2. Lane Width &
3. Shoulder Width</td><td>Optimize safety and operations by distributing available cross-sectional width.</td><td>Select optimal combination of lane and shoulder width based on site characteristics.</td></tr>
<tr><td>Provide advance warning of lane width reduction.</td><td>Signing.</td></tr>
<tr><td rowspan="9">Improve ability to stay within the lane.</td><td>Wide pavement markings.</td></tr>
<tr><td>Recessed pavement markings.</td></tr>
<tr><td>Raised pavement markings.</td></tr>
<tr><td>Delineators.</td></tr>
<tr><td>Lighting.</td></tr>
<tr><td>Centerline rumble strips.</td></tr>
<tr><td>Shoulder rumble strips.</td></tr>
<tr><td>Painted edgeline rumble strips.</td></tr>
<tr><td>Paved or partially-paved shoulders.</td></tr>
<tr><td rowspan="2">Improve ability to recover if driver leaves the lane.</td><td>Safety edge.</td></tr>
</table>

TABLE 22 (CONTINUED)
Potential Mitigation Strategies

Design Element	Objective	Potential Mitigation Strategies
	Reduce crash severity if driver leaves the roadway.	Remove or relocate fixed objects.
		Traversable slopes.
		Breakaway safety hardware.
		Shield fixed objects and steep slopes.
	Provide space for enforcement and disabled vehicles.	Pull-off areas.
4. Bridge Width	Provide advance warning and delineation of narrow bridge. Improve visibility of narrow bridge, bridge rail, and lane lines.	Signing.
		Reflectors on approach guardrail and bridge rail.
		Post-mounted delineators.
		Object markers.
		High-visibility bridge rail.
		Bridge lighting.
		Enhanced pavement markings.
	Maintain pavement on bridge that will provide safe driving conditions.	Skid-resistant pavement.
		Anti-icing systems.
	Reduce crash severity if driver leaves the roadway.	Crashworthy bridge rail and approach guardrail.
	Provide space for disabled vehicles or emergencies on long bridges.	Pull-off areas.
	Provide quick response to disabled vehicles or emergencies on long bridges.	Surveillance.
5. Horizontal Alignment & 6. Superelevation	Provide advance warning.	Signing.
		Pavement marking messages.
		Dynamic curve warning systems.
	Provide delineation.	Chevrons.
		Post-mounted delineators.
		Reflectors on barrier.
	Improve ability to stay within the lane.	Widen the roadway.
		Skid-resistant pavement.
		Enhanced pavement markings.
		Lighting.
		Centerline rumble strips.
		Shoulder rumble strips.

TABLE 22 (CONTINUED)
Potential Mitigation Strategies

Design Element	Objective	Potential Mitigation Strategies
Potential Mitigation Strategies		Painted edgeline rumble strips.
	Improve ability to recover if driver leaves the lane.	Paved or partially paved shoulders.
		Safety edge.
	Reduce crash severity if driver leaves the roadway.	Remove or relocate fixed objects.
		Traversable slopes.
		Breakaway safety hardware.
		Shield fixed objects and steep slopes.
7. Vertical Alignment	See (8) Grade and (9) Stopping Sight Distance.	
8. Grade	Provide advance warning.	Signing.
	Improve safety and operations for vehicles ascending or descending steep grades.	Climbing lanes.
		Downgrade lanes.
	Capture out-of-control vehicles descending steep grades.	Escape ramps.
	Improve ability to stay within the lane.	Enhanced pavement markings.
		Delineators.
		Centerline rumble strips.
		Shoulder rumble strips.
		Painted edgeline rumble strips.
	Improve ability to recover if driver leaves the lane.	Paved or partially-paved shoulders.
		Safety edge.
	Reduce crash severity if driver leaves the roadway.	Remove or relocate fixed objects.
		Traversable slopes.
		Breakaway safety hardware.
		Shield fixed objects and steep slopes.
	Address drainage on flat grades.	Adjusting gutter profile on curbed cross sections.
		Continuous drains.
9. Stopping Sight Distance	Mitigate sight distance restrictions.	Signing and speed advisory plaques (crest vertical curves).
		Lighting (sag vertical curves).
		Adjust placement of lane within the roadway cross section (horizontal).

TABLE 22 (CONTINUED)
Potential Mitigation Strategies

Design Element	Objective	Potential Mitigation Strategies
		Cross-sectional elements to manage speed.
	Improve ability to avoid crashes.	Wide shoulders.
		Wider clear recovery area.
	Improve driver awareness on approach to intersections.	Advanced warning signs.
		Dynamic warning signs.
		Larger or additional STOP/YIELD signs.
		Intersection lighting.
10. Cross Slope	Provide warning of slick pavement.	Signing.
	Improve surface friction.	Pavement grooving (PCC pavement).
		Open-graded friction courses (HMA pavement).
	Improve drainage.	Transverse pavement grooving (PCC pavement).
		Open-graded friction courses (HMA pavement).
		Pavement edge drains.
	Mitigate cross-slope break on the high side of superelevated curves.	Modified shoulder cross slope.
11. Vertical Clearance	Advance warning.	Signing.
	Preventing impacts with low structures.	Alternate routes.
		Large vehicle restrictions.
12. Lateral Offset to Obstruction	Improve visibility of objects near the roadway.	Delineate objects.
		Lighting.
	Optimize operations by distributing available cross-sectional width.	Provide full outside lane width and/or additional offset.
	Improve visibility of the lane lines.	Enhanced pavement markings.
13. Structural Capacity	Not addressed in this Guide.	

1. Design Speed

As discussed in Chapter 3, design speed is a design control, and the chosen design speed affects many of the geometric elements of a highway. Design exceptions for design speed are also rare, for two reasons: 1) the adopted criteria encompass a range of design speeds, which provides a great deal of design flexibility; and 2) design exceptions, when needed, are normally prepared for the specific design elements and not the design control.

In the rare cases when a design exception is used for design speed, one mitigation measure to consider is choosing cross-sectional elements and dimensions that serve to manage operating speeds so they are at or below the design speed. For example, on a transitional roadway between a rural and urban environment, a more-enclosed urban cross-section with curb and gutter gives drivers a visual cue that they are entering a reduced-speed environment. It may also feel less comfortable for a driver to maintain high speeds on such a cross section compared to a more-open, rural cross section with full-width lanes and wide shoulders. Just as design speed is selected by the designer, cross-sectional elements can be chosen that help manage operating speeds.

Target areas: Any highway where a design exception is used for design speed.

Strategy: Cross-sectional elements to manage speed.

2. Lane Width and 3. Shoulder Width

Lane and shoulder width strategies have been combined in this discussion because normally they are evaluated in combination when there is limited cross-sectional width. The two criteria are also interrelated in terms of their effects on safety and operations.

Distribute Cross-Sectional Width

Target areas: Highways with limited cross-sectional width.

Strategy: Optimized lane and shoulder widths.

In locations where cross-sectional width is constrained, evaluating how that width can be distributed most effectively between the lane and shoulder should be evaluated. This strategy is basically an exercise in trade-offs—taking some of the lane width to use for additional shoulder width or vice versa, depending on the location and the objectives.

The optimal distribution will depend on site-specific characteristics. For example, on a rural two-lane roadway with no shoulders and a history of run-off-road crashes, an effective strategy may be to distribute some of the available width to accommodate a narrow paved shoulder and rumble strips, at the expense of narrower lanes. The objective would be to reduce the probability of run-off-road crashes. For another highway, with heavy truck volumes and a curvilinear alignment, maintaining full 12-foot lanes at the expense of some of the shoulder width may be a more-optimal design. The objective would be minimizing truck off-tracking into adjacent lanes or the shoulder. The key is to look at the site-specific characteristics such as highway type, traffic and truck volumes, geometry, crash history, and crash type. With this information, various combinations of lane and shoulder widths can be evaluated with the goal of optimizing safety and traffic operations at the design exception location.

Case Study 1 (presented in Chapter 5) illustrates how one State evaluated multiple combinations of lane and shoulder width on a segment of urban freeway where the cross section was constrained.

Provide Advance Warning of Lane Width Reduction

Target areas: High-speed roadways with narrow lanes.

Strategy: Advance signing of narrow lanes.

Signs can be used to warn drivers in advance of a change in lane width. Messages such as a ROAD

NARROWS sign (Figure 26) may be used alone or in combination with an advisory speed plaque. The *Manual of Uniform Traffic Control Devices (*MUTCD) provides guidance on the size of warning signs for various highway types but notes that larger signs may be used when appropriate. Larger warning signs should be considered for design exception locations.

Use of advance warning signs as a stand-alone measure is unlikely to sufficiently mitigate a design exception for lane width, but at some locations it can be an effective component of a more comprehensive approach.

FIGURE 26
Signs can be used to warn drivers in advance of a change in lane width.

Target areas: High-speed roadways with narrow lanes or shoulders.

Strategy: Delineators.

Improve Ability to Stay Within the Travel Lane

Another category of mitigation strategies for both lane and shoulder widths is aimed at enhancing a driver's ability to stay within the lane. One method is to provide clear delineation and better visibility of the lanes. Wide pavement markings (Figure 27), recessed pavement markings with high retroreflectivity (Figure 28), and raised pavement markings (Figure 29) can help drivers stay within their lane—particularly at night, when the pavement is wet or when visibility is poor. Both raised and recessed pavement markings will have higher costs than standard painting. Recessed pavement markings may provide extra advantages in areas of the country where snow and ice removal can cause additional wear on painted or raised markings.

Target areas: High-speed roadways with narrow lanes or shoulders.

Strategy: Enhanced pavement markings.

Roadside delineators (Figure 30) can help drivers see changes in roadway geometry. Lighting (Figure 31) will have higher up-front costs and ongoing utility costs, but is another strategy that can enhance a driver's ability to see and stay within the travel lane. Depending on the type of highway, traffic volumes, crash history, and other site-specific characteristics, lighting may be appropriate for the entire length of the design exception location, or it may be appropriate only for selected segments. For example, for a high-speed rural roadway with narrow lane or shoulder widths, lighting could be installed along horizontal curves or along segments with a history of lane-departure crashes.

Target areas: Urban freeways and other high-speed urban roadways, or segments of high-speed rural roadways with a high crash history or a higher probability of run-off-road crashes.

Strategy: Lighting.

FIGURE 27
Wide pavement markings.

FIGURE 28
Recessed pavement markings.

FIGURE 29
Raised pavement markings.

FIGURE 30
Post-mounted delineators.

FIGURE 31
Lighting.

In addition to visible delineation, shoulder and centerline rumble strips improve a driver's ability to stay within the lane by providing both an audible warning and a slight vibration within the vehicle that a driver can feel. On rural two-lane roadways with narrow lane widths, drivers may have a tendency to shy to the outside when meeting other vehicles. Shoulder rumble strips (Figure 32) warn drivers that they are outside the lane. Another concern on two-lane undivided roadways are cross-centerline head-on or sideswipe crashes. Similar to shoulder rumble strips, centerline rumble strips (Figure 33) can be used to warn drivers that they are driving near the centerline and are close to encroaching on the opposing lane. Centerline rumble strips are normally used on high-speed rural two-lane highways. Shoulder rumble strips are an effective strategy on any high-speed rural highway. Agencies are encouraged to work in cooperation with local and state bicycle groups on shoulder rumble strip issues. By involving bicyclists early in the process, designs can be developed that achieve the safety benefits of rumble strips while at the same time accommodating the needs of bicyclists. The gap pattern illustrated in Figure 32 is one method that can be used to better accommodate bicyclists.

Target areas: High-speed rural highways.

Strategy: Shoulder rumble strips.

Target areas: Two-lane, undivided, rural highways.

Strategy: Centerline rumble strips.

FIGURE 32
Shoulder rumble strips.

FIGURE 33
Centerline rumble strips.

An emerging strategy that has been tried in several States is combining edgeline pavement markings with shoulder rumble strips (Figure 34). The rumble strips are placed at the edge of the travel lane. This allows rumble strips to be placed on roadways with very limited cross-sectional width and narrow paved shoulders. The edgeline marking is then painted directly over the rumble strips. Several advantages of this strategy have been observed.

Target areas: High-speed rural highways and areas where snow removal operations are causing deterioration of pavement markings.

Strategy: Painted edgeline rumble strips.

First, the pavement marking on the near-vertical face of the rumble strip reflects more light back towards the driver at night, creating a more-visible edgeline. Second, in northern states, the paint and beads that are in the depressed portion of the rumble strip are less prone to wear from snow plowing. This can extend the life and performance of the painted edgeline.

FIGURE 34
Painted edgeline rumble strips.

Improve Ability to Recover if Driver Leaves the Lane

When a driver leaves the lane or the paved portion of the roadway at high speeds, there is a significant safety risk. As discussed in Chapter 3, pavement edge dropoffs can increase this risk.

> **Target areas:** All high-speed highways.
>
> **Strategy:** Paved or partially paved shoulders.

Paved or partially paved shoulders (Figure 35) move the pavement edge and potential dropoffs farther from the travel lane. Another strategy is to construct the pavement edge to allow safer recovery for drivers who leave the paved section of the roadway. The safety edge (Figure 36) accomplishes this by providing a beveled edge of pavement instead of a near-vertical edge. This strategy can be used with both hot mix asphalt (HMA) and portland cement concrete (PCC) pavements. Working with contractors is recommended because some modifications to paving equipment will be necessary. The safety edge is particularly worth considering for areas with very limited cross-sectional width, where there is not enough width for paved or partially paved shoulders. Many roadways on the local system fit this description.

> **Target areas:** High-speed highways, especially those with no paved shoulder or narrow paved shoulders.
>
> **Strategy:** Safety edge.

FIGURE 35
Partially paved shoulders.

Reduce the Crash Severity if the Driver Leaves the Roadway

Because the probability of run-off-road crashes is higher at locations with design exceptions for lane or shoulder width, special attention should be paid to providing clear recovery areas and implementing measures to reduce the severity of these crashes.

> **Target areas:** Any high-speed or rural highway.
>
> **Strategy:** Clear recovery area, traversable slopes, breakaway safety hardware, and barriers where appropriate.

Fixed objects should be removed (Figure 37) or relocated to a place where they are less likely to be hit—at or beyond the clear zone, if possible. Signs, light poles, and other necessary roadside hardware should be installed with crashworthy breakaway supports (Figure 38). Foreslopes, transverse slopes, and drainage structures should be made traversable. In some cases, fixed objects or steep slopes should be shielded with barriers (Figure 39). Although the use of barriers may increase crash frequency, crash severity is expected to decrease.

FIGURE 36
Safety edge (top) and after the shoulder has been graded over the edge (bottom).

FIGURE 37
Fixed object removal. Separate box culverts were extended, connected, and covered at this interchange.

FIGURE 38
Breakaway light poles.

FIGURE 39
Shielding fixed objects with barrier.

Provide Pull-Off Areas where Shoulder Width is Limited

Where shoulder width is limited, another mitigation strategy is to provide regularly spaced pull-off areas (Figure 40). Pull-off areas provide several advantages. First, they provide room to store disabled vehicles, which is particularly important for maintaining operations on high-volume highways. A disabled vehicle can be parked or quickly removed from a travel lane to a pull-off area, allowing traffic to flow in all available traffic lanes as quickly as possible. Second, pull-off areas provide an area for law enforcement to detain vehicles in areas with narrow shoulders. This increases safety for law enforcement personnel, the stopped driver, and passing drivers. Operations are likely to be improved as well because drivers are more likely to maintain normal speeds and stay within their lane if law enforcement activities are being conducted a sufficient distance from the travel lanes in a pull-off area.

Target areas: High-speed roadways with narrow shoulders.

Strategy: Pull-off areas.

If possible, pull-off areas should be located where lane departure crashes are less likely, such as tangent sections or on the inside of horizontal curves.

Case Study 4 (presented in Chapter 8) illustrates how one State is using pull-off areas on a historic urban freeway with extremely narrow shoulders.

FIGURE 40
Pull-off area on the inside of a horizontal curve.

4. Bridge Width

The strategies for mitigating narrow bridges are aimed primarily at improving a driver's ability to see the narrowed cross section on the bridge, the bridge rail, and the lane lines. Safety benefits are a reduced probability of sideswipe or head-on crashes with other vehicles on the bridge, as well as fewer impacts with the bridge rail and approach guardrail. Operational benefits may result from an increase in driver comfort. A driver who can clearly see these cross-sectional elements is more likely to maintain normal operating speeds or at least not dramatically reduce speeds at the bridge. This is particularly important for maintaining efficient traffic flow on urban freeways and can also reduce the probability of rear-end crashes on high-speed, high-volume highways.

Signing

Signs can be used to warn drivers in advance of a narrow bridge (Figure 41). In some situations, flashers installed in conjunction with the sign may further increase driver awareness. The MUTCD provides guidance on the size of warning signs for various highway types but notes that larger signs may be used when appropriate. Larger warning signs should be considered for design exception locations.

Target areas: Any narrow bridge location.

Strategy: Advance signing of narrow bridge.

Use of advance warning signs as a stand-alone measure is unlikely to sufficiently mitigate a design exception for bridge width, but at some locations it can be an effective component of a more comprehensive approach.

FIGURE 41
Signs can be used to warn drivers in advance of a narrow bridge.

Delineation

Target areas: Any narrow bridge location.

Strategy: Delineation.

Delineation of the narrowed cross section at the bridge is another strategy for providing advance warning. One method that provides very good delineation at night is reflectors or reflector tabs that are placed on the approach guardrail and along the bridge rail (Figure 42). Post-mounted delineators approaching the bridge are another option. Instead of providing just a single point of delineation, such as an object marker, reflectors and delineators allow the driver to better see the cross section narrowing as well as the most narrow segment of the cross section—the bridge.

FIGURE 42
Reflector tabs on guardrail.

Object markers placed at the ends of the bridge rail is a common treatment (Figure 43). In areas where agricultural equipment or other wide vehicles are using the bridge, one issue to consider when using object markers or other post-mounted signs at the ends of the bridges is that they may prevent this type of equipment from being able to cross the bridge. In these cases, using reflectors on the approach guardrail and the bridge rail or other methods to achieve delineation of the narrow bridge should be considered instead of post-mounted delineation.

FIGURE 43
Object markers and post-mounted delineators at a narrow bridge.

Installing high-visibility bridge rails are another method for delineating narrow bridges. White concrete has been used by some agencies to enhance the visibility of bridge rail at night or when visibility is poor (Figure 44). There are also proprietary products on the market with features that make bridge rails more visible.

Target areas: Any narrow bridge location.

Strategy: High-visibility bridge rail.

FIGURE 44
White concrete bridge rail.

Bridge Lighting

Lighting is another way to make narrow bridges more visible to drivers. Although most often used in urban areas, lighting may be appropriate on some rural bridges, particularly if there is a history of safety problems.

Target areas: Narrow bridges in urban areas; bridges in areas with a high number of pedestrians and other non-motorized users; bridges where traffic volumes are high; bridges with a history of crashes or operational problems.

Strategy: Lighting at narrow bridges.

Skid-Resistant Pavement and Anti-Icing Systems

Particularly in northern regions of the country where icing on bridges is a common problem, measures to maintain skid-resistant pavement should be considered to help drivers maintain control on slick pavement. Pavement grooving and other textures (Figures 62 and 63) can be placed at the time the bridge deck and bridge approach is constructed. Textures can also be milled into existing pavement. Although relatively expensive to deploy, automated anti-icing systems (Figure 45) may be appropriate, at especially problematic locations.

Target areas: Any narrow bridge.

Strategy: Skid-resistant pavement.

Target areas: Bridges on high volume, high-speed highways or bridges with a history of safety problems.

Strategy: Anti-icing systems.

FIGURE 45
Anti-icing system on a bridge.

Crashworthy Bridge Rail and Approach Guardrail

Because of the higher probability of impacts with the bridge rail and approach guardrail at narrow bridge locations, crashworthy barrier that meets or exceeds NCHRP Report 350 crash test criteria should be used (Figure 46). This includes the bridge rail, the guardrail, the stiffened guardrail transition that connects to the bridge rail, and the guardrail terminal.

Target areas: Any narrow bridge location.

Strategy: Crashworthy bridge rail and approach guardrail.

Safety hardware that complies with *Report 350* criteria is required on new installations on the NHS. Upgrading older systems, regardless of highway system, is encouraged—particularly at design exception locations. In areas with high volumes of large vehicles, barrier that has passed test-level 4 or 5 criteria should be considered. Test-levels 4 and 5 include crash tests with single-unit trucks and tractor-semi-trailers, respectively.

The *AASHTO Roadside Design Guide* provides guidance on barrier flare rates. Flared approach guardrail, particularly when combined with reflectors, can visually transition a driver into the narrowed cross section of the bridge (Figure 42).

FIGURE 46
Bridge rail and guardrail transition in compliance with *NCHRP Report 350.*

Target areas: Any narrow bridge location.

Strategy: Enhanced pavement markings and lane delineation.

Pavement Markings and Lane Delineation

Other mitigation strategies for narrow bridge width that are discussed in other sections of this chapter include enhanced pavement markings; see the Lane Width and Shoulder Width section.

In addition to the safety benefits of helping drivers see and stay within the lane, improved lane delineation is expected to increase driver comfort at narrow bridges and improve operations.

Target areas: Long bridges.

Strategy: Emergency pull-off areas.

Emergency Pull-off Areas

If a design exception for bridge width cannot be avoided for long bridges, emergency pull-off areas should be considered. Pull-off areas on bridges should be safely terminated, either by flaring the bridge rail at an appropriate rate or through the use of an impact attenuator on any blunt end facing traffic.

Surveillance

Target areas: Long bridges.

Strategy: Surveillance.

Another strategy for long bridges is to use intelligent transportation systems (ITS) such as cameras to monitor long bridges for crashes, disabled vehicles, or other problems. This will allow law enforcement and other emergency responders to get to the scene as quickly as possible, which may prevent a crash. It also allows a disabled vehicle to be removed from the narrow bridge as quickly as possible, which will improve safety as well as minimize the amount of time a lane is blocked.

5. Horizontal Alignment and 6. Superelevation

Horizontal alignment and superelevation strategies have been combined in this discussion because they are normally evaluated in combination. The two criteria are also interrelated in terms of their effects on safety and operations.

Signing and Pavement Marking Messages

Signs can be used to warn drivers in advance of sharp horizontal curves and where there is non-standard superelevation (Figures 47 and 48). The most commonly used are the curve warning sign (for advisory speeds of 30 mi/h or greater) and the turn warning sign (for advisory speeds less than 30 mi/hr). Advisory speed plaques mounted below the warning sign are often used. In some situations, flashers installed in conjunction with the sign may further increase driver awareness. The MUTCD provides guidance on the size of warning signs for various highway types but notes that larger signs may be used when appropriate. Larger warning signs should be considered for design exception locations.

Target areas: Any highway, particularly high-speed highways, at the approach to sharp or unexpected horizontal curves.

Strategy: Advance warning with signing and pavement markings.

Another consideration, besides the radius of the curve and the rate of superelevation, is the roadway alignment leading up to the curve. For example, a curve on a highway with a predominantly curvilinear alignment is more expected by the driver. Conversely, a sharp curve along a highway with a predominantly straight alignment or at the end of a long tangent is more likely to surprise a driver. Advance warning is especially important in these situations.

Curve warning messages painted on the pavement are another method for providing advance warning of horizontal curves. One example is the painted message SLOW, along with a painted turn arrow.

Dynamic Message Signs

At some curves, signs that provide dynamic messages to drivers may be an effective countermeasure (Figure 49). Changeable, real-time information can be communicated to the driver, such as the current recommended speed and the driver's current operating speed.

Target areas: Curves with a history of safety problems. A common application is to mitigate truck rollover crashes on sharp curves at interchange ramps and loops.

Strategy: Dynamic message signs.

FIGURE 47
Turn warning sign with flashing beacon.

FIGURE 48
Curve warning sign. Note how vertical alignment can affect visibility of the curve.

FIGURE 49
Dynamic curve warning system.

Delineation

In addition to advance warning, delineation is a common mitigation strategy for horizontal curves. There are several ways to effectively delineate horizontal curves:

> **Target areas:** Any sharp or unexpected horizontal curve.
>
> **Strategy:** Delineation.

- Chevrons (Figure 50). The MUTCD provides guidance on chevron size for various highway types but notes that larger signs may be used when appropriate. Larger chevrons should be considered for design exception locations.
- Post-mounted delineators (Figure 51).
- Reflectors on barrier. If barrier is used along the horizontal curve, low-cost delineation can be provided with reflectors installed along the barrier (Figure 52).

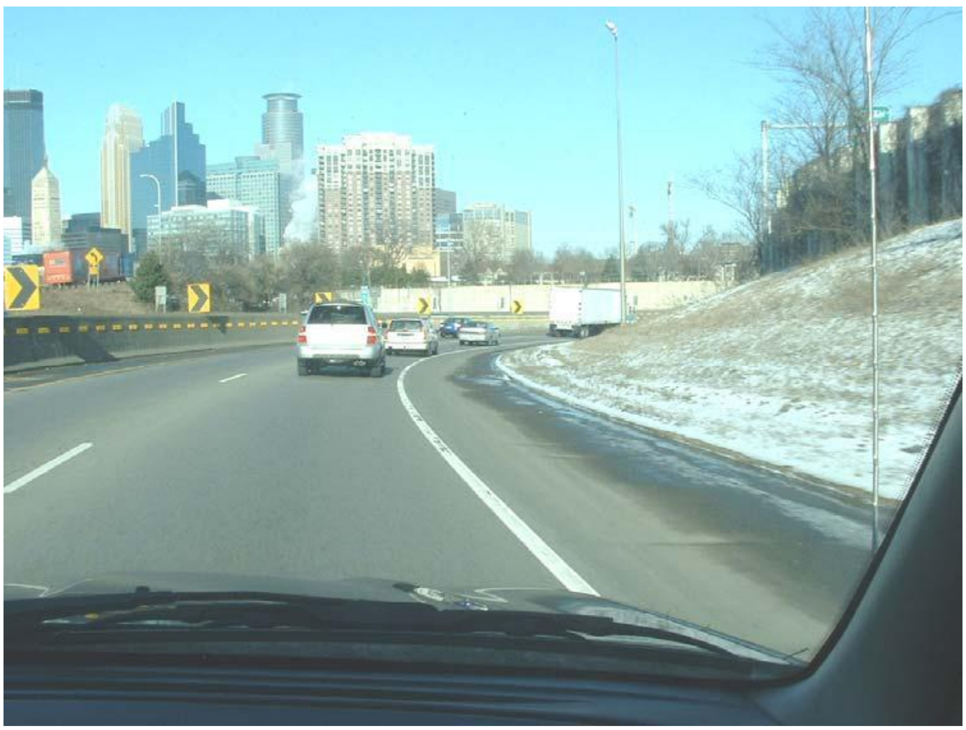


FIGURE 50
Delineation with large chevrons.

FIGURE 51
Delineation with post-mounted delineators.

FIGURE 52
Delineation with reflectors on barrier.

Widen the Roadway

Target areas: Curves on highways with large truck volumes, cross-centerline crashes, or run-off-road crashes.

Strategy: Widen the roadway.

Widening the travel lanes at horizontal curves can mitigate off-tracking of trucks and other large vehicles into adjacent lanes. Additional lane width will make it easier for all drivers to maneuver through the curve without leaving the travel lane. If cross-centerline crashes are a problem at a curve, a narrow median, preferably with centerline rumble strips, can provide some separation between the directions of traffic. If run-off-road crashes are more prevalent, widening the shoulder will help a driver that has left the travel lanes safely recover. Lane widening can also be beneficial on ramps and loops, particularly where there is a history of run-off-road crashes. The AASHTO *Policy on Geometric Design of Highways and Streets* provides design guidance on lane widening through curves.

Skid-Resistant Pavement

Another strategy aimed at keeping drivers on the roadway is to provide pavement treatments to improve surface friction and skid resistance such as grooving of PCC pavement and open-graded friction courses for HMA pavement. Pavement grooving and other textures (Figures 62 and 63) can be placed at the time pavement is constructed or they can be milled into existing pavement. See the Cross Slope section for more information.

> **Target areas:** Any horizontal curve.
>
> **Strategy:** Grooved, textured, or open-graded pavements to improve surface friction and skid resistance.

Other Horizontal Curve Strategies

Because horizontal curves are a contributing factor to lane departure crashes, many of the strategies for preventing or reducing the severity of these crashes are applicable. See the Lane and Shoulder Width discussion earlier in this chapter for additional information on the following strategies:

- Enhanced pavement markings
- Lighting
- Shoulder, centerline, and painted edgeline rumble strips
- Paved or partially paved shoulders
- Safety edge
- Clear recovery area, traversable slopes, breakaway safety hardware, and barrier where appropriate

> **Target areas:** Any horizontal curve.
>
> **Strategy:** Preventing or reducing the severity of lane departure crashes.

7. Vertical Alignment

Most design exceptions for vertical alignment are related to grade and stopping sight distance. The following two sections discuss these elements.

8. Grade

The strategies for mitigating grade are aimed at providing drivers with advance warning as they approach a steep grade, improving the ability of traffic to safely ascend and descend steep grades, and improving drainage in locations with flat grades.

> **Target areas:** Any highway with steep grades.
>
> **Strategy:** Signing.

Steep Grades

Signs can be used to warn drivers in advance of steep grades (Figure 53). The MUTCD provides guidance on the size of warning signs for various highway types but notes that larger signs may be used when appropriate. Larger warning signs should be considered for design exception locations. Use of advance warning signs as a stand-alone measure is unlikely to sufficiently mitigate a design exception for grade, but it can be an effective component of a more comprehensive approach.

Climbing lanes are a common strategy for improving safety and operations on uphill grades (Figure 54). From an operations standpoint, traffic can continue at free-flow speeds by passing trucks and other slow-moving vehicles. From a safety perspective, providing passing opportunities with a climbing lane reduces the probability of risky passing maneuvers. Similarly, adding a lane on the downgrade side of the facility may also be beneficial in some situations, where large trucks or other slow-moving vehicles create additional risk for faster-moving vehicles approaching from behind.

Target areas: High-speed highways with steep grades (most common on rural highways).

Strategy: Climbing lanes and downgrade lanes.

FIGURE 53
Advance warning of a steep grade.

FIGURE 54
Climbing lane.

For steep downhill grades with large truck volumes, escape ramps can be an effective strategy for capturing heavy vehicles that have lost control (Figure 55). Case Study 2 (presented in Chapter 6) illustrates an innovative truck escape ramp constructed in a mountainous region with very severe grades.

Target areas: High-speed highways with steep grades and high truck volumes (most common in regions with mountainous terrain).

Strategy: Escape ramps.

Strategies should be considered for improving drivers' ability to stay within the lane or their ability to recover if they leave the lane, and reducing crash severity if the vehicle leaves the roadway. The Lane and Shoulder Width discussion earlier in this chapter has additional information on the following strategies:

Target areas: Any highway with steep grades.

Strategy: Preventing or reducing the severity of lane departure crashes.

- Enhanced pavement markings
- Delineation
- Shoulder, centerline, and painted edgeline rumble strips
- Paved or partially-paved shoulders
- Safety edge
- Clear recovery area, traversable slopes, breakaway safety hardware, and barrier where appropriate

FIGURE 55
Truck escape ramp.

Flat Grades

For proper drainage of the pavement surface, there needs to be adequate slope in the transverse direction (cross slope) and in the longitudinal direction (grade). To mitigate grades that are too flat, measures should be considered that will improve drainage on the highway.

> **Target areas:** Urban arterials, normally with speeds of 45 mi/h or less.
>
> **Strategy:** Adjusting the gutter profile.

> **Target areas:** High-speed roadways with flat grades; areas where fast removal of surface water and minimizing spread onto the roadway is especially important.
>
> **Strategy:** Special drainage systems.

In areas with curbed cross sections, the profile of the gutter can be adjusted by slightly varying the cross slope of the lanes. This creates a "rolling" gutter profile that increases the grade along the curb between inlets, thereby creating more efficient flow and removal of water in the gutter.

In some areas, more expensive drainage systems may be appropriate. Continuous drainage systems can be installed in areas with flat grades (Figure 56). These drains capture the water along the length of the highway segment with flat grades, and the pipe or channel underlying the drain can be sloped to move water efficiently through the system.

FIGURE 56
Continuous drainage system.

9. Stopping Sight Distance

The strategies for mitigating sight distance problems are aimed at mitigating sight distance restrictions, improving drivers' ability to avoid crashes, and improving driver awareness on the approach to intersections.

Target areas: Crest vertical curves.

Strategy: Signing.

FIGURE 57
Sign for crest vertical curve with inadequate stopping sight distance.

Stopping Sight Distance on Vertical Curves

Advance signing (Figure 57) should be considered in areas with design exceptions for stopping sight distance at crest vertical curves. The MUTCD recommends this sign be supplemented with a speed advisory plaque.

The MUTCD provides guidance on the size of warning signs for various highway types but notes that larger signs may be used when appropriate. Larger warning signs should be considered for design exception locations.

Use of advance warning signs as a stand-alone measure may not be sufficient to mitigate a design exception for stopping sight distance, but at some locations it can be an effective component of a more comprehensive approach.

Target areas: Sag vertical curves.

Strategy: Lighting.

Because headlight sight distance is the control at sag vertical curves, the most common mitigation measure at these locations is to install lighting.

Horizontal Stopping Sight Distance

One common horizontal sight obstruction is concrete barrier. Lower-height barrier should be considered in these situations. There are vertical-shaped concrete barriers in the height range of 29 to 32 inches that are compliant with *NCHRP Report 350* criteria at test-level 4 (crash testing with a single-unit truck at 60 mi/h). Case Study 4 (presented in Chapter 8) illustrates how one State is using a lower-height median barrier to maximize horizontal sight distance.

Target areas: Horizontal curves.

Strategy: Lower-height barrier.

In some cases, slight adjustments to lane width or the placement of the lane within the roadway cross section can increase horizontal stopping sight distance. This strategy must be evaluated carefully to ensure that it does not create other safety or operational problems, particularly if the lanes are narrowed.

Target areas: Horizontal curves.

Strategy: Adjusting placement of lane within the roadway cross section.

Target areas: Any location with limited stopping sight distance.

Strategy: Select cross-sectional elements to manage speed.

Select Cross-Sectional Elements to Manage Speed

In some locations, mitigation measures to consider for either vertical or horizontal sight distance design exception locations are cross-sectional elements and dimensions that manage operating speeds so they are at or below the speeds corresponding to the available sight distance. For example, an urban cross section with curb and gutter gives the driver a visual cue that they are in a reduced-speed environment. A more-closed cross section may also affect driver comfort and cause drivers to slow down. This strategy should not create additional design exceptions.

Improve Ability to Avoid Crashes

Where there is insufficient sight distance to vehicles or other objects on the roadway ahead, a fundamental strategy is to design shoulders and a roadside that will improve a driver's ability to avoid a crash. Wider shoulders will give drivers a better chance to safely avoid a crash and remain on the roadway. Providing additional clear recovery area on the roadside will reduce the probability of a severe run-off-the-road crash if the driver leaves the roadway.

Target areas: Any location with limited stopping sight distance.

Strategy: Provide wider shoulders and wider clear zones.

Improve Driver Awareness on Approach to Intersections

At some locations, the visibility of approaching intersections and associated traffic control devices may be restricted because of inadequate horizontal or vertical sight distances.

Mitigation measures can be implemented to make the driver more aware of the intersection. Advance signing can be installed to warn drivers of the intersection before it is clearly visible. In some situations, flashers installed in conjunction with the sign may further increase driver awareness. At intersections with a high crash history, high traffic volumes, severe sight restrictions, or other concerns, ITS applications may be appropriate strategies. For example, detectors can be placed in the pavement on a minor road approach to a major highway. A flasher on the major highway can be installed to warn drivers that vehicles are at the minor road approach, entering the intersection (Figure 58).

Target areas: Any location with limited sight distance to an intersection.

Strategy: Static or dynamic warning of intersection or entering traffic.

FIGURE 58
Intersection warning sign with flashers activated by vehicles entering from the side road.

Measures can also be taken if the sight distance to traffic control devices at an intersection is limited. Examples include: installing larger STOP or YIELD signs, installing STOP signs on both sides of the roadway, adding a STOP sign on the left side near the centerline within an island, and installing a flasher on top of the STOP sign to improve visibility because of limited vertical sight distance (Figure 59).

Target areas: Any location with limited sight distance to intersection signs.

Strategy: Repositioning, adding, or enhancing intersection signs.

FIGURE 59
A STOP sign with a flashing beacon improves visibility of the sign at this intersection with limited vertical sight distance.

Target areas: Any location with limited sight distance to an intersection, particularly intersections with a history of night crashes.

Strategy: Intersection lighting.

Another strategy for improving intersection recognition, particularly where there is a history of night crashes, is intersection lighting (Figure 60).

FIGURE 60
Intersection lighting.

10. Cross Slope

The primary concern for locations with insufficient cross slope is inadequate drainage and ponding of water on the travel lanes. SLIPPERY WHEN WET signs may be used to warn drivers of pavements with insufficient cross slope that may become more slick than sections with normal cross slope (Figure 61).

Target areas: High-speed roadways with insufficient cross slope.

Strategy: SLIPPERY WHEN WET signing.

FIGURE 61
SLIPPERY WHEN WET sign.

The MUTCD provides guidance on the size of warning signs for various highway types but notes that larger signs may be used when appropriate. Larger warning signs should be considered for design exception locations.

Another strategy aimed at helping drivers maintain control on slick pavements is pavement grooving and other textures that improve surface friction (Figures 62 and 63). This strategy is appropriate for pavements with cross slopes that are either too flat or too steep. For PCC pavement, textures can be placed at the time of construction or milled into existing pavement. Longitudinal grooving will minimize noise—both externally and for drivers. For HMA pavement, open-graded surface courses can be used to improve surface friction.

Target areas: Any highway with cross slopes that are either too flat or too steep.

Strategy: Grooved, textured, or open-graded pavements to improve surface friction.

FIGURE 62
Longitudinal texture applied to fresh pavement to improve surface friction.

Improving drainage should be considered for roadways with insufficient cross slope. Transverse grooving on PCC pavement can improve surface drainage (Figure 63). On HMA pavement, open-graded friction courses with a higher percentage of voids allows water to drain more quickly through the surface course to an impervious intermediate course, and out into an edge drain or the ditch. This strategy should be considered on resurfacing projects in situations where the cross slope cannot be increased to the acceptable range. In some locations, more expensive continuous drainage systems may be appropriate (Figure 56).

Target areas: Any highway with insufficient cross slope.

Strategy: Improve drainage through transverse grooving on PC pavement and open-graded surface courses on HMA pavement.

FIGURE 63
Transverse grooving to improve surface drainage and friction.

On the high side of superelevated curves, the cross-slope break should not exceed 8 percent. One mitigation strategy to consider is to move the breakpoint outward in the transverse direction (Figure 64), reducing the probability of a driver crossing over the breakpoint. Another strategy is to slope the shoulder in the same direction as the traveled lanes through the area with high superelevation. In northern regions, however, a downside to this strategy is that any ice or snow on the shoulder will drain onto the roadway as it melts during the day, creating the potential for ice to form on the traveled lanes as temperatures fall. Figure 64 illustrates how the cross slope of the shoulder can be transitioned to mitigate a steep cross-slope break. In this example, a portion of the shoulder is paved flat (no cross slope), adjacent to the steep cross slope of the travel lanes. The remainder of the shoulder is sloped in the opposite direction. This is an effective method for non-paved shoulders to prevent gravel or soil from washing onto the travel lanes and for controlling drainage across the travel lanes. There are additional ways to modify the cross-slope break, including rounding over the breakpoint on HMA pavements.

Target areas: Highly superelevated highways where the cross-slope break exceeds 8 percent.

Strategy: Adjustment of the high-side shoulder cross slope.

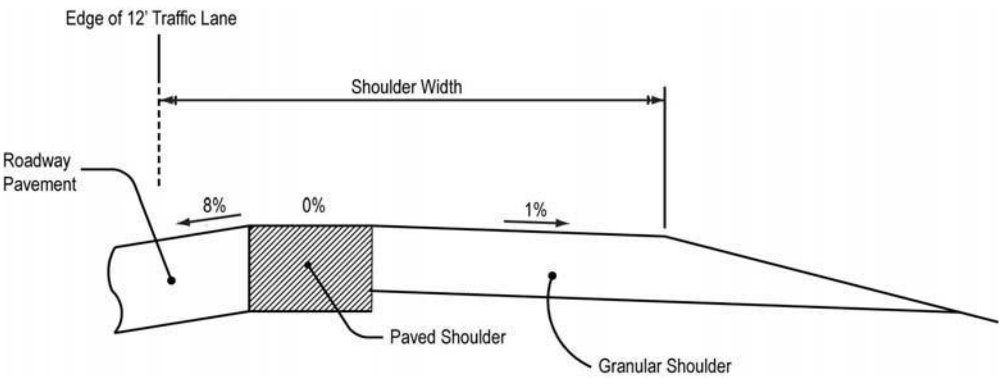


FIGURE 64
An example of transitioning the cross slope of the shoulder to mitigate a cross-slope break greater than 8%. Rounding at the breakpoint is an option with HMA pavement.

11. Vertical Clearance

Signing is the most common mitigation strategy for vertical clearance (Figures 65 and 66). Whenever vertical clearance criteria are not met, advance warning should be placed at the nearest intersecting road or wide point in the road at which a vehicle can detour or turn around. The MUTCD provides guidance on the size of warning signs for various highway types but notes that larger signs may be used when appropriate. Larger warning signs should be considered for design exception locations. In some locations, electronic message signs have been used to provide enhanced warning.

Target areas: Any highway with a structure that has low vertical clearance.

Strategy: Signing.

An innovative strategy for providing additional warning is to combine the sign with chimes that are hung from a sign truss at the same height as the vertical clearance of the structure (Figure 67). If a truck hits the chimes, the driver is alerted that the truck will not clear the structure.

Target areas: Highways with a nearby detour route that is designed to carry heavy vehicles.

Strategy: Detours.

Target areas: Highways where an alternate route for large vehicles exists—Non-interstate highways.

Strategy: Prohibiting large vehicles.

FIGURE 65
Vertical clearance signing.

FIGURE 66
Vertical clearance signing.

FIGURE 67
Warning sign with hanging chimes installed at the same height as the vertical clearance of the structure.

In some locations, it may be appropriate to provide marked detours for trucks and other large vehicles that allow them to bypass the low structure. Similarly, it may be appropriate to prohibit large vehicles on certain routes to prevent impacts with low structures.

12. Lateral Offset to Obstruction

As discussed in Chapter 3, a lateral offset to obstruction is not the same as the clear zone. A lateral offset, by definition, deals with objects so close to the roadway that there may be adverse impacts to the operation of the highway. Some examples of these objects include walls, barriers, bridge piers, sign and signal supports, trees, and utility poles. The clear zone is a clear recovery area, free of rigid obstacles and steep slopes, which serves a safety function.

Target areas: Any highway with roadside obstacles near the traveled lanes—most commonly, urban arterials.

Strategy: Delineate roadside obstacles.

Assuming an object cannot be removed or relocated, the primary mitigation strategy is to make the objects highly visible to drivers. Delineation with reflectors or reflective sheeting (Figures 68 and 69) is one method to make the objects more visible, particularly at night. Another strategy to consider is lighting. In addition to making roadside objects more visible, lighting has many other benefits in urban areas where design exceptions for lateral offset are most common—from public safety benefits to improved pedestrian safety.

FIGURE 68
Reflective sheeting on utility poles.

FIGURE 69
Reflective sheeting on utility poles.

Target areas: Any highway with roadside obstacles near the traveled lanes—most commonly, urban arterials.

Strategy: Narrow selected cross-sectional elements to provide additional offset to the obstruction.

On urban arterials with more than two lanes, another strategy to consider is distributing the available cross-sectional width to provide additional offset to the obstruction. For example, through lanes, turn lanes, or medians could be narrowed slightly in order to provide additional offset or additional space for on-street parking. With this strategy, care must be taken to ensure that any operational benefits gained in the outside lanes are not lost to poorer performance on the inside lanes. Each site will have unique characteristics that need to be evaluated before determining an optimal distribution of the cross section—traffic volumes, traffic composition, the available cross-sectional width, speed studies, and offset distance to the obstruction.

Target areas: Any highway with roadside obstacles near the traveled lanes—most commonly, urban arterials.

Strategy: Enhanced pavement markings.

Another mitigation strategy for lateral offset is clear delineation of the lane lines. See the Lane and Shoulder Width section for information on enhanced pavement markings.

13. Structural Capacity

Mitigation strategies for structural capacity are not addressed in this Guide.

Design Speed Criteria (Minimums/Ranges)						
Facility Type	**Context**	**Design Speed**				
		AASHTO (2004)	**AASHTO (2011)**	**RRR**	**New Construction**	
					SIS	**Non-SIS**
Interstates and Freeways	**Urban**	50	50-70	50-70 (SIS=60-70**)	70 (Urbanized 60)*	50-70
	Rural	70	70	70	70*	70
Arterials-Urban		30	30-60	30 (SIS=50**)	50**	40-60
Arterials-Rural	**Level**	60	60-75	55	65*	55-70
	Rolling	50	50-60			
Collector-Urban		30	30	30 (SIS=50**)	50**	35-50
Collector-Rural	**Level**	40-60	40-60	55	65*	55-65
	Rolling	30-60	30-60	55	65*	55-65

Vertical Clearance Criteria

<table>
<tr><td rowspan="2"></td><td></td><td colspan="3">Facility Above (All: Interstate, Freeway, Arterial, Collector, Railroad)</td><td>Signs/Signals/Peds</td><td>DMS</td></tr>
<tr><td>Criteria</td><td>FDOT New Const.</td><td>FDOT RRR</td><td>AASHTO</td><td>All</td><td>All</td></tr>
<tr><td rowspan="6">Facility Below</td><td>Interstate</td><td rowspan="4">16.5'</td><td>16'</td><td>16' (14' Alt)</td><td rowspan="4">17.5' FDOT
(New/RRR)
17' AASHTO</td><td rowspan="4">19.5'</td></tr>
<tr><td>Freeway</td><td rowspan="3">14.5'</td><td>16' (14' Alt)</td></tr>
<tr><td>Arterial</td><td>16' New/14' Existing</td></tr>
<tr><td>Collector, Other</td><td>14'</td></tr>
<tr><td>Railroad</td><td colspan="2">23.5'</td><td>23'</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Railroad: Elect</td><td colspan="3">24.25'</td><td>N/A</td><td>N/A</td></tr>
</table>