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CHAPTER 13 ROADWAY SEGMENTS

13.1. INTRODUCTION

Chapter 13 presents the Accident Modification Factors (AMFs) for design, traffic control, and operational treatments on roadway segments. Pedestrian and bicyclist treatments, and the effects on expected average crash frequency of other treatments such as illumination, access points, and weather issues, are also discussed. The information presented in this chapter is used to identify effects on expected average crash frequency resulting from treatments applied to roadway segments.

Chapter 13 presents the Accident Modification Factors (AMFs) for design, traffic control, and operational treatments on roadway segments.

The *Part D Introduction and Applications Guidance* section provides more information about the processes used to determine the AMFs presented in this chapter.

Chapter 13 is organized into the following sections:

- Definition, Application, and Organization of AMFs (Section 13.2)
- Definition of a Roadway Segment (Section 13.3)
- Crash Effects of Roadway Elements (Section 13.4)
- Crash Effects of Roadside Elements (Section 13.5)
- Crash Effects of Alignment Elements (Section 13.6)
- Crash Effects of Roadway Signs (Section 13.7)
- Crash Effects of Roadway Delineation (Section 13.8)
- Crash Effects of Rumble Strips (Section 13.9)
- Crash Effects of Traffic Calming (Section 13.10)
- Crash Effects of On-Street Parking (Section 13.11)
- Crash Effects of Roadway Treatments for Pedestrians and Bicyclists (Section 13.12)
-
-
- Crash Effects of Highway Lighting (Section 0)
- Crash Effects of Roadway Access Management (Section 13.14)
- Crash Effects of Weather Issues (Section 13.15)
- Conclusion (Section 13.16)

Appendix A presents the crash trends for treatments for which AMFs are not currently known, and a listing of treatments for which neither AMFs nor trends are unknown.

13.2. DEFINITION, APPLICATION, AND ORGANIZATION OF AMFS

AMFs quantify the change in expected average crash frequency (crash effect) at a site caused by implementing a particular treatment (also known as a countermeasure, intervention, action, or alternative), design modification, or change in operations. AMFs are used to estimate the potential change in expected crash frequency or crash severity plus or minus a standard error due to implementing a

Chapter 3 provides a thorough definition and explanation of AMFs.

particular action. The application of AMFs involves evaluating the expected average crash frequency with or without a particular treatment, or estimating it with one treatment versus a different treatment.

Specifically, the AMFs presented in this chapter can be used in conjunction with activities in *Chapter 6 Select Countermeasures*, and *Chapter 7 Economic Appraisal*. Some *Part D* AMFs are included in *Part C* for use in the predictive method. Other *Part D* AMFs are not presented in *Part C* but can be used in the methods to estimate change in crash frequency described in Section C.7 of the *Part C Introduction and Applications Guidance*. *Chapter 3 Fundamentals*, Section 3.5.3 Accident Modification Factors provides a comprehensive discussion of AMFs including: an introduction to AMFs, how to interpret and apply AMFs, and applying the standard error associated with AMFs.

In all *Part D* chapters, the treatments are organized into one of the following categories:

1. AMF is available;
2. Sufficient information is available to present a potential trend in crashes or user behavior, but not to provide an AMF;
3. Quantitative information is not available.

Treatments with AMFs (Category 1 above) are typically estimated for three accident severities: fatal, injury, and non-injury. In the HSM, fatal and injury are generally combined and noted as injury. Where distinct AMFs are available for fatal and injury severities, they are presented separately. Non-injury severity is also known as property-damage-only severity.

Treatments for which AMFs are not presented (Categories 2 and 3 above) indicate that quantitative information currently available did not meet the criteria for inclusion in the HSM. However, in Category 2 there was sufficient information to identify a trend associated with the treatments. The absence of an AMF indicates additional research is needed to reach a level of statistical reliability and stability to meet the criteria set forth within the HSM. Treatments for which AMFs are not presented are discussed in Appendix A.

13.3. DEFINITION OF A ROADWAY SEGMENT

Section 13.4 provides a summary of roadway elements with AMFs.

A roadway is defined as "the portion of a highway, including shoulders, for vehicular use; a divided highway has two or more roadways."[17] A roadway segment consists of a continuous portion of a roadway with similar geometric, operational, and vehicular characteristics. Roadways where significant changes in these characteristics are observed from one location to another should be analyzed as separate segments. [30]

13.4. CRASH EFFECTS OF ROADWAY ELEMENTS

13.4.1. Background and Availability of AMFs

Roadway elements vary depending on road type, road function, environment and terrain. Exhibit 13-1 summarizes common treatments related to roadway elements and the corresponding AMF availability.

Exhibit 13-1: Summary of Treatments Related to Roadway Elements

HSM Section	Treatment	Rural Two-Lane Road	Rural Multi-Lane Highway	Rural Frontage Road	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.4.2.1	Modify lane width	✓	✓	✓	-	-	-	-
13.4.2.2	Add lanes by narrowing existing lanes and shoulders	N/A	-	N/A	✓	-	-	-
13.4.2.3	Remove through lanes or "road diets"	N/A	N/A	N/A	N/A	N/A	✓	N/A
13.4.2.4	Add or widen paved shoulder	✓	✓	✓	-	-	-	-
13.4.2.5	Modify shoulder type	✓	-	-	-	-	-	-
13.4.2.6	Provide a raised median	-	✓	N/A	-	-	✓	-
13.4.2.7	Change width of existing median	N/A	✓	N/A	-	-	✓	-
Appendix A	Increase median width	-	T	N/A	T	T	-	-

NOTE:
✓ = Indicates that an AMF is available for this treatment.
T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
- = Indicates that an AMF is not available and a trend is not known.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

13.4.2. Roadway Element Treatments with AMFs

13.4.2.1. Modify Lane Width

Rural two-lane roads

Widening lanes on rural two-lane roads reduces a specific set of related accident types, namely single-vehicle run-off-road accidents and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions. The AMF for lane width is determined with the equations presented in Exhibit 13-2, which are illustrated by the graphs in Exhibit 13-3.[10,16,33] The crash effect of lane width varies with traffic volume, as shown in the exhibits.

Relative to a 12-ft lanes base condition, 9-ft wide lanes increase the frequency of related accident types identified above. [10,16]

For roads with an AADT of 2,000 or more, lane width has a greater effect on expected average crash frequency. Relative to 12-ft lanes, 9-ft wide lanes increase the frequency of related accident types identified above more than either 10-ft or 11-ft lanes.[16,33]

For lane widths other than 9, 10, 11, and 12 ft, the crash effect can be interpolated between the lines shown in Exhibit 13-3.

If lane widths for the two directions of travel on a roadway segment differ, the AMF is determined separately for the lane width in each direction of travel and then averaged.[16] The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is 12 ft lanes.

Exhibit 13-2: AMF for Lane Width on Rural Two-Lane Roadway Segments[16]

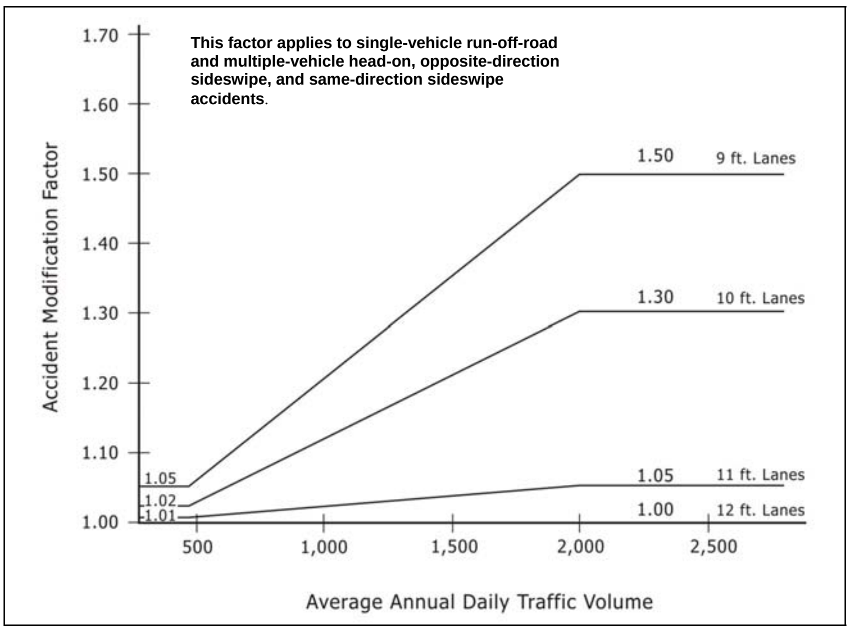
Lane Width	Average Annual Daily Traffic (AADT) (vehicles/day)		
	< 400	400 to 2000	> 2000
9 ft or less	1.05	$1.05+2.81\times10^{-4}$(AADT-400)	1.50
10 ft	1.02	$1.02+1.75\times10^{-4}$(AADT-400)	1.30
11 ft	1.01	$1.01+2.5\times10^{-5}$(AADT-400)	1.05
12 ft or more	1.00	1.00	1.00

NOTE: The collision types related to lane width to which these AMFs apply are single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents.

Standard error of the AMF is unknown.

To determine the AMF for changing lane width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

Exhibit 13-3: Potential Crash Effects of Lane Width on Rural Two-Lane Roads Relative to 12-ft Lanes [3]



NOTE: Standard error of the AMF is unknown.
To determine the AMF for changing lane width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

Exhibit 13-23 and Equation 13-3 in Section 13.4.3 (Conversion Factor for Total-Crashes) may be used to express the lane width AMFs in terms of the crash effect on total crashes, rather than just the accident types identified in Exhibit 13-2 and Exhibit 13-3.[10,16,33]

The gray box below presents an example of how to apply the preceding equations and graphs to assess the total crash effects of modifying the lane width on a rural two-lane highway.

Effectiveness of Modifying Lane Width

Question:

As part of improvements to a 5-mile section of a rural two-lane road, the local jurisdiction has proposed widening the roadway from 10-ft to 11-ft lanes. What will be the likely reduction in expected average crash frequency for opposite direction sideswipe crashes, and for total crashes?

Given Information:

- Existing roadway = rural two-lane
- AADT = 2,200 vehicles per day
- Expected average crash frequency without treatment for the five mile segment (see Part C Predictive Method):

a) 9 opposite direction sideswipe crashes/year

b) 30 total crashes/year

Find:

- Expected average opposite direction sideswipe crash frequency with the implementation of 11-ft lanes
- Expected average total crash frequency with the implementation of 11-ft lanes
- Expected average opposite direction sideswipe crash frequency reduction
- Expected average total crash frequency reduction

Answer:

1) Identify the Applicable AMFs

a) Exhibit 13-3 for opposite direction sideswipe crashes

b) Equation 13-3 or Exhibit 13-23 for all crashes

Note that for a conversion from *opposite direction sideswipe* crashes to *all* crashes the information in Section 13.4.3 which contains Equation 13-3 and Exhibit 13-23 may be applied.

2) Calculate the AMF for the existing condition 10-ft lane width

a) For opposite direction sideswipe crashes

AMF_{ra} = 1.30 (Exhibit 13-3)

b) For total crashes

AMF_{total} = (1.30-1.00) x 0.30 + 1.00 = 1.09 (Equation 13-3 or Exhibit 13-23)

3) Calculate the AMF for the proposed condition 11-ft lane width

a) For opposite direction sideswipe crashes

AMF_{ra} = 1.05 From (Exhibit 13-3)

b) For total crashes

AMF_{total} = (1.05-1.00) x 0.30 + 1.00 = 1.01 (Equation 13-3 or Exhibit 13-23)

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Effectiveness of Modifying Lane Width (Continued)

4) Calculate the treatment ($AMF_{Treatment}$) corresponding to the change in lane width for opposite direction sideswipe crashes and for all crashes.

   a) For opposite direction sideswipe crashes

   $AMF_{ra\ Treatment}$ = 1.05/1.30 = 0.81

   b) For total crashes

   $AMF_{total\ Treatment}$ = 1.01/1.09 = 0.93

5) Apply the treatment AMF ($AMF_{Treatment}$) to the expected number of crashes at the intersection without the treatment.

   a) For opposite direction sideswipe crashes

   = 0.81(9 crashes/year) = 7.3 crashes/year

   b) For total crashes

   = 0.93(30 crashes/year) = 27.9 crashes/year

6) Calculate the difference between the expected number of crashes without the treatment and the expected number with the treatment.

   Change in Expected Average Crash Frequency:

   a) For opposite direction sideswipe crashes

   9.0 – 7.3 = 1.7 crashes/year reduction

   b) For total crashes

   30.0 – 27.9 = 2.1 crashes/year reduction

7) **Discussion: The proposed change in lane width may potentially reduce opposite direction sideswipe crashes by 1.7 crashes/year and total crashes by 2.1 crashes per year. Note that a standard error has not been determined for this AMF, therefore a confidence interval cannot be calculated.**

Rural Multilane Highways

Widening lanes on rural multilane highways reduces the same specific set of related accident types as rural two-lane highways, namely single-vehicle run-off-road accidents and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions. The AMF for lane width is determined with the equations presented in Exhibit 13-4 for undivided multilane highways and in Exhibit 13-6 for divided multilane highways. These equations are illustrated by the graphs shown in Exhibit 13-5 and Exhibit 13-7, respectively. The crash effect of lane width varies with traffic volume, as shown in the exhibits.

For roads with an AADT of 400 or less, lane width has a small crash effect. Relative to a 12-ft lanes base condition, 9-ft wide lanes increase the frequency of related accident types identified above.

For roads with an AADT of 2,000 or more, lane width has a greater effect on expected average crash frequency. Relative to 12-ft lanes, 9-ft wide lanes increase the frequency of related accident types identified above more than either 10-ft or 11-ft lanes.

For lane widths other than 9, 10, 11, and 12 ft, the crash effect can be interpolated between the lines shown in Exhibits 13-3b and 13-3d. Lanes less than 9 ft wide can be assigned an AMF equal to 9-ft lanes. Lanes greater than 12-ft wide can be assigned a crash effect equal to 12-ft lanes.

The effect of lane width on undivided rural multilane highways is equal to approximately 75% of the effect of lane width on rural two-lane roads.(34) Where the lane widths on a roadway vary, the AMF is determined separately for the lane width in each direction of travel and the resulting AMFs are then averaged. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is 12-ft lanes.

Exhibit 13-4: AMF for Lane Width on Undivided Rural Multilane Roadway Segments(34)

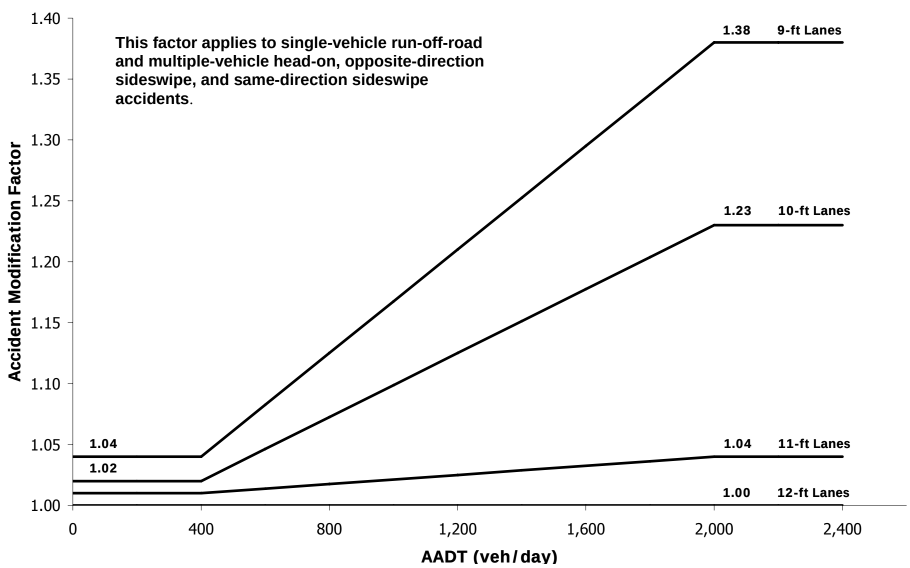
Lane Width	Average Annual Daily Traffic (AADT) (veh/day)		
	< 400	400 to 2000	> 2000
9 ft or less	1.04	$1.04+2.13\times10^{-4}$(AADT-400)	1.38
10 ft	1.02	$1.02+1.31\times10^{-4}$(AADT-400)	1.23
11 ft	1.01	$1.01+1.88\times10^{-5}$(AADT-400)	1.04
12 ft or more	1.00	1.00	1.00

NOTE: The collision types related to lane width to which these AMFs apply are single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents.

Standard error of the AMF is unknown.

To determine the AMF for changing lane width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

Exhibit 13-5: Potential crash Effects of Lane Width on Undivided Rural Multilane Roads Relative to 12-ft Lanes (34)



NOTE: Standard error of the AMF is unknown.

To determine the AMF for changing lane width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

The effect of lane width on divided rural multilane highways is equal to approximately 50% of the effect of lane width on rural two-lane roads.(34) Where the lane widths on a roadway vary, the AMF should be determined separately for the lane width in each direction of travel and the resulting AMFs is then averaged. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is 12-ft lanes.

Exhibit 13-6: AMF for Lane Width on Divided Rural Multilane Roadway Segments(34)

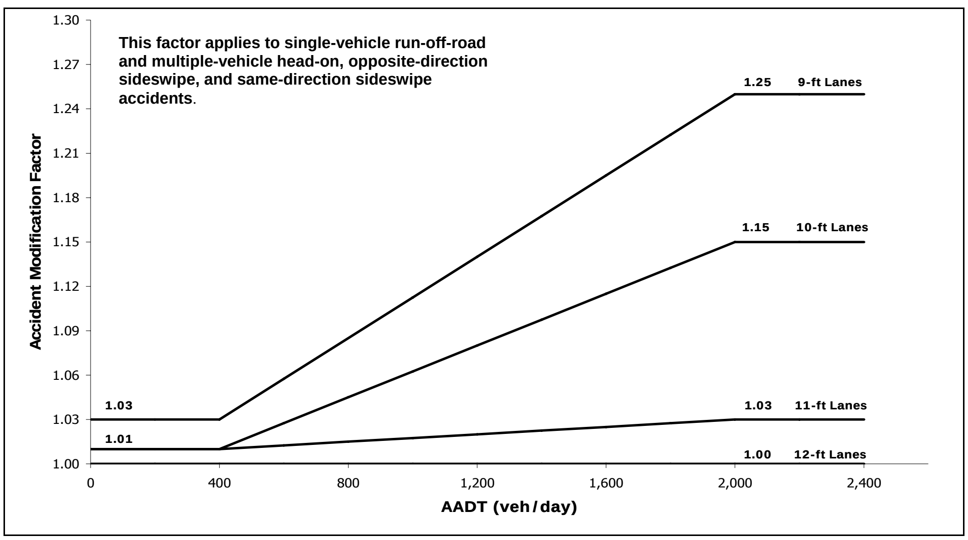
Lane Width	Average Annual Daily Traffic (AADT) (veh/day)		
	< 400	400 to 2000	> 2000
9 ft or less	1.03	$1.03+1.38\times10^{-4}(AADT-400)$	1.25
10 ft	1.01	$1.01+8.75\times10^{-5}(AADT-400)$	1.15
11 ft	1.01	$1.01+1.25\times10^{-5}(AADT-400)$	1.03
12 ft or more	1.00	1.00	1.00

NOTE: The collision types related to lane width to which these AMFs apply are single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents.

Standard error of the AMF is unknown.

To determine the AMF for changing lane width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

Exhibit 13-7: Potential Crash Effects of Lane Width on Divided Rural Multilane Roads Relative to 12-ft Lanes (34)



NOTE: Standard error of the AMF is unknown.
To determine the AMF for changing lane width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

Equation 13-3 in Section 13.4.3 (Conversion Factor for Total Crashes) may be used to express the lane width AMFs in terms of the crash effect on total crashes, rather than just the collision types identified in in the exhibits presented above.

Rural Frontage Roads

Rural frontage roads differ from rural two-lane roads because they have restricted access along at least one side of the road, a higher percentage of turning traffic, and periodic ramp-frontage-road terminals with yield control(22). AMFs for rural frontage roads are provided separately from AMFs for rural two-lane roads.

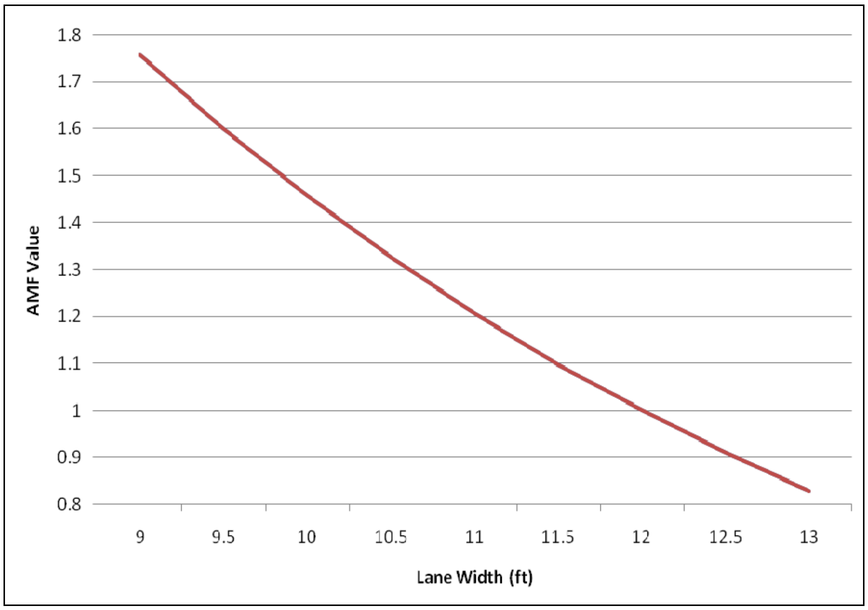
Equation 13-1 presents the AMF for lane width on rural frontage roads between successive interchanges[22]. Exhibit 13-8 is based on Equation 13-1. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is 12 ft lanes.

$$AMF_{LW} = e^{-0.188(LW-12.0)} \tag{13-1}$$

where:

LW = average lane width (ft)

Exhibit 13-8: Potential Crash Effects of Lane Width on Rural Frontage Roads[22]



NOTE: The standard error of the AMF is unknown.
To determine the AMF for changing lane width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

The average lane width represents the total width of the traveled way divided by the number of through lanes on the frontage road. Relative to 12-ft lanes, 9-ft wide lanes increase the number of accidents more than either 10-ft or 11-ft lanes.

Both one-way and two-way frontage roads were considered in the development of this AMF. Development of this AMF was limited to lane widths ranging from 9 to 13 ft and AADT values from 100 to 6,200.

13.4.2.2. Add Lanes by Narrowing Existing Lanes and Shoulders

This treatment consists of maintaining the existing roadway right-of-way and implementing additional lanes by narrowing existing lanes and shoulders. This treatment is only applicable to roadways with multiple lanes in one direction.

Freeways

The crash effects of adding a fifth lane to a base condition four-lane urban freeway within the existing right-of-way, by narrowing existing lanes and shoulders are shown in Exhibit 13-9.[4] The crash effects of adding a sixth lane to a base condition five-lane urban freeway by accident severity are also shown in Exhibit 13-9.[4]

These AMFs apply to urban freeways with median barriers with a base condition (i.e., the condition in which the AMF = 1.00) of 12-ft lanes. The type of median barrier is undefined.

For this treatment, lanes are narrowed to 11-ft lanes and the inside shoulders are narrowed to provide the additional width for the extra lane. The new lane may be used as a general purpose lane or a High Occupancy Vehicle (HOV) lane.

Exhibit 13-9: Potential Crash Effects of Adding Lanes by Narrowing Existing Lanes and Shoulders [4]

Treatment	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
Four to five lane conversion	Urban (Freeway)	79,000 to 128,000, one direction	All types (All severities)	**1.11**	**0.05**
			All types (Injury and Non-injury tow-away)	**1.10***	**0.07**
			All types (Injury)	**1.11**	**0.08**
Five to six lane conversion		77,000 to 126,000, one direction	All types (All severities)	**1.03***	**0.08**
			All types (Injury and Non-injury tow-away)	**1.04***	**0.1**
			All types (Injury)	**1.07***	**0.1**
Base Condition: Four or Five 12-ft lanes depending on initial roadway geometry.					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

Accident migration is generally not found to be a statistically significant outcome of this treatment.[20]

13.4.2.3. Remove Through Lanes or "Road Diets"

A "road diet" usually refers to the conversion of a four-lane undivided road into three lanes: two through lanes plus a center two-way left-turn lane. The remaining roadway width may be converted to bicycle lanes, sidewalks, or on-street parking.[4]

Urban arterials

The effect on crash frequency of removing two through lanes on urban four-lane undivided roads and adding a center two-way left-turn lane is shown in Exhibit 13-10.[15] The base condition for this AMF (i.e., the condition in which the AMF = 1.00) is a four lane roadway cross section. Original lane width is unknown.

Exhibit 13-10: Potential Crash Effects of Four to Three Lane Conversion or "Road Diet"(15)

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Four to three lane conversion	Urban (Arterials)	Unspecified	All types (All severities)	**0.71**	**0.02**
Base Condition: Four-lane roadway cross section.					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.
Original lane width is unknown.

13.4.2.4. Add or Widen Paved Shoulder

Rural two-lane roads

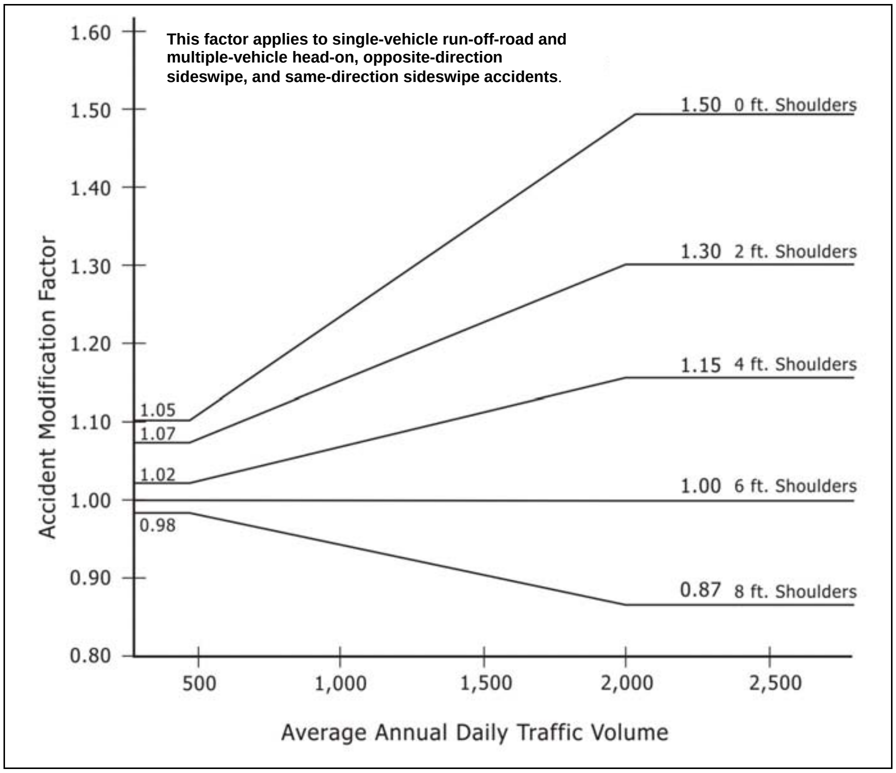
Widening paved shoulders on rural two-lane roads reduces the same related accidents types as widening lanes; single-vehicle run-off-road accidents, multi-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions. The AMF for shoulder width is determined with the equations presented in Exhibit 13-11, which are illustrated by the graph in Exhibit 13-12.[16,33,36] The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is a 6 ft shoulder width.

Exhibit 13-11: AMF for Shoulder Width on Rural Two-Lane Roadway Segments

Shoulder Width	Average Annual Daily Traffic (AADT) (vehicles/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 shoulder width to which this AMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents.
Standard error of the AMF is unknown.
To determine the AMF for changing paved shoulder width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

Exhibit 13-12: Potential Crash Effects of Paved Shoulder Width on Rural Two-Lane Roads Relative to 6-ft Paved Shoulders[16]



NOTE: Standard error of AMF is unknown.

To determine the AMF for changing paved shoulder width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

For roads with an Average Annual Daily Traffic Volume (AADT) of 400 or less, shoulder width has a small crash effect. Relative to 6-ft paved shoulders, no shoulders (0-ft) increase the related accident types by a small amount.[16,33,36] Relative to 6-ft paved shoulders, shoulders 8-ft wide decrease the related collision types by a small amount.[16,33,36]

For shoulder widths within the range of 0 to 8-ft, the crash effect can be interpolated between the lines shown in Exhibit 13-12. Shoulders greater than 8-ft wide can be assigned an AMF equal to 8-ft wide shoulders. [16]

If the shoulder widths for the two travel directions on a roadway segment differ, the AMF is determined separately for each travel direction and then averaged.[16]

Exhibit 13-23 and Equation 13-3 in Section 13.4.3 (Conversion Factor for Total-Crashes) may be used to express the crash effect of paved shoulder width on rural two-lane roads as an effect on total accidents, rather than just the accident types identified in Exhibit 13-12.[16]

Rural multilane highways

Research by Harkey et al. [15] concluded that the shoulder width AMF presented in Exhibit 13-11 and Exhibit 13-12 may be applied to undivided segments of rural multilane highways, as well as to rural two-lane highways.

The AMF for changing shoulder width on multilane divided highways in Exhibit 13-13 applies to the shoulder on the right side of a divided roadway. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is an 8 ft shoulder width.

Exhibit 13-13: Potential Crash Effects of Paved Right Shoulder Width on Divided Segments*(15)*

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
8 to 6-ft conversion	Rural (Multi-lane Highways)	Unspecified	All types (Unspecified)	1.04	N/A
8 to 4-ft conversion				1.09	N/A
8 to 2-ft conversion				1.13	N/A
8 to 0-ft conversion				1.18	N/A
Base Condition: 8-ft shoulder width.					

NOTE: N/A = Standard error of AMF is unknown

Rural frontage roads

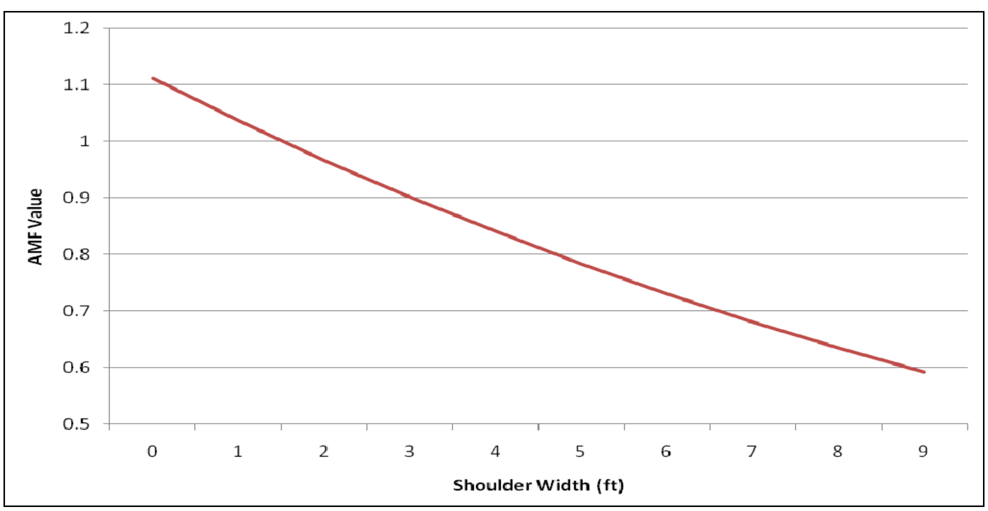
Rural frontage roads typically consist of an environment that is slightly more complex than a traditional rural two-lane highway. Equation 13-2 presents an AMF for shoulder width on rural frontage roads,[22] Exhibit 13-14 is based on Equation 13-2. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is a shoulder width (SW) of 1.5-ft.

$$AMF_{SW} = e^{-0.070(SW-1.5)} \qquad (13\text{-}2)$$

where:

SW = average paved shoulder width ([left shoulder width + right shoulder width]/2) (ft)

Exhibit 13-14: Potential Crash Effects of Paved Shoulder Width on Rural Frontage Roads*(22)*



NOTE: The standard error of the AMF is unknown.

To determine the AMF for changing lane width and/or AADT, divide the "new" condition AMF by the "existing" condition AMF.

The average paved shoulder width represents the sum of the left shoulder width and the right shoulder width on the frontage road divided by two. Both one-way and two-way frontage roads were considered in the development of this AMF. Development of this AMF was limited to shoulder widths ranging from 0 to 9 ft and AADT values from 100 to 6,200.

13.4.2.5. Modify Shoulder Type

Rural two-lane roads

The crash effect of modifying the shoulder type on rural two-lane roads is shown in Exhibit 13-15.(16,33,36) The crash effect varies by shoulder width and type, assuming that a paved shoulder is the base condition (i.e., the condition in which the AMF = 1.00) and that some type of shoulder is currently in place. Note that this AMF cannot be applied for a single shoulder type (horizontally across the table), the AMF in Exhibit 13-15 is exclusively for application to a situation that consists of modification from one shouler type to another shoulder type (vertically in the table for one given shoulder width).

Exhibit 13-15: Potential Crash Effects of Shoulder Type on Rural Two-Lane Roads for Related Accident Types *(16,33,36)*

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF							
				Shoulder type	**Shoulder width (ft)**						
					1	**2**	**3**	**4**	**6**	**8**	**10**
Modify Shoulder Type	Rural (Two-lane Roads)	Unspecified	Single-vehicle run-off-road accidents and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions (Unspecified)	**Paved**	1.00	1.00	1.00	1.00	1.00	1.00	1.00
				Gravel	1.00	1.01	1.01	1.01	1.02	1.02	1.03
				Composite	1.01	1.02	1.02	1.03	1.04	1.06	1.07
				Turf	1.01	1.03	1.04	1.05	1.08	1.11	1.14
Base Condition: Paved shoulder											

NOTE: Composite shoulders are 50 percent paved and 50 percent turf.

Standard error of the crash effect is unknown.

The related accident types to which this AMF applies include single-vehicle run-off-road accidents and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions.

To determine the AMF for changing the shoulder type, divide the "new" condition AMF by the "existing" condition AMF.

This AMF cannot be applied for a single shoulder type to identify a change in shoulder width (horizontally in the table). This AMF is to be applied exclusively to a situation that consists of modification from one shoulder type to another shoulder type (vertically in the table for one given shoulder width).

If the shoulder types for two travel directions on a roadway segment differ, the AMF is determined separately for the shoulder type in each direction of travel and then averaged.(16)

Exhibit 13-23 and Equation 13-3 in Section 13.4.3 (Conversion Factor for Total-Crashes) may be used to determine the crash effect of shoulder type on total accidents, rather than just the accident types identified in Exhibit 13-15.

13.4.2.6. Provide a Raised Median

Urban two-lane roads

The crash effects of a raised median on urban two-lane roads are shown in Exhibit 13-16.[(8)] This effect may be related to the restriction of turning maneuvers at minor intersections and access points.[(8)] The type of raised median was unspecified.

The base condition of the AMF (i.e., the condition in which the AMF = 1.00) is the absence of a raised median.

Exhibit 13-16: Potential Crash Effects of Providing a Median on Urban Two-Lane Roads [(8)]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Provide a raised median	Urban (Two-lane)	Unspecified	All types (Injury)	**0.61**	**0.1**
Base Condition: Absence of raised median.					

NOTE: Based on International studies: Leong 1970; Thorson and Mouritsen 1971; Muskaug 1985; Blakstad and Giaever 1989

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Rural multi-lane highways and urban arterials

The crash effects of providing a median on urban arterial multi-lane roads are shown in Exhibit 13-17.[(8)] Providing a median on rural multi-lane roads reduces both injury and non-injury crashes, as shown in Exhibit 13-17.[(8)] The base condition of the AMF (i.e., the condition in which the AMF = 1.00) is the absence of a raised median.

Exhibit 13-17: Potential Crash Effects of Providing a Median on Multi-Lane Roads [(8)]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Provide a median	Urban (Arterial Multi-lane[(a)])	Unspecified	All types (Injury)	**0.78**[?]	**0.02**
			All types (Non-injury)	**1.09**[?]	**0.02**
	Rural (Multi-lane[(a)])		All types (Injury)	**0.88**	**0.03**
			All types Non-(Injury)	**0.82**	**0.03**
Base Condition: Absence of raised median.					

NOTE: Based on US studies: Kihlberg and Tharp 1968; Garner and Deen 1973; Harwood 1986; Squires and Parsonson 1989; Bowman and Vecellio 1994; Bretherton 1994; Bonneson and McCoy 1997 and International studies: Leon 1970; Thorson and Mouritsen 1971; Andersen 1977; Muskaug 1985; Scriven 1986; Blakstad and Giaever 1989; Dijkstra 1990; Kohler and Schwamb 1993; Claessen and Jones 1994

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

(a) Includes minor intersections

? Treatment results in a decrease in injury crashes and an increase in non-injury crashes. See Part D Introduction and Applications Guide.

13.4.2.7. Change the Width of an Existing Median

The main objective of widening medians is to reduce the frequency of severe cross-median collisions.

Rural multilane highways and urban arterials

Exhibit 13-18 through Exhibit 13-22 present AMFs for changing the median width on divided roads with traversable medians. These AMFs are based on the work by Harkey et al.(15). Separate AMFs are provided for roads with full access control and with partial or no access control. For urban arterials, the AMFs are also dependent upon whether the arterial has four lanes or more. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the presence of traversable median width of 10-ft. The type of traversable median (grass, depressed) was not identified.

Exhibit 13-18: Potential Crash Effects of Median Width on Rural Four-Lane Roads with Full Access Control(15)

Median width (ft)	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
10 to 20-ft conversion	Rural (4 lanes with full access control)	2,400 to 119,000	Cross Median Crashes (Unspecified)	**0.86**	**0.02**
10 to 30-ft conversion				**0.74**	**0.04**
10 to 40-ft conversion				**0.63**	**0.05**
10 to 50-ft conversion				**0.54**	**0.06**
10 to 60-ft conversion				**0.46**	**0.07**
10 to 70-ft conversion				**0.40**	**0.07**
10 to 80-ft conversion				**0.34**	**0.07**
10 to 90-ft conversion				**0.29**	**0.07**
10 to 100-ft conversion				**0.25**	**0.06**
Base condition: Traversable median width of 10-ft					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Exhibit 13-19: Potential Crash Effects of Median Width on Rural Four-Lane Roads with Partial or No Access Control(15)

Median width (ft)	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
10 to 20-ft conversion	Rural (4 lanes with partial or no access control)	1,001 to 90,000	Cross Median Crashes (Unspecified)	**0.84**	**0.03**
10 to 30-ft conversion				**0.71**	**0.06**
10 to 40-ft conversion				**0.60**	**0.07**
10 to 50-ft conversion				**0.51**	**0.08**
10 to 60-ft conversion				**0.43**	**0.09**
10 to 70-ft conversion				**0.36**	**0.09**
10 to 80-ft conversion				**0.31**	**0.09**
10 to 90-ft conversion				**0.26**	**0.08**
10 to 100-ft conversion				**0.22**	**0.08**
Base condition: Traversable median width of 10-ft					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Exhibit 13-20: Potential Crash Effects of Median Width on Urban Four-Lane Roads with Full Access Control[(15)]

Median width (ft)	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
10 to 20-ft conversion	Urban (4 lanes with full access control)	4,410 to 131,000	Cross Median Crashes (Unspecified)	**0.89**	**0.04**
10 to 30-ft conversion				**0.80**	**0.07**
10 to 40-ft conversion				**0.71**	**0.09**
10 to 50-ft conversion				**0.64**	**0.1**
10 to 60-ft conversion				**0.57**	**0.1**
10 to 70-ft conversion				**0.51**	**0.1**
10 to 80-ft conversion				**0.46**	**0.1**
10 to 90-ft conversion				**0.41**	**0.1**
10 to 100-ft conversion				**0.36**	**0.1**
Base condition: Traversable median width of 10-ft					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Exhibit 13-21: Potential Crash Effects of Median Width on Urban Roads with at least Five Lanes with Full Access Control[(15)]

Median width (ft)	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
10 to 20-ft conversion	Urban (5 or more lanes with full access control)	2,555 to 282,000	Cross Median Crashes (Unspecified)	**0.89**	**0.04**
10 to 30-ft conversion				**0.79**	**0.07**
10 to 40-ft conversion				**0.71**	**0.1**
10 to 50-ft conversion				**0.63**	**0.1**
10 to 60-ft conversion				**0.56**	**0.1**
10 to 70-ft conversion				**0.50**	**0.1**
10 to 80-ft conversion				**0.45**	**0.1**
10 to 90-ft conversion				*0.40*	*0.2*
10 to 100-ft conversion				*0.35*	*0.2*
Base condition: Traversable median width of 10-ft					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.
Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

Exhibit 13-22: Potential Crash Effects of Median Width on Urban Four-Lane Roads with Partial or No Access Control(15)

Median width (ft)	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
10 to 20-ft conversion	Urban (4 lanes with partial or No access control)	1,880 to 150,000	Cross Median Crashes (Unspecified)	**0.87**	**0.04**
10 to 30-ft conversion				**0.76**	**0.06**
10 to 40-ft conversion				**0.67**	**0.08**
10 to 50-ft conversion				**0.59**	**0.1**
10 to 60-ft conversion				**0.51**	**0.1**
10 to 70-ft conversion				**0.45**	**0.1**
10 to 80-ft conversion				**0.39**	**0.1**
10 to 90-ft conversion				**0.34**	**0.1**
10 to 100-ft conversion				**0.30**	**0.1**
Base condition: Traversable median width of 10-ft					

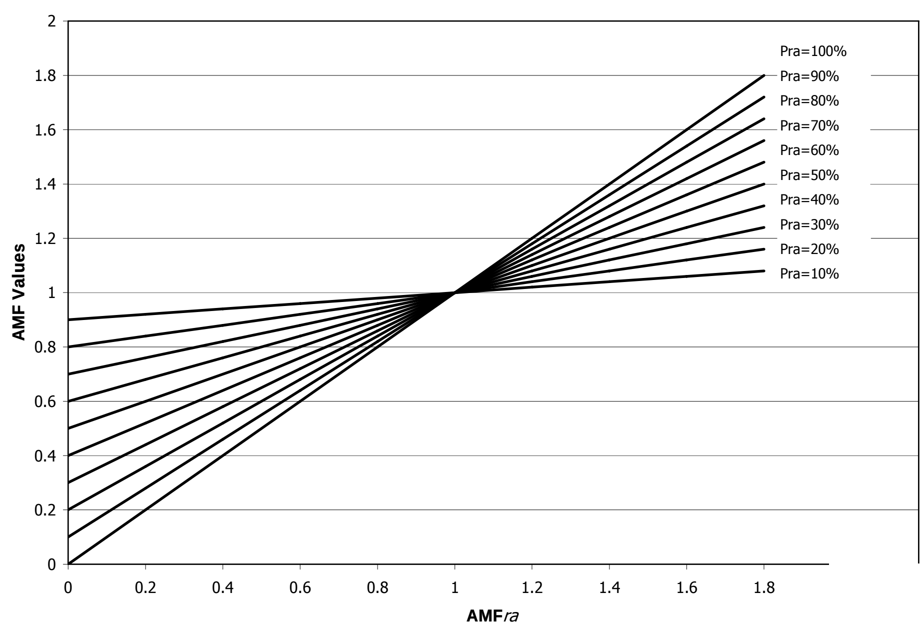
NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

13.4.3. Conversion Factor for Total-Crashes

This section presents an equation for the conversion of AMFs for crashes related to specific accident types into AMFs for total crashes.

Exhibit 13-23 and Equation 13-3 may be used to express the lane width AMF (Section 13.4.2.1), add or widen paved shoulder AMF (Section 13.4.2.4), and modify shoulder type AMF (Section 13.4.2.5) in terms of the crash effect on total accidents, rather than just the related accident types identified in the respective sections. (10,16,33)

Exhibit 13-23: Potential Crash Effects of Lane Width on Rural Two-Lane Roads on Total Accidents(16)



$$AMF = (AMF_{ra} - 1.0) \times p_{ra} + 1.0 \quad (13\text{-}3)$$

Where,

AMF = accident modification factor for total accidents

AMF_{ra} = accident modification factor for related accidents, i.e., single-vehicle run-off-road accidents and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions

P_{ra} = related accidents expressed as a proportion of total accidents

13.5. CRASH EFFECTS OF ROADSIDE ELEMENTS

13.5.1. Background and Availability of AMFs

This section presents roadside element treatments with AMFs.

The roadside is defined as the *"area between the outside shoulder edge and the right-of-way limits. The area between roadways of a divided highway may also be considered roadside"*.[23] The AASHTO Roadside Design Guide is an invaluable resource for roadside design, including clear zones, geometry, features and barriers.[23]

The knowledge presented here may be applied to roadside elements as well as to the median of divided highways. Exhibit 13-24 summarizes common treatments related to roadside elements and the corresponding AMF availability.

Exhibit 13-24: Summary of Treatments Related to Roadside Elements

HSM Section	Treatment	Rural Two-Lane Road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.5.2	Flatten sideslopes	✓	✓	-	-	-	-
13.5.2.2	Increase distance to roadside features	✓	-	✓	-	-	-
13.5.2.3	Change roadside barrier along embankment to less rigid type	✓	✓	✓	✓	✓	✓
13.5.2.4	Install median barrier	N/A	✓	T	-	-	-
13.5.2.5	Install crash cushions at fixed roadside features	✓	✓	✓	✓	✓	✓
13.5.2.6	Reduce roadside hazard rating	✓	-	-	-	-	-
Appendix	Increase clear roadside recovery distance	T	-	-	-	-	-
Appendix	Install curbs	-	-	-	-	T	T
Appendix	Increase the distance to utility poles and decrease utility pole density	T	T	T	T	T	T
Appendix	Install roadside barrier along embankments	T	T	T	T	T	T

NOTE:
✓ = Indicates that an AMF is available for this treatment.
T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
- = Indicates that an AMF is not available and a trend is not known.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

13.5.2. Roadside Element Treatments with AMFs

13.5.2.1. Flatten Sideslopes

Rural two-lane roads

The effect on total accidents of flattening the roadside slope of a rural two-lane road is shown in Exhibit 13-25.(15) The effect on single-vehicle accidents of flattening side slopes is shown in Exhibit 13-26. (15) The base conditions of the AMFs (i.e., the condition in which the AMF = 1.00) is the sideslope in the *before* condition.

Exhibit 13-25: Potential Crash Effects on Total Accidents of Flattening Sideslopes(15)

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF				
				Sideslope in Before Condition	Sideslope in After Condition			
					1V:4H	1V:5H	1V:6H	1V:7H
Flatten Sideslopes	Rural (Two-lane Road)	Unspecified	All types (Unspecified)	1V:2H	0.94	0.91	0.88	0.85
				1V:3H	0.95	0.92	0.89	0.85
				1V:4H		0.97	0.93	0.89
				1V:5H			0.97	0.92
				1V:6H				0.95
Base Condition: Existing sideslope in *before* condition.								

NOTE: Standard error of the AMF is unknown.

Exhibit 13-26: Potential Crash Effects on Single Vehicle Accidents of Flattening Sideslopes (15)

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF				
				Sideslope in Before Condition	Sideslope in After Condition			
					1V:4H	1V:5H	1V:6H	1V:7H
Flatten Sideslopes	Rural (Two-lane Road)	Unspecified	Single Vehicle (Unspecified)	1V:2H	0.90	0.85	0.79	0.73
				1V:3H	0.92	0.86	0.81	0.74
				1V:4H		0.94	0.88	0.81
				1V:5H			0.94	0.86
				1V:6H				0.92
Base Condition: Existing sideslope in *before* condition.								

NOTE: Standard error of the AMF is unknown.

The gray box below presents an example of how to apply the preceding AMFs to assess the crash effects of modifying the sideslope on a rural two-lane highway.

Effectiveness of Modifying Sideslope

Question:

A high crash frequency segment of a rural two-lane highway is being analyzed for a series of improvements. Among the improvements, the reduction of the 1V:3H sideslope to a 1V:7H sideslope is being considered. What will be the likely reduction in expected average crash frequency for single vehicle crashes and total crashes?

Given Information:

- Existing roadway = rural two-lane
- Existing sideslope = 1V:3H
- Proposed sideslope = 1V:7H
- Expected average crash frequency without treatment for the segment (See Part C Predictive Method):

  a) 30 total crashes/year

  b) 8 single vehicle crashes/year

Find:

- Expected average total crash frequency with the reduction in sideslope
- Expected average single vehicle crash frequency with the reduction in sideslope
- Expected average total crash frequency reduction
- Expected average single vehicle crash frequency reduction

Answer:

1) Identify the AMFs corresponding to the change in sideslope from 1V:3H to 1V:7H

   a) For total crashes

   AMF_{Total} = 0.85 (Exhibit 13-25)

   b) For single vehicle crashes

   $AMF_{Single\ Vehicle}$ = 0.74 (Exhibit 13-26)

2) Apply the treatment AMF ($AMF_{Treatment}$) to the expected number of crashes on the rural two-lane highway without the treatment.

   a) For total crashes

   = 0.85 x 30 crashes/year = 25.5 crashes/year

   b) For single vehicle crashes

   = 0.74 x 8 crashes/year = 5.9 crashes/year

3) Calculate the difference between the expected number of crashes without the treatment and the expected number with the treatment.

   Change in Expected Average Crash Frequency

   a) For total crashes

   30.0 – 25.5 = 4.5 crashes/year reduction

   b) For single vehicle crashes

   8.0 – 5.9 = 2.1 crashes/year reduction

4) **Discussion: The change in sideslope from 1V:3H to 1V:7H may potentially cause a reduction of 4.5 total crashes/year and 2.1 single vehicle crashes/year. A standard error is not available for these AMFs.**

Rural multi-lane highways

Exhibit 13-27 presents AMFs for the effect of sideslopes on multi-lane undivided roadway segments. These AMFs were developed by Harkey et al. [10] from the work of Zegeer et al.[6] The base condition for this AMF (i.e., the condition in which the AMF = 1.00) is a sideslope of 1V:7H or flatter.

Exhibit 13-27: Potential Crash Effects of Sideslopes on Undivided Segments[15,34]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
1V:7H or Flatter	Rural (Multi-lane Highway)	Unspecified	All types (Unspecified)	1.00	N/A
1V:6H				1.05	
1V:5H				1.09	
1V:4H				1.12	
1V:2H or Steeper				1.18	
Base Condition: Provision of a 1V:7H sideslope.					

13.5.2.2. Increase the Distance to Roadside Features

Rural two-lane roads and Freeways

The crash effects of increasing the distance to roadside features from 3.3-ft to 16.7-ft, or from 16.7-ft to 30.0-ft are shown in Exhibit 13-28.[8] AMF values for other increments may be interpolated from the values presented in Exhibit 13-28.

The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is a distance of either 3.3-ft or 16.7-ft to roadside features depending on original geometry.

Exhibit 13-28: Potential Crash Effects of Increased Distance to Roadside Features [8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Increase distance to roadside features from 3.3-ft to 16.7-ft	Rural (Two-lane roads and Freeways)	Unspecified	All types (All severities)	**0.78**	**0.02**
Increase distance to roadside features from 16.7-ft to 30.0-ft				**0.56**	**0.01**
Base Condition: Distance to roadside features of 3.3-ft or 16.7-ft depending on original geometry.					

NOTE: Based on US studies: Cirillo (1967), Zegeer et al. (1988)
Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.
Distance measured from the edgeline or edge of travel lane

13.5.2.3. Change Roadside Barrier along Embankment to Less Rigid Type

The type of roadside barrier applied can vary from very rigid to less rigid. In order of rigidity, the following generic types of barriers are available: [8]

- Concrete (most rigid)
- Steel
- Wire or cable (least rigid)

Rural two-lane roads, rural multi-lane highways, freeways, expressways, urban and suburban arterials

Changing the type of roadside barrier along an embankment to a less rigid type reduces the number of injury run-off-road accidents, as shown in Exhibit 13-29.[8] The AMF for fatal run-off-road accidents is shown in Exhibit 13-29.[8] A less rigid barrier type may not be suitable in certain circumstances.

The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the use of rigid barrier.

Exhibit 13-29: Potential Crash Effects of Changing Barrier to Less Rigid Type[8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Change barrier along embankment to less rigid type	Unspecified (Unspecified)	Unspecified	Run-off-road (Injury)	**0.68**	**0.1**
			Run-off-road (Fatal)	*0.59*	*0.3*
Base Condition: Provision of a rigid roadside barrier.					

NOTE: Based on US studies: Glennon and Tamburri 1967; Tamburri, Hammer, Glennon, Lew 1968; Williston 1969; Woods, Bohuslav and Keese 1976; Ricker, Banks, Brenner, Brown and Hall 1977; Perchonok, Ranney, Baum, Morris and Eppick 1978; Hall 1982; Bryden and Fortuniewicz 1986; Schultz 1986; Ray, Troxel and Carney 1991; Hunter, Stewart and Council 1993; Gattis, Alguire and Narla 1996; Short and Robertson 1998; and International studies: Good and Joubert 1971; Pettersson 1977; Schandersson 1979; Boyle and Wright 1984; Domhan 1986; Corben, Deery, Newstead, Mullan and Dyte 1997; Ljungblad 2000

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

Distance to roadside barrierl is unspecified.

13.5.2.4. Install Median Barrier

A median barrier is *"a longitudinal barrier used to prevent an errant vehicle from crossing the highway median."*[8] The AASHTO *Roadside Design Guide* provides performance requirements, placement guidelines, and structural and safety characteristics of different median barrier systems.[1]

Rural multi-lane highways

Installing any type of median barrier on rural multi-lane highways reduces fatal and injury accidents of all types, as shown in Exhibit 13-30.[8]

The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of a median barrier.

Exhibit 13-30: Potential Crash Effects of Installing a Median Barrier [8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install any type of median barrier	Unspecified (Multi-lane divided highways)	AADT of 20,000 to 60,000	All types (Fatal)	**0.57?**	**0.1**
Install any type of median barrier	Unspecified (Multi-lane divided highways)	AADT of 20,000 to 60,000	All types (Injury)	**0.70?**	**0.06**
Install any type of median barrier	Unspecified (Multi-lane divided highways)	AADT of 20,000 to 60,000	All types (All severities)	**1.24?**	**0.03**
Install steel median barrier	Unspecified (Multi-lane divided highways)	AADT of 20,000 to 60,000	All types (Injury)	**0.65**	**0.08**
Install cable median barrier	Unspecified (Multi-lane divided highways)	AADT of 20,000 to 60,000	All types (Injury)	**0.71**	**0.1**
Base Condition: Absence of a median barrier.					

NOTE: Based on US studies: Billion 1956; Moskowitz and Schaefer 1960; Beaton, Field and Moskowitz 1962; Billion and Parsons 1962; Billion, Taragin and Cross 1962; Sacks 1965; Johnson 1966; Williston 1969; Galati 1970; Tye 1975; Ricker, Banks, Brenner, Brown and Hall 1977; Hunter, Steward and Council 1993; Sposito and Johnston 1999; Hancock and Ray 2000; Hunter et al 2001; and International studies: Moore and Jehu 1968; Good and Joubert 1971; Andersen 1977; Johnson 1980; Statens vagverk 1980; Martin et al 1998; Nilsson and Ljungblad 2000

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

? Treatment results in a decrease in fatal and injury crashes and an increase in crashes of all severities. See Part D Introduction and Applications Guide.

Width of the median where the barrier was installed and the use of barrier warrants are unspecified.

13.5.2.5. Install Crash Cushions at Fixed Roadside Features

Rural two-lane roads, rural multi-lane highways, freeways, expressways, urban and suburban arterials

The crash effects of installing crash cushions at fixed roadside features are shown in Exhibit 13-31.[8] The crash effects for fatal and non-injury crashes with fixed objects are also shown in Exhibit 13-31.[12] The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of crash cushions.

Exhibit 13-31: Potential Crash Effects of Installing Crash Cushions at Fixed Roadside Features [8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install crash cushions at fixed roadside features	Unspecified (Unspecified)	Unspecified	Fixed object (Fatal)	*0.31*	*0.3*
Install crash cushions at fixed roadside features	Unspecified (Unspecified)	Unspecified	Fixed object (Injury)	**0.31**	**0.1**
Install crash cushions at fixed roadside features	Unspecified (Unspecified)	Unspecified	Fixed object (Non-injury)	*0.54*	*0.3*
Base Condition: Absence of crash cushions.					

NOTE: Based on US studies: Viner and Tamanini 1973; Griffin 1984; Kurucz 1984; and International studies: Schoon 1990; Proctor 1994

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

The placement and type of crash cushions and fixed objects are unspecified.

13.5.2.6. Reduce Roadside Hazard Rating

For reference, the quantitative descriptions of the seven roadside hazard rating (RHR) levels are summarized in Exhibit 13-32. Photographs that illustrate the roadside design for each RHR level are presented in Appendix A.

Exhibit 13-32: Quantitative Descriptors for the Seven Roadside Hazard Ratings (16)

Rating	Clear zone width	Sideslope	Roadside
1	Greater than or equal to 30 ft	Flatter than 1V:4H; recoverable	N/A
2	Between 20 and 25 ft	About 1V:4H; recoverable	
3	About 10 ft	About 1V:3H or 1V:4H; marginally recoverable	Rough roadside surface
4	Between 5 and 10 ft	About 1V:3H or 1V:4H; marginally forgiving, increased chance of reportable roadside crash	May have guardrail (offset 5 to 6.5 ft) May have exposed trees, poles, other objects (offset 10 ft)
5		About 1V:3H; virtually non-recoverable	May have guardrail (offset 0 to 5 ft) May have rigid obstacles or embankment (offset 6.5 to 10 ft)
6	Less than or equal to 5 ft	About 1V:2H; non-recoverable	No guardrail Exposed rigid obstacles (offset 0 to 6.5 ft)
7		1V:2H or steeper; non-recoverable with high likelihood of severe injuries from roadside crash	No guardrail Cliff or vertical rock cut

NOTE: Clear zone width, guardrail offset, and object offset are measured from the pavement edgeline
N/A = no description of roadside is provided.

Rural two-lane roads

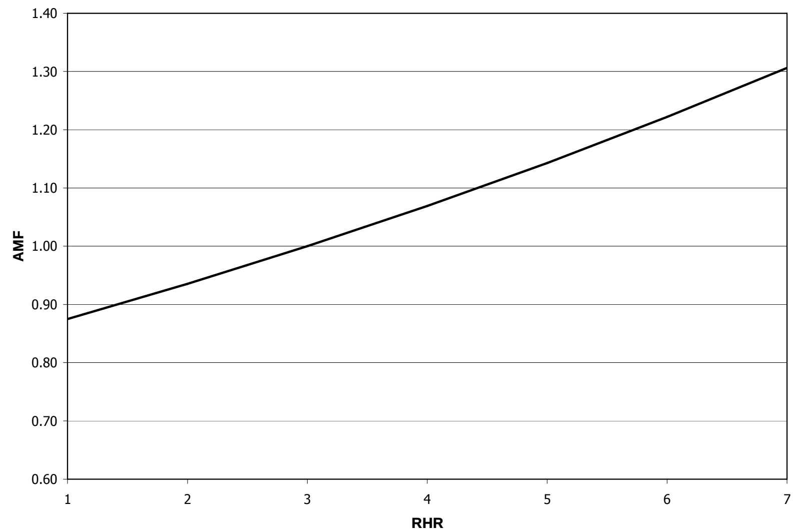
The AMFs for roadside design are presented in Equation 13-4 and Exhibit 13-33, using RHR equal to 3 as the base condition (i.e., the condition in which the AMF = 1.00).

$$AMF = \frac{e^{-0.6869+0.0668\times RHR}}{e^{-0.4865}} \qquad (13\text{-}4)$$

Where,

RHR = Roadside hazard rating for the roadway segment.

Exhibit 13-33: Potential Crash Effects of Roadside Hazard Rating for Total Accidents on Rural Two-Lane Highways(16)



NOTE: Standard error of AMF is unknown.
To determine the AMF for changing RHR, divide the "new" condition AMF by the "existing" condition AMF.
RHR = Roadside Hazard Rating

Section 13.6 summarizes treatments with AMFs related to alignment elements.

13.6. CRASH EFFECTS OF ALIGNMENT ELEMENTS

13.6.1. Background and Availability of AMFs

Exhibit 13-34 summarizes common treatments related to alignment elements and the corresponding AMF availability.

Exhibit 13-34: Summary of Treatments Related to Alignment Elements

HSM Section	Treatment	Rural Two-Lane Road	Urban Two-Lane Road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.6.2.1	Modify horizontal curve radius and length, and provide spiral transitions	✓	-	-	-	-	-	-
13.6.2.2	Improve superelevation of horizontal curve	✓	-	-	-	-	-	-
13.6.2.3	Change vertical grade	✓	-	-	-	-	-	-
Appendix A	Modify Tangent Length Prior to Curve	T	T	T	T	T	T	T
Appendix A	Modify Horizontal Curve Radius	-	-	-	-	-	T	T

NOTE:
✓ = Indicates that an AMF is available for this treatment.
T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
- = Indicates that an AMF is not available and a trend is not known.

13.6.2. Alignment Treatments with AMFs

13.6.2.1. Modify Horizontal Curve Radius and Length, and Provide Spiral Transitions

Rural two-lane roads

The probability of an accident generally decreases with longer curve radii, longer horizontal curve length, and the presence of spiral transitions.*(16)* The crash effect for horizontal curvature, radius, and length of a horizontal curve and presence of spiral transition curve is presented as an Accident Modification Function, as shown in Equation 13-5, the standard error of this AMF is unknown. This equation applies to all types of roadway segment accidents.*(16,35)* Exhibit 13-35 illustrates a graphical representation of Equation 13-5. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of curvature.

$$AMF_{3r} = \frac{(1.55 \times L_c) + \left(\frac{80.2}{R}\right) - (0.012 \times S)}{(1.55 \times L_c)} \qquad (13\text{-}5)$$

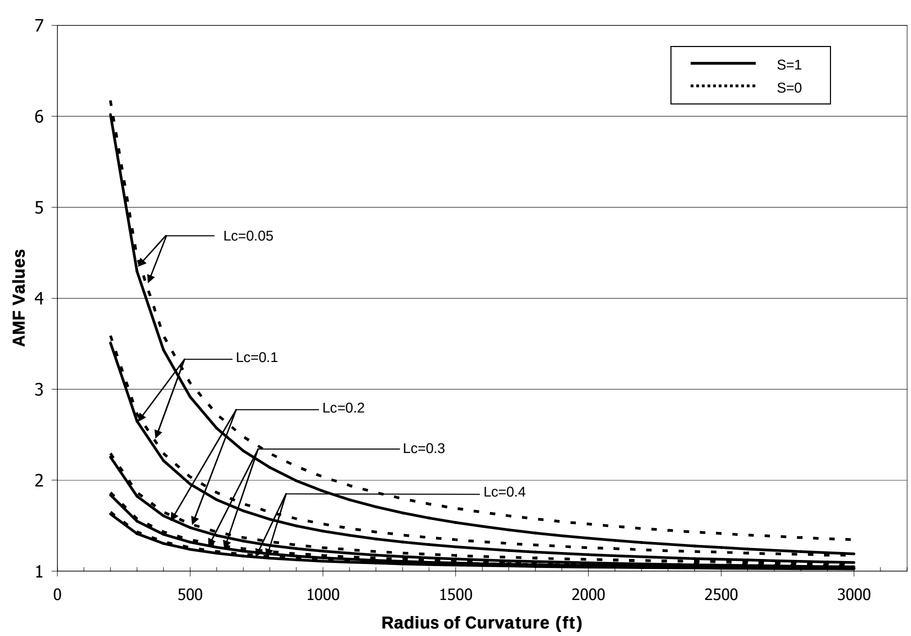
Where,

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

Exhibit 13-35: Potential Crash Effect of the Radius, Length, and Presence of Spiral Transition Curves in a Horizontal Curve



13.6.2.2. Improve Superelevation of Horizontal Curves

Rural two-lane roads

Crash effects of superelevation variance on a horizontal curve are shown in Exhibit 13-36.[16,35] The base condition of the AMFs summarized in Exhibit 13-36 (i.e., the condition in which the AMF = 1.00) is an SV value that is less than 0.01.

Exhibit 13-36: Potential Crash Effects of Improving Superelevation Variance (SV) of Horizontal Curves on Rural Two-Lane Roads[16,35]

<table>
<tr><th>Treatment</th><th>Setting
(Road type)</th><th>Traffic Volume</th><th>Accident type
(Severity)</th><th>AMF</th></tr>
<tr><td>Improve
SV < 0.01</td><td rowspan="3">Rural
(Two-lane)</td><td rowspan="3">Unspecified</td><td rowspan="3">All types
(All severities)</td><td>1.00</td></tr>
<tr><td>Improve
0.01 ≤ SV < 0.02</td><td>= 1.00 + 6 (SV - 0.01)</td></tr>
<tr><td>Improve
SV > 0.02</td><td>= 1.06 + 3 (SV - 0.02)</td></tr>
<tr><td colspan="5">Base Condition: Superelevation variance < 0.01.</td></tr>
</table>

NOTE: Standard error of AMF is unknown.

Based on a horizontal curve radius of 842.5 ft.

SV = Superelevation variance. Difference between recommended design value for superelevation and existing superelevation on a horizontal curve, where existing superelevation is less than recommended.

To determine the AMF for changing superelevation, divide the "new" condition AMF by the "existing" condition AMF.

13.6.2.3. Change Vertical Grade

Rural two-lane roads

Crash effects of increasing the vertical grade of a rural two-lane road, with a posted speed of 55 mph and a surfaced or stabilized shoulder, are shown in Exhibit 13-37.[35] The crash effect of increasing the vertical grade for accidents of all types and severities relative to a flat roadway (i.e., 0% grade) is also shown in Exhibit 13-37.[16]

These AMFs may be applied to each individual grade section on the roadway, without respect to the sign of the grade (i.e., upgrade or downgrade). These AMFs may be applied to the entire grade from one point of vertical intersection (PVI) to the next.[16]

The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is a level (0% grade) roadway.

Exhibit 13-37: Potential Crash Effects of Changing Vertical Grade on Rural Two-Lane Roads(16,24)

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Increase vertical grade by 1%	Rural (Two-lane)	Unspecified	SV ROR (All severities(24))	**1.04^**	**0.02**
			All types (All severities(16))	1.02	N/A
Base Condition: Level roadway (0% grade)					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.
SVROR = single-vehicle run-off-road accidents
AMFs are based on roads with 55 mph posted speed limit, 12 ft lanes, and no horizontal curves.
^ Observed variability suggests that this treatment could result in no crash effect. See Part D Applications Guidance.
N/A = Standard error of AMF is unknown.

13.7. CRASH EFFECTS OF ROADWAY SIGNS

13.7.1. Background and Availability of AMFs

Traffic signs are typically classified into three categories: regulatory signs, warning signs, and guide signs. As defined in the Manual on Uniform Traffic Control Devices (MUTCD),[19] regulatory signs provide notice of traffic laws or regulations, warning signs give notice of a situation that might not be readily apparent, and guide signs show route designations, destinations, directions, distances, services, points of interest, and other geographical, recreational or cultural information.

The MUTCD provides standards and guidance for signing within the right-of-way of all types of highways open to public travel. Many agencies supplement the MUTCD with their own guidelines and standards.

Exhibit 13-38 summarizes common treatments related to signs and the corresponding AMF availability.

Exhibit 13-38: Summary of Treatments Related to Roadway Signs

HSM Section	Treatment	Rural Two-Lane Road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Local Street or Arterial	Suburban Arterial
13.7.2.1	Install combination horizontal alignment/advisory speed signs (W1-1a, W1-2a)	✓	✓	✓	✓	✓	✓
13.7.2.2	Install changeable accident ahead warning signs	-	-	✓	-	-	-
13.7.2.3	Install changeable "Queue Ahead" warning signs	-	-	✓	-	-	-
13.7.2.4	Install changeable speed warning signs	✓	✓	✓	✓	✓	✓
Appendix A	Install signs to conform to MUTCD	-	-	-	-	T	-

NOTE:
✓ = Indicates that an AMF is available for this treatment.
T = T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
- = Indicates that an AMF is not available and a trend is not known.

13.7.2. Roadway Sign Treatments with AMFs

13.7.2.1. Install Combination Horizontal Alignment/Advisory Speed Signs (W1-1a, W1-2a)

Combination horizontal alignment/advisory speed signs are installed prior to a change in the horizontal alignment to indicate that drivers need to reduce speed.[9]

Rural two-lane roads, rural multi-lane highways, expressways, freeways, urban and suburban arterials

Compared to no signage, providing combination horizontal alignment/advisory speed signs reduces the number of all types of injury accidents, as shown in Exhibit 13-39.[8] The crash effect on all types of non-injury accidents is also shown in Exhibit 13-39.

The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of any signage.

Exhibit 13-39: Potential Crash Effects of Installing Combination Horizontal Alignment/ Advisory Speed Signs (W1-1a, W1-2a) [(8)]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install combination horizontal alignment/ advisory speed signs	Unspecified (Unspecified)	Unspecified	All types (Injury)	**0.87**	**0.09**
			All types (Non-injury)	*0.71*	*0.2*
Base Condition: Absence of any signage.					

NOTE: Based on US studies: McCamment 1959; Hammer 1969 and international study: Rutley 1972
Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.
Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

13.7.2.2. Install Changeable Accident Ahead Warning Signs

Freeways

Changeable accident warning signs on freeways inform drivers of an accident on the roadway ahead. The crash effect of installing changeable accident ahead warning signs on urban freeways is shown in Exhibit 13-40.[(8)] The base condition of the AMF (i.e., the condition in which the AMF = 1.00) is the absence of accident ahead warning signs.

Exhibit 13-40: Potential Crash Effects of Installing Changeable Accident Ahead Warning Signs [(8)]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install changeable accident ahead warning signs	Urban (Freeways)	Unspecified	All types (Injury)	*0.56*	*0.2*
Base Condition: Absence of changeable accident ahead warning signs.					

NOTE: Based on International study: Duff 1971
Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

13.7.2.3. Install Changeable "Queue Ahead" Warning Signs

Changeable "Queue Ahead" warning signs give road users real-time information about queues on the road ahead.

Freeways

Crash effects of installing changeable "Queue Ahead" warning signs are shown in Exhibit 13-41.[(8)] The crash effect on rear-end non-injury accidents is also shown in Exhibit 13-41.[(8)] The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence changeable "Queue Ahead" warning signs.

Exhibit 13-41: Potential Crash Effects of Installing Changeable "Queue Ahead" Warning Signs [(8)]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install changeable "Queue Ahead" warning signs	Urban (Freeways)	Unspecified	Rear-end (Injury)	**0.84?**	**0.1**
			Rear-end (Non-Injury)	*1.16?*	*0.2*
Base Condition: Absence of changeable "Queue Ahead" warning signs.					

NOTE: Based on International studies: Erke and Gottlieb 1980; Cooper, Sawyer and Rutley 1992; Persaud, Mucsi and Ugge 1995

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

? Treatment results in a decrease in injury crashes and an increase in non-injury crashes. See Part D Introduction and Applications Guide.

13.7.2.4. Install Changeable Speed Warning Signs

Individual changeable speed warning signs give individual drivers real-time feedback regarding their speed.

Rural two-lane roads, rural multi-lane highways, expressways, freeways, urban and suburban arterials

The crash effect of installing individual changeable speed warning signs is shown in Exhibit 13-42. The base condition of the AMF (i.e., the condition in which the AMF = 1.00) is the absence of changeable speed warning signs.

Exhibit 13-42: Potential Crash Effects of Installing Changeable Speed Warning Signs for Individual Drivers [(8)]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install changeable speed warning signs for individual drivers	Unspecified (Unspecified)	Unspecified	All types (All severities)	*0.54*	*0.2*
Base Condition: Absence of changeable speed warning signs.					

NOTE: Based on International study: Van Houten and Nau 1981

Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

13.8. CRASH EFFECTS OF ROADWAY DELINEATION

13.8.1. Background and Availability of AMFs

Delineation includes all methods of defining the roadway operating area for drivers, and has long been considered an essential element for providing guidance to drivers. Methods of delineation include devices such as pavement markings (made from a variety of materials), raised pavement markers (RPMs), chevron signs, object markers, and post-mounted delineators (PMDs).[(11)] Delineation may be used alone to convey regulations, guidance, or warnings.[(19)] Delineation may also be used to supplement other traffic control devices, such as signs and signals. The MUTCD provides guidelines for retroreflectivity, color, placement, types of materials and other delineation issues.(19)

Exhibit 13-43 summarizes common treatments related to delineation and the corresponding AMF availability.

Exhibit 13-43: Summary of Treatments Related to Delineation

HSM Section	Treatment	Rural Two-Lane Road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.8.2.1	Install post-mounted delineators (PMDs)	✓	-	-	-	-	-
13.8.2.2	Place standard edgeline markings	✓	-	-	-	-	-
13.8.2.3	Place wide edgeline markings	✓	-	-	-	-	-
13.8.2.4	Place centerline markings	✓	-	N/A	N/A	-	-
13.8.2.5	Place edgeline and centerline markings	✓	✓	N/A	N/A	-	-
13.8.2.6	Install edgelines, centerlines and post-mounted delineators	✓	✓	N/A	N/A	-	-
13.8.2.7	Install snowplowable permanent raised pavement markers (RPMs)	✓	-	✓	-	-	-
Appendix A	Install chevron signs on horizontal curves	-	-	-	-	T	T
Appendix A	Provide distance markers	-	-	T	-	-	-
Appendix A	Place converging chevron pattern markings	-	-	-	-	T	T
Appendix A	Place edgeline and directional pavement markings on horizontal curves	T	-	-	-	-	-

NOTE:
✓ = Indicates that an AMF is available for this treatment.
T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
- = Indicates that an AMF is not available and a trend is not known.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

13.8.2. Roadway Delineation Treatments with AMFs

13.8.2.1. Install Post-Mounted Delineators (PMDs)

Post-mounted delineators (PMDs) are considered guidance devices rather than warning devices.(9) PMDs are typically installed in addition to existing edgeline and centerline markings.

Rural two-lane roads

The crash effects of installing PMDs on rural two-lane roads, including tangent and curved road sections, is shown in Exhibit 13-44. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of post-mounted delineators.

Exhibit 13-44: Potential Crash Effects of Installing Post-Mounted Delineators [8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install post-mounted delineators	Rural (Two-lane undivided)	Unspecified	All types (Injury)	**1.04***	**0.1**
			All types (Non-injury)	**1.05***	**0.07**
Base Condition: Absence of post-mounted delineators					

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

13.8.2.2. Place Standard Edgeline Markings (4 to 6 in)

The MUTCD contains guidance on installing edgeline pavement markings.[9]

Rural two-lane roads

The crash effects of installing standard edgeline markings, 4 to 6 inches wide, on rural two-lane roads that currently have centerline markings is shown in Exhibit 13-45. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of standard edgeline markings.

Exhibit 13-45: Potential Crash Effects of Placing Standard Edgeline Markings [8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Place standard edgeline marking	Rural (Two-lane)	Unspecified	All types (Injury)	**0.97***	**0.04**
			All types (Non-injury)	**0.97***	**0.1**
Base Condition: Absence of standard edgeline markings.					

NOTE: Based on US studies: Thomas 1958; Musick 1960; Williston 1960; Basile 1962; Tamburri, Hammer, Glennon and Lew 1968; Roth 1970; Bali, Potts, Fee, Taylor and Glennon 1978 and International studies: Charnock and Chessell 1978, McBean 1982; Rosbach 1984; Willis, Scott and Barnes 1984; Corben, Deery, Newstead, Mullan and Dyte 1997

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

13.8.2.3. Place Wide (8-in) Edgeline Markings

The MUTCD indicates that wide (8 inch) solid edgeline markings can be installed for greater emphasis.[9]

Rural two-lane roads

The crash effects of placing 8 inches wide edgeline markings on rural two-lane roads that currently have standard edgeline markings are shown in Exhibit 13-46.[8] The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the use of standard edgeline markings (4 to 6 inches wide).

Exhibit 13-46: Potential Crash Effects of Placing Wide Edgeline Markings[8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Place wide edgeline markings	Rural (Two-lane)	Unspecified	All types (Injury)	**1.05*?**	**0.08**
			All types (Non-injury)	*0.99*?*	*0.2*
Base Condition: Standard edgeline markings (4 to 6 inches wide).					

NOTE: Based on U.S. studies: Hall 1987; Cottrell 1988; Lum and Hughes 1990

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

? Treatment results in an increase in injury crashes and a decrease in non-injury crashes. See Part D Introduction and Applications Guide.

13.8.2.4. Place Centerline Markings

The MUTCD provides guidelines and warrants for centerline marking application.[9]

Rural two-lane roads

The crash effects of placing centerline markings on rural two-lane roads that currently do not have centerline markings are shown in Exhibit 13-47.[8] The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of centerline markings.

Exhibit 13-47: Potential Crash Effects of Placing Centerline Markings[8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Place centerline markings	Rural (Two-lane)	Unspecified	All types (Injury)	**0.99*?**	**0.06**
			All types (Non-injury)	**1.01*?**	**0.05**
Base Condition: Absence of centerline markings.					

NOTE: Based on US studies: Tamburri, Hammer, Glennon and Lew 1968; Glennon 1986 and International studies: Engel and Krogsgard Thomsen 1983

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

? Treatment results in a decrease in injury crashes and an increase in non-injury crashes. See Part D Introduction and Applications Guide.

Study does not report if the roadway segments meet MUTCD guidelines for centerline marking application

13.8.2.5. Place Edgeline and Centerline Markings

The MUTCD provides guidelines and warrants for edgeline and centerline marking application.[9]

Rural two-lane roads and rural multi-lane highways

Placing edgeline and centerline markings where no markings exist decreases injury accidents of all types, as shown in Exhibit 13-48. The base condition of the AMF (i.e., the condition in which the AMF = 1.00) is the absence of markings.

Exhibit 13-48: Potential Crash Effects of Placing Edgeline and Centerline Markings [8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Place edgeline and centerline markings	Rural (Two-lane/ Multilane undivided)	Unspecified	All types (Injury)	**0.76**	**0.1**
Base Condition: Absence of markings.					

NOTE: Based on US study: Tamburri, Hammer, Glennon and Lew, 1968
Study does not report if the roadway segments meet MUTCD guidelines for edgeline and centerline marking application
Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

13.8.2.6. Install Edgelines, Centerlines and Post-Mounted Delineators

Edgeline markings, centerline markings and post-mounted delineators are often combined on roadway segments.

Rural two-lane road and rural multi-lane highways

The crash effects of installing edgelines, centerlines, and post mounted delineators where no markings exist are shown in Exhibit 13-49. The base condition of the AMF (i.e., the condition in which the AMF = 1.00) is the absence of markings.

Exhibit 13-49: Potential Crash Effects of Installing Edgelines, Centerlines and Post-Mounted Delineators [8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install edgelines, centerlines and delineators	Urban/ Rural (Two-lane/ multilane Undivided)	Unspecified	All types (Injury)	**0.55**	**0.1**
Base Condition: Absence of markings.					

NOTE: Based on US studies: Tamburri, Hammer, Glennon and Lew 1968, Roth 1970
Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

13.8.2.7. Install Snowplowable Permanent Raised Pavement Markers (RPMs)

Implementing snowplowable permanent raised pavement markers (RPMs) requires consideration of traffic volumes and horizontal curvature.[2]

Rural two-lane roads

The crash effects of installing snowplowable RPMs on low volume (AADT of 0 to 5,000), medium volume (AADT of 5,001 to 15,000), and high volume (AADT of 15,001 to 20,000) roads are shown in Exhibit 13-50.(2)

The varying crash effect by traffic volume is likely due to the lower design standards (e.g., narrower lanes, narrower shoulders, etc.) associated with low-volume roads.(2) Providing improved delineation, such as RPMs, may cause drivers to increase their speeds. The varying crash effect by curve radius is likely related to the negative impact of speed increases.(2) The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence raised pavement markers.

Exhibit 13-50: Potential Crash Effects of Installing Snowplowable Permanent Raised Pavement Markers (RPMs) *(2)*

Treatment	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
Install snowplowable permanent RPMs	Rural (Two-lane with radius > 1640 ft)	0 to 5,000	Nighttime All types (All severities)	**1.16**	**0.03**
		5,001 to 15,000		**0.99***	**0.06**
		15,001 to 20,000		**0.76**	**0.08**
	Rural (Two-lane with radius ≤ 1640 ft)	0 to 5,000		**1.43**	**0.1**
		5,001 to 15,000		**1.26**	**0.1**
		15,001 to 20,000		**1.03***	**0.1**
Base Condition: Absence of raised pavement markers.					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

Freeways

The crash effects of installing snowplowable RPMs on rural four-lane freeways for nighttime crashes by traffic volume is shown in Exhibit 13-51.(2) The varying crash effect by traffic volume is likely due to the lower design standards (e.g., narrower lanes, narrower shoulders, etc.) associated with lower-volume roads.(2) The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence raised pavement markers.

Exhibit 13-51: Potential Crash Effects of Installing Snowplowable Permanent Raised Pavement Markers (RPMs) [2]

Treatment	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
Install snowplowable PRPMs	Rural (Four-lane freeways)	≤ 20,000	Nighttime All types (All severities)	*1.13**	*0.2*
		20,001 to 60,000		*0.94**	*0.3*
		> 60,000		*0.67*	*0.3*
Base Condition: Absence of raised pavement markers.					

NOTE: *Italic* text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

13.9. CRASH EFFECTS OF RUMBLE STRIPS

13.9.1. Background and Availability of AMFs

Rumble strips warn drivers by creating vibration and noise when driven over. The objective of rumble strips is to reduce crashes caused by drowsy or inattentive drivers. In general, rumble strips are used in areas where the noise generated is unlikely to disturb adjacent residents; that is, in non-residential areas. The decision to incorporate rumble strips may also depend on the presence of bicyclists on the roadway segment.

Jurisdictions have not identified additional maintenance requirements with respect to rumble strips.[23] The vibratory effects of rumble strips can be felt in snow and icy conditions and may act as a guide to drivers in inclement weather.[13] Analysis of downstream crash data for shoulder rumble strips found migration and/or spillover of crashes to be unlikely.[13]

Exhibit 13-52 summarizes common treatments related to rumble strips and the corresponding AMF availability.

Exhibit 13-52: Summary of Treatments Related to Rumble Strips

HSM Section	Treatment	Rural Two-Lane Road	Urban Two-Lane Road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.9.2.1	Install continuous shoulder rumble strips	-	-	✓	✓	-	-	-
13.9.2.2	Install centerline rumble strips	✓	-	-	N/A	N/A	-	-
Appendix A	Install continuous shoulder rumble strips and wider shoulders	-	-	-	T	-	-	-
Appendix A	Install transverse rumble strips	T	-	-	-	-	-	-

NOTE:
✓ = Indicates that an AMF is available for this treatment.
T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
- = Indicates that an AMF is not available and a trend is not known.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

13.9.2. Rumble Strip Treatments with AMFs

13.9.2.1. Install Continuous Shoulder Rumble Strips

Shoulder rumble strips are installed on a paved roadway shoulder near the travel lane. Shoulder rumble strips are made of a series of indented, milled, or raised elements intended to alert inattentive drivers, through vibration and sound, that their vehicles have left the roadway. On divided highways, shoulder rumble strips are typically installed on both the inner and outer shoulders (i.e., median and right shoulders).[(28)]

The impact of shoulder rumble strips on motorcycles or bicyclists has not been quantified in terms of crash experience.[(29)]

Continuous shoulder rumble strips are applied with consistently small spacing between each groove (generally less than 1-ft. There are no gaps of smooth pavement longer than about 1-ft.

Rural multi-lane highways

The crash effects of installing continuous shoulder rumble strips on rural multi-lane divided highways, with posted speeds of 55 to 70 mph are shown in Exhibit 13-53.[(6)] The crash effects on all types of injury severity and single-vehicle run-off-road accidents are also shown in Exhibit 13-53. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence shoulder rumble strips.

Exhibit 13-53: Potential Crash Effects of Installing Continuous Shoulder Rumble Strips on Multi-Lane Highways *(6)*

Treatment	Setting (Road type)	Traffic Volume (AADT)	Accident type (Severity)	AMF	Std. Error
Install continuous milled-in shoulder rumble strips	Rural (Multi-lane divided)	2,000 to 50,000	All types (All severities)	**0.84**	**0.1**
			All types (Injury)	*0.83*	*0.2*
			SV ROR (All severities)	*0.90**	*0.3*
			SV ROR (Injury)	*0.78**	*0.3*
Base Condition: Absence of shoulder rumble strips.					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.
Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.
SV ROR = Single-Vehicle Run-off-road accidents
* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

Freeways

There are specific circumstances in which installing continuous shoulder rumble strips on all four shoulders reduces single-vehicle run-off-road (SV ROR) accidents. The specific circumstances are SV ROR crashes with contributing factors including alcohol, drugs, inattention, inexperience, fatigue, illness, distraction, and glare. The AMFs are presented in Exhibit 13-54.(25)

The crash effects on all SV ROR accidents of all severities and injury severity are also shown in Exhibit 13-54. There is no evidence that shoulder rumble strips have an effect on multi-vehicle accidents within the boundaries of the treatment area.(13) The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of shoulder rumble strips.

Exhibit 13-54: Potential Crash Effects of Installing Continuous Shoulder Rumble Strips on Freeways *(25,13)*

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install continuous milled-in shoulder rumble strips *(6)*	Urban/Rural (Freeway)	Unspecified	Specific SV ROR (All severities)	**0.21**	**0.07**
Install continuous rolled-in shoulder rumble strips *(11)*	Urban/Rural (Freeway)		SV ROR (All severities)	**0.82**	**0.1**
			SV ROR (Injury)	*0.87*	*0.2*
	Rural (Freeway)		SV ROR (All severities)	*0.79*	*0.2*
			SV ROR (Injury)	*0.93**	*0.3*
Base Condition: Absence of shoulder rumble strips.					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.
Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.
SV ROR = Single Vehicle Run-off-road accidents
Specific SV ROR crashes have certain causes including alcohol, drugs, inattention, inexperience, fatigue, illness, distraction, and glare.
* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

The gray box below presents an example of how to apply the preceding AMFs to assess the crash effects of implementing rumble strips on an urban freeway.

Part D Introductions and Applications Guidance provides information about the application of AMFs.

Effectiveness of Implementing Rumble Strips

Question:

The installation of rumble strips is being considered along an urban freeway segment to reduce single vehicle run of the road (SV ROR) crashes. What will be the likely change in expected average crash frequency?

Given Information:

- Existing roadway = urban freeway
- Average crash frequency without treatment = 22 crashes/year

Find:

- Average crash frequency with installation of rumble strips
- Change in average crash frequency

Answer:

1) Identify the applicable AMF

   AMF = 0.82 (Exhibit 13-54)

2) Calculate the 95th percentile confidence interval estimation of crashes with the treatment

   = (0.82 ± 2 x 0.10) x (22 crashes/year) = 13.6 or 22.4 crashes/year

   A standard error is provided for this AMF in Exhibit 13-54 as 0.10. The multiplication of the standard error by 2 yields a 95% probability that the true value is between 13.6 and 22.4 crashes/year. See Section 3.5.3 in *Chapter 3 Fundamentals* for a detailed explanation.

3) Calculate the difference between the number of crashes without the treatment and the number of crashes with the treatment.

   Change in Average Crash Frequency:

   Low Estimate = 22.4 – 22.0 = -0.4 crashes/year increment

   High Estimate = 22.4 – 13.6 = 8.8 crashes/year reduction

4) **Discussion: This example illustrates that the installation of rumble strips is more likely to result in a decrease in expected average crash frequency. However, there is also a probability that crashes will remain unchanged or experience a slight increase.**

13.9.2.2. Install Centerline Rumble Strips

Centerline rumble strips are installed on undivided roadways, along the centerline that divides opposing traffic. Centerline rumble strips target head-on and opposite-direction sideswipe crashes. A secondary target is drift-off run-off-road-to-the-left crashes. Centerline rumble strips may reduce risky passing, but this is not their primary intent and the effect on risky passing is not known.

National guidelines do not exist for the application of centerline rumble strips. Appendix A contains information about the placement of centerline rumble strips in relation to centerline markings.

Rural two-lane roads

The crash effects of installing centerline rumble strips on rural two-lane roads are shown in Exhibit 13-55.[8] The crash effects for frontal and opposing-direction sideswipe accidents are also shown in Exhibit 13-55.

The AMFs are applicable to a range of centerline rumble strip designs (e.g., milled in, rolled in, formed, raised) and placements (e.g., continuous, intermittent).[26] The AMFs are also applicable to horizontal curves and tangent sections, passing and no-passing zones.[26] The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of centerline rumble strips.

Exhibit 13-55: Potential Crash Effects of Installing Centerline Rumble Strips [14]

Treatment	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
Install centerline rumble strips	Rural (Two-lane)	5,000 to 22,000	All types (All severities)	**0.86**	**0.05**
			All types (Injury)	**0.85**	**0.08**
			Frontal and opposing-direction sideswipe (All severities)	**0.79**	**0.1**
			Frontal and opposing-direction sideswipe (Injury)	*0.75*	*0.2*
Base Condition: Absence of centerline rumble strips.					

NOTE: Based on centerline rumble strip installation in seven states: California, Colorado, Delaware, Maryland, Minnesota, Oregon, and Washington

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

13.10. CRASH EFFECTS OF TRAFFIC CALMING

13.10.1. Background and Availability of AMFs

Some objectives of traffic calming are to reduce traffic speed and/or traffic volume, in order to reduce conflicts between local traffic and through traffic, make it easier for pedestrians to cross the road, and reduce traffic noise. Traffic calming measures and devices are applied in different combinations to suit the specific road environment and the specific result desired.

Traffic calming measures have grown in application over the past 15 years in North America. Various factors have contributed including the desire to provide a shared space between vehicular, pedestrian, and bicyclist traffic.

Exhibit 13-56 summarizes common treatments related to traffic calming and the corresponding AMF availability.

Exhibit 13-56: Summary of Treatments Related to Traffic Calming

HSM Section	Treatment	Rural Two-Lane Road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.10.2.1	Install speed humps	N/A	N/A	N/A	N/A	✓	✓
Appendix A	Install transverse rumble strips	-	-	N/A	N/A	T	T
Appendix A	Apply several traffic calming measures to a road segment	N/A	N/A	N/A	N/A	✓	-

NOTE:
✓ = Indicates that an AMF is available for this treatment.
T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
- = Indicates that an AMF is not available and a trend is not known.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

13.10.2. Traffic Calming Treatments with AMFs

This section provides a summary of traffic calming treatments with AMFs.

13.10.2.1. Install Speed Humps

Speed humps are most commonly used on residential roads in urban or suburban environments to reduce speeds and, in some cases, to reduce traffic volumes.

Urban and suburban arterials

The crash effects of installing speed humps for treated roads and for adjacent untreated roads are shown in Exhibit 13-57.[(8)] The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of speed humps.

Exhibit 13-57: Potential Crash Effects Of Installing Speed Humps [(8)]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Adjacent to roads with speed humps	Urban/ Suburban (Residential Two-lane)	Unspecified	All types (Injury)	**0.95***	**0.06**
Install speed humps				*0.60*	*0.2*
Base Condition: Absence of speed humps.					

NOTE: Based on U.S. studies: Ewing 1999 and International studies: Baguley 1982; Blakstad and Giæver 1989; Giæver and Meland 1990; Webster 1993; Webster and Mackie 1996; ETSC 1996; Al Masaeid 1997; Eriksson and Agustsson 1999; Agustsson 2001

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.

13.11. CRASH EFFECTS OF ON-STREET PARKING

13.11.1. Background and Availability of AMFs

There are two broad types of parking facilities: at the curb or on-street parking, and off-street parking in lots or parking structures.[22] Parking safety is influenced by a complex set of driver and pedestrian attitudinal and behavioral patterns.[32]

Certain kinds of accidents may be caused by curb or on-street parking operations, these include:

- Sideswipe and rear-end crashes resulting from lane changes due to the presence of a parking vehicle or contact with a parked car;
- Sideswipe and rear-end crashes resulting from vehicles stopping prior to entering the parking stall;
- Sideswipe and rear-end crashes resulting from vehicles exiting parking stalls and making lane changes; and
- Pedestrian crashes resulting from passengers alighting from the street-side doors of parked vehicles, or due to pedestrians obscured by parked vehicles.

Exhibit 13-58 summarizes common treatments related to on-street parking and the corresponding AMF availability.

Section 13.11 provides a summary of parking treatments with AMFs.

Exhibit 13-58: Summary of Treatments Related to On-Street Parking

HSM Section	Treatment	Rural Two-Lane Road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.11.2.1	Prohibit on-street parking	N/A	N/A	N/A	N/A	✓	N/A
13.11.2.2	Convert free to regulated on-street parking	N/A	N/A	N/A	N/A	✓	N/A
13.11.2.3	Implement time-limited on-street parking restrictions	N/A	N/A	N/A	N/A	✓	N/A
13.11.2.4	Convert angle parking to parallel parking	N/A	N/A	N/A	N/A	✓	N/A

NOTE:
✓ = Indicates that an AMF is available for this treatment.
- = Indicates that an AMF is not available and a trend is not known.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

13.11.2. Parking Treatments with AMFs

13.11.2.1. Prohibit On-Street Parking

Many factors may be considered before removing or altering on-street parking. These factors include parking demand, road geometry, traffic operations, and safety.

Urban arterials

Crash effects of prohibiting on-street parking on urban arterials with AADT traffic volumes from 30,000 to 40,000 are shown in Exhibit 13-59. The base condition of the AMFs summarized in Exhibit 13-59 (i.e., the condition in which the AMF = 1.00) is the provision of on-street parking.

Exhibit 13-59: Potential Crash Effects of Prohibiting On-Street Parking[22,19]

Treatment	Setting (Road type)	Traffic Volume AADT	Accident type (Severity)	AMF	Std. Error
Prohibit on-street parking	Urban (Arterial (64 ft wide))	30,000	All types (All severities)	**0.58**	**0.08**
Prohibit on-street parking	Urban (Arterial)	30,000 to 40,000	All types (Injury)	**0.78+**	**0.05**
			All types (Non-injury)	**0.72+**	**0.02**
Base Condition: Provision of on-street parking.					

NOTE: (10) Based on U.S. studies: Crossette and Allen 1969; Bonneson and McCoy 1997 and International studies: Madelin and Ford 1968; Good and Joubert 1973; Main 1983; Westman 1986; Blakstad and Giaever 1989

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

+ Combined AMF, See Part D Introduction and Applications Guide.

Accident migration is a possible result of prohibiting on-street parking.[19] Drivers may use different streets to find on-street parking, or they may take different routes to off-street parking. Shifts in travel modes may also occur as a result of the reduction in parking spaces caused by prohibiting on-street parking. Drivers may choose to walk, cycle, or use public transportation. However, the crash effects are not certain at this time.

13.11.2.2. Convert Free to Regulated On-Street Parking

Regulated on-street parking includes time-limited parking, reserved parking, area/place-limited parking, and paid parking.

Urban arterials

The crash effects of converting free parking to regulated on-street parking on urban arterials are shown in Exhibit 13-60.[8] The crash effect on injury accidents of all types is also shown in Exhibit 13-60. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the provision of free parking.

Exhibit 13-60: Potential Crash Effects of Converting from Free to Regulated On-Street Parking [8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Convert free to regulated parking	Urban (Arterial)	Unspecified	All types (Injury)	**0.94*?**	**0.08**
			All types (Non-injury)	**1.19?**	**0.05**
Base Condition: Provision of free parking.					

NOTE: Based on U.S. studies: Cleveland, Huber and Rosenbaum 1982 and International studies: Dijkstra 1990
Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.
* Observed variability suggests that this treatment could result in an increase, decrease or no change in crashes. See Part D Introduction and Applications Guidance.
? Treatment results in a decrease in injury crashes and an increase in non-injury crashes. See Part D Introduction and Applications Guide.

13.11.2.3. Implement Time-Limited On-Street Parking Restrictions

Time-limited on-street parking may consist of parking time limitations ranging from 15 minutes to several hours.

Urban arterials

The crash effects of implementing time-limited parking restrictions to regulate previously unrestricted parking on urban arterials and collectors are shown in Exhibit 13-61.[8] The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the provision of unrestricted parking.

Exhibit 13-61: Potential Crash Effects of Implementing Time-Limited On-Street Parking [8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Implement time-limited parking restrictions	Urban (Arterial and Collector)	Unspecified	All types (All severities)	**0.89**	**0.06**
			Parking-related accidents (All severities)	**0.21**	**0.09**
Base Condition: Provision of unrestricted parking.					

NOTE: Based on U.S. studies: DeRose 1966; LaPlante 1967
Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

13.11.2.4. Convert Angle Parking to Parallel Parking

In recent years, some agencies have replaced angle curb parking configurations with parallel parking for safety and operational reasons. Converting angle parking to parallel parking reduces the number of parking spaces, but increases the sightlines for drivers exiting the parking position and reduces weaving time.

Urban arterials

The crash effect of converting angle parking to parallel parking on urban arterials is incorporated in an AMF for on-street parking that includes the crash effects not only of angle vs. parallel parking, but also of the type of development along the arterial and the proportion of curb length with on-street parking.[5] The base condition of the AMF (i.e., the condition in which the AMF = 1.00) is the absence of on-street parking. An AMF for changing from angle parking to parallel parking can be determined by dividing the AMF determined for parallel parking by the AMF determined for angle parking. This AMF applies to total roadway segment accidents. The standard error for this AMF is unknown.

The AMF is determined as:

$$AMF_{1r} = 1.00 + p_{pk}\ (f_{pk} - 1.00) \qquad (13\text{-}6)$$

Where,

AMF_{1r} = accident modification factor for the effect of on-street parking on total accidents;

f_{pk} = factor from Exhibit 13-63;

p_{pk} = proportion of curb length with on-street parking = (0.5 Lpk/L');

L_{pk} = sum of curb length with on-street parking for both sides of the road combined; and

L' = total roadway segment length with deductions for intersection widths, crosswalks, and driveway widths.

Exhibit 13-62: Potential Crash Effects of Implementing On-Street Parking*(5)*

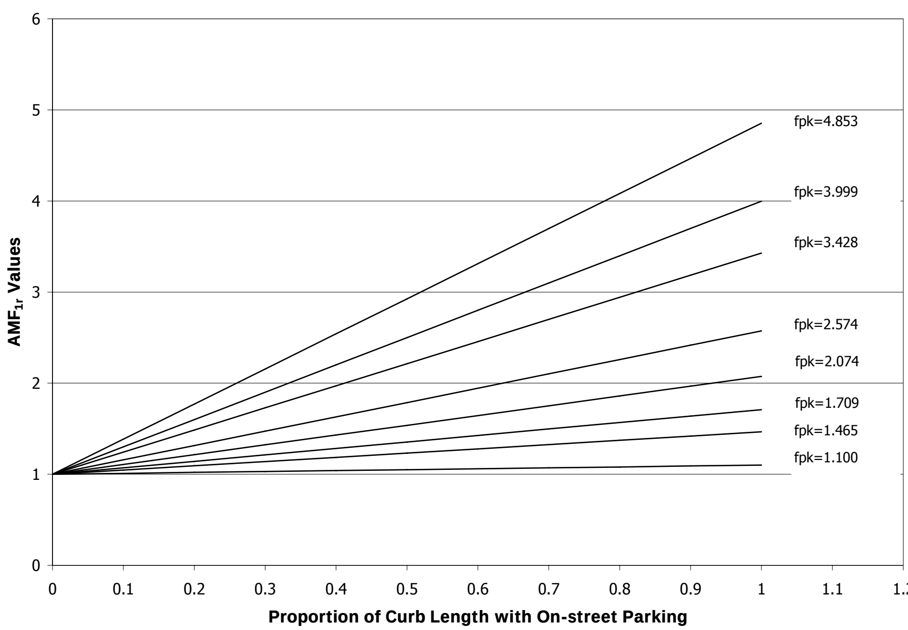


Exhibit 13-63: Type of Parking and Land Use Factor (f_{pk} in Equation 13-6)

Road type	Type of parking and land use			
	Parallel parking		Angle parking	
	Residential / other	Commercial or industrial / institutional	Residential / other	Commercial or industrial / institutional
2U	1.465	2.074	3.428	4.853
3T	1.465	2.074	3.428	4.853
4U	1.100	1.709	2.574	3.999
4D	1.100	1.709	2.574	3.999
5T	1.100	1.709	2.574	3.999

NOTE: 2U = Two-lane undivided arterials. 3T = Three-lane arterial including a center two-way left-turn lane (TWLTL). 4U = Four-lane undivided arterial. 4D = Four-lane divided arterial (i.e., including a raised or depressed median). 5T = Five-lane arterial including a center TWLTL.

Accident migration is a possible result of converting angle parking to parallel parking, in part because of the reduced number of parking spaces. Drivers may use different streets to find on-street parking, or take different routes to off-street parking. Shifts in travel modes may also occur as a result of the reduction in parking spaces as a result of converting angle parking to parallel parking. However, the crash effect is not certain at this time.

The gray box below presents an example of how to apply the preceding equations and graphs to assess the crash effects of modifying angle to parallel parking on a residential two-lane arterial road.

Effectiveness of Modifying Angle to Parallel Parking

Question:

A 3,000-ft segment of a two-lane undivided arterial in a residential area currently provides angle parking for nearby residents on about 80% of its total length. The local jurisdiction is investigating the impacts of modifying the parking scheme to parallel parking. What will be the likely reduction in expected average crash frequency for the entire 3,000-ft segment?

Given Information:

- Existing roadway = Two-lane undivided arterial (2U in Exhibit 13-63)
- Setting = Residential area
- Length of roadway = 3,000-ft
- Percent of roadway with Parking = 80%
- Expected average crash frequency with angle parking for the entire 3,000-ft segment (Seep Part C Predictive Method) = 8 crashes/year

The Part D Introduction and Applications Guide provides information about applying AMFs.

Find:

- Expected average crash frequency with modification from angle to parallel parking
- Change in expected average crash frequency

Answer:

5) Identify the parking and land use factor for existing condition angle parking
   f_{pk} = 3.428 (Exhibit 13-63)

6) Identify the parking and land use factor for proposed condition parallel parking
   f_{pk} = 1.465 (Exhibit 13-63)

7) Calculate the AMF for the existing condition
   AMF = 2.94 (Equation 13-6 or Exhibit 13-62)

8) Calculate the AMF for the proposed condition
   AMF= 1.37 (Equation 13-6 or Exhibit 13-62)

9) Calculate the treatment AMF ($AMF_{Treatment}$) corresponding to the change in parking scheme

   $AMF_{Treatment}$ = 1.37/2.94 = 0.47

   The treatment AMF is calculated as the ratio between the existing condition AMF and the proposed condition AMF. Whenever the existing condition is not equal to the base condition for a given AMF, a division of existing condition AMF (where available) and proposed condition AMF will be required.

10) Apply the treatment AMF ($AMF_{Treatment}$) to the expected number of crashes along the roadway segment without the treatment.

    = 0.47 x 8 crashes/year = 3.8 crashes/year

11) Calculate the difference between the expected number of crashes without the treatment and the expected number of crashes with the treatment.

    Change in Expected Average Crash Frequency:

    = 8.0 – 3.8 = 4.2 crashes/year reduction

12) **Discussion: the change in parking scheme may potentially result in a reduction of 4.2 crashes/year. A standard error was not available for this AMF.**

1113

Section 13.12 presents information about pedestrian and bicyclist treatments with AMFs.

13.12. CRASH EFFECTS OF ROADWAY TREATMENTS FOR PEDESTRIANS AND BICYCLISTS

13.12.1. Background and Availability of AMFs

Pedestrians and bicyclists are considered vulnerable road users as they are more susceptible to injury than vehicle occupants when involved in a traffic crash. Vehicle occupants are usually protected by the vehicle.

The design of accessible pedestrian facilities is required and is governed by implementing regulations under the Rehabilitation Act of 1973 and the Americans with Disabilities Act (ADA) of 1990. These two acts reference specific design and construction standards for usability.[(6)] Appendix A presents a discussion of design guidance resources including the PEDSAFE Guide.

For most treatments concerning pedestrian and bicyclist safety at intersections, the road type is unspecified. Where specific site characteristics are known, they are stated.

Exhibit 13-64 summarizes common roadway treatments for pedestrians and bicyclists, there are currently no AMFs available for these treatments. Appendix A presents general information and potential trends in crashes and user behavior for applicable roadway types.

Exhibit 13-64: Summary of Roadway Treatments for Pedestrians and Bicyclists

HSM Section	Treatment	Rural Two-Lane Road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
Appendix A	Provide a sidewalk or shoulder	N/A	N/A	N/A	N/A	T	-
Appendix A	Install raised pedestrian crosswalks	N/A	N/A	N/A	N/A	T	T
Appendix A	Install pedestrian-activated flashing yellow beacons with overhead signs and advance pavement markings	N/A	N/A	N/A	N/A	T	T
Appendix A	Install overhead electronic signs with pedestrian-activated crosswalk flashing beacons	N/A	N/A	N/A	N/A	T	-
Appendix A	Reduce posted speed limit through school zones during school times	T	T	N/A	N/A	T	T
Appendix A	Provide pedestrian overpasses and underpasses	-	-	N/A	N/A	-	T
Appendix A	Mark crosswalks at uncontrolled locations, intersection or mid-block	-	N/A	N/A	N/A	T	T
Appendix A	Use alternative crosswalk markings at mid-block locations	-	N/A	N/A	N/A	T	T
Appendix A	Use alternative crosswalk devices at mid-block locations	-	N/A	N/A	N/A	T	T
Appendix A	Provide a raised median or refuge island at marked and unmarked crosswalks	N/A	N/A	N/A	N/A	T	T
Appendix A	Provide a raised or flush median or center two-way left-turn lane at marked and unmarked crosswalks	N/A	N/A	N/A	N/A	T	T
Appendix A	Install pedestrian refuge islands or split pedestrian crossovers	N/A	N/A	N/A	N/A	T	T
Appendix A	Widen median	N/A	-	N/A	N/A	T	T
Appendix A	Provide dedicated bicycle lanes (BLs)	N/A	N/A	N/A	N/A	T	-
Appendix A	Provide wide curb lanes (WCLs)	N/A	N/A	N/A	N/A	T	-
Appendix A	Provide shared bus/bicycle lanes	N/A	N/A	N/A	N/A	T	-
Appendix A	Re-stripe roadway to provide bike lane	N/A	N/A	N/A	N/A	T	-
Appendix A	Pave highway shoulders for bicyclist use	T	T	N/A	N/A	N/A	-
Appendix A	Provide bicycle boulevards	N/A	N/A	N/A	N/A	T	-
Appendix A	Provide separate bicycle facilities	N/A	N/A	N/A	N/A	T	-

NOTE:
T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

13.13. CRASH EFFECTS OF HIGHWAY LIGHTING

13.13.1. Background and Availability of AMFs

Artificial illumination, also known as lighting, is often provided on roadway segments in urban and suburban areas. Lighting is also often provided at rural locations where road users may need to make a decision.

Exhibit 13-65 summarizes common treatments related to highway lighting and the corresponding AMF availability.

Exhibit 13-65: Summary of Treatments Related to Highway Lighting

HSM Section	Treatment	Rural Two-Lane Road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.13.2.1	Provide highway illumination	✓	✓	✓	✓	✓	✓
NOTE: ✓ = Indicates that an AMF is available for this treatment.							

13.13.2. Highway Lighting Treatments with AMFs

13.13.2.1. Provide Highway Lighting

Rural two-lane roads, rural multilane highways, freeways, expressways, urban and suburban arterials

The crash effects of providing highway lighting on roadway segments that previously had no lighting are shown in Exhibit 13-66. The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the absence of lighting.

Exhibit 13-66: Potential Crash Effects of Providing Highway Lighting*(7,8,12,27)***

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Provide highway lighting	All settings (All types)	Unspecified	All types (Nighttime injury) *(8)*	**0.72**	**0.06**
			All types (Nighttime Non-injury) *(8)*	**0.83**	**0.07**
			All types (Nighttime injury)*(15)*	0.71	N/A°
			All types (Nighttime all severities)*(15)*	0.80	N/A°
Base Condition: Absence of lighting.					

NOTE: Based on U.S. studies: Harkey at al., 2008; and International studies: Elvik and Vaa 2004

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

° Standard error of the AMF is unknown.

The AMFs for nighttime injury accidents and nighttime accidents for all severity levels were derived by Harkey et al.[15] using the results from Elvik and Vaa[8] along with information on the distribution of accidents by injury severity and time of day from the states of Minnesota and Michigan.

13.14. CRASH EFFECTS OF ROADWAY ACCESS MANAGEMENT

13.14.1. Background and Availability of AMFs

Section 13.14.1 presents information about access management treatments with AMFs.

Access management is a set of techniques designed to manage the frequency and magnitude of conflict points at residential and commercial access points. The purpose of an access management program is to balance the mobility required from a roadway facility with the accessibility needs of adjacent land uses.(31)

The management of access, namely the location, spacing, and design of driveways and intersections, is considered to be one of the most critical elements in roadway planning and design. Access management provides or manages access to land development while simultaneously preserving traffic safety, capacity, and speed on the surrounding road system, thus addressing congestion, capacity loss, and accidents on the nation's roadways.(21)

This section presents the crash effects of access density, or the number of access points per unit length, along a roadway segment. An extensive TRB website containing access management information is available at www.accessmanagement.gov.

Separate predictive methods are provided in *Part C* of the HSM for public-road intersections. However, where intersection characteristics or side-road traffic volume data are lacking, some minor, very-low-volume intersections may be treated as driveways for analysis purposes.

Exhibit 13-67 summarizes common treatments related to access points and the corresponding AMF availability.

Exhibit 13-67: Summary of Treatments Related to Access Management

HSM Section	Treatment	Rural Two-Lane Road	Urban Two-Lane Road	Suburban Two-Lane Roads	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.14.2.1	Modify access point density	✓	N/A	N/A	-	N/A	-	✓	✓
Appendix	Reduce number of median crossings and intersections	-	N/A	N/A	-	N/A	-	T	T

NOTE:
✓ = Indicates that an AMF is available for this treatment.
T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
- = Indicates that an AMF is not available and a trend is not known.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

13.14.2. Access Management Treatments with AMFs

13.14.2.1. Modify Access Point Density

Access point density refers to the number of access points per mile.

Rural two-lane roads

The crash effects of decreasing access point density on rural two-lane roads are presented in Equation 13-5[16] and Exhibit 13-68. The base condition (i.e., the condition in which the AMF = 1.00) for access point density is five access points per mile. The standard error of the AMF is unknown.

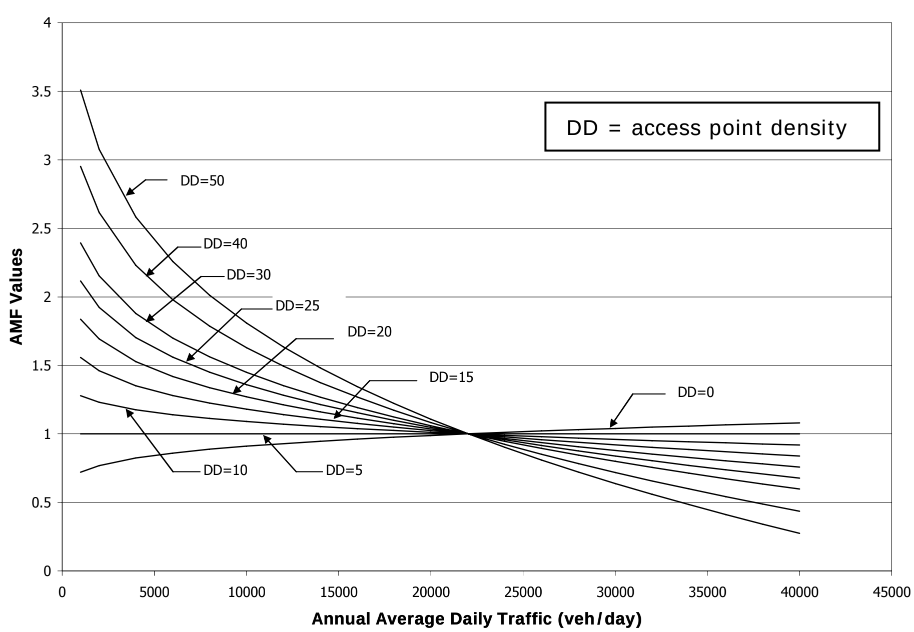
$$AMF = \frac{0.322 + DD \times [0.05 - 0.005 \times \ln(AADT)]}{0.322 + 5 \times [0.05 - 0.005 \times \ln(AADT)]} \qquad (13\text{-}7)$$

Where,

AADT = average annual daily traffic volume of the roadway being evaluated; and

DD = access point density measured in driveways per mile.

Exhibit 13-68: Potential Crash Effects of Access Point Density on Rural Two-lane Roads



Urban and Suburban Arterials

The crash effects of decreasing access point density on urban and suburban arterials are shown in Exhibit 13-69. [8]

The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is the initial driveway density prior to the implementation of the treatment as presented in Exhibit 13-69.

Exhibit 13-69: Potential Crash Effects of Reducing Access Point Density[8]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Reduce driveways from 48 to 26-48 per mile	Urban and suburban (Arterial)	Unspecified	All types (Injury)	**0.71**	**0.04**
Reduce driveways from 26-48 to 10-24 per mile				**0.69**	**0.02**
Reduce driveways from 10-24 to less than 10 per mile				**0.75**	**0.03**
Base Condition: Initial driveway density per mile based on values in this table (48, 26-48, and 10-24 per mile).					

NOTE: Based on International studies: Jensen 1968; Grimsgaard 1976; Hvoslef 1977; Amundsen 1979; Grimsgaard 1979; Hovd 1979; Muskaug 1985

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

13.15. CRASH EFFECTS OF WEATHER ISSUES

Section 13.15 presents information about weather related treatements with AMFs.

13.15.1. Background and Availability of AMFs

The weather cannot be controlled, but measures are available to mitigate inclement weather and the resulting impact on roadways.

Exhibit 13-70 summarizes common treatments related to weather issues and the corresponding AMF availability.

Exhibit 13-70: Summary of Treatments Related to Weather Issues

HSM Section	Treatment	Rural Two-Lane Road	Rural Multilane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.15.2.1	Implement faster response times for winter maintenance	✓	✓	✓	✓	✓	✓
Appendix A	Apply preventive chemical anti-icing during the whole winter season	T	T	T	T	T	T
Appendix A	Install changeable fog warnings signs	-	-	T	-	-	-
Appendix A	Install snow fences for the whole winter season	T	T	-	-	N/A	N/A
Appendix A	Raise the state of preparedness for winter maintenance	T	T	T	T	T	T

NOTE:
✓ = Indicates that an AMF is available for this treatment.
T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.
- = Indicates that an AMF is not available and a trend is not known.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

13.15.2. Weather Related Treatments with AMFs

13.15.2.1. Implement Faster Response Times for Winter Maintenance

Most jurisdictions that experience regular snowfall have developed acceptable response times for snow, slush, and ice control. For example, a jurisdiction may clear or plow the road before snow depth exceeds two inches. Standards for snow clearance vary by road type or function and traffic volume. Depending on snowfall intensity, the maximum snow depth standard implies a certain maximum response time before snow is cleared. If snow falls very intensely, the response is faster than when snow falls as scattered snowflakes.

As it starts to snow, road surface conditions worsen and it is generally expected that the accident rate will increase. After snow clearance or reapplication of de-icing treatments, the action of traffic continues to melt whatever snow or ice might be left, and the accident rate is generally expected to return to the before-snow rate.

If maintenance crews operate with a faster response time or if maintenance crews are deployed when less snow has accumulated (i.e., maintenance standards are raised), the expected increase in the accident rate could be reversed at an earlier time, possibly resulting in fewer total crashes. [1]

The effects of different winter maintenance standards for different road types on accidents during winter are likely a function of the season's duration and severity. The longer the winter season, and the more often there is adverse weather, the more important the standard of winter maintenance becomes for safety.

Rural two-lane roads, rural multilane highways, freeways, expressways, urban and suburban arterials

A jurisdiction's road system is usually classified into a hierarchy with respect to the minimum standards for winter maintenance. The hierarchy is based on traffic volume and road function. The strictest standards usually apply to freeways or arterial roads, whereas local residential roads may not be cleared at all. The crash effects of taising a road's standards for winter maintenance by one class are shown in Exhibit 13-71.[(8)] The base conditions of the AMFs (i.e., the condition in which the AMF = 1.00) consist of the original maintenance hierarchy assigned to a roadway prior to the implementation of the treatment.

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[1] Accident rate is used in this discussion as the number of accidents that occur prior to snow maintenance. The number of accidents depends on the amount of traffic on the roads between the start of snowfall and snow maintenance.

Exhibit 13-71: Potential Crash Effects of Raising Standards for Winter Maintenance for the Whole Winter Season[8][2]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Raise standard for winter maintenance	All settings (All types)	Any volume	All types (Injury)	**0.89**	**0.02**
			All types (Non-injury)	**0.73**	**0.02**
Base Condition: Original maintenance hierarchy assigned to a roadway prior to the implementation of the treatment.					

NOTE: Based on International studies: Ragnøy 1985; Bertilsson 1987; Schandersson 1988; Eriksen and Vaa 1994; Vaa 1996

Bold text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

13.16. CONCLUSION

The treatments discussed in this chapter focus on the potential crash effects of roadway segment factors such as roadway and roadside objects, roadway alignment, traffic calming, on-street parking, pedestrian and bicycle factors, illumination, access management, and weather. The information presented is the AMFs known to a degree of statistical stability and reliability for inclusion in this edition of the HSM. Additional qualitative information regarding potential roadway treatments is contained in Appendix A.

The remaining chapters in *Part D* present treatments related to other site types such as intersections and interchanges. The material in this chapter can be used in conjunction with activities in *Chapter 6 Select Countermeasures*, and *Chapter 7 Economic Appraisal*. Some *Part D* AMFs are included in *Part C* for use in the predictive method. Other *Part D* AMFs are not presented in *Part C* but can be used in the methods to estimate change in crash frequency described in Section C.7 of the *Part C Introduction and Applications Guidance*.

[2] Nearly all studies were conducted in the Scandinavian countries. The length and severity of the winter season varies substantially between regions of these countries. In the south of Sweden, for example, there may not be any snow at all during winter and only a few days with freezing rain or ice on the road. In the northern parts of Finland, Norway and Sweden, snow usually falls in October and remains on the ground until late April. Most roads in these areas, at least in rural areas, are fully or partly covered by snow throughout the winter.

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APPENDIX A

A.1 INTRODUCTION

The appendix presents general information, trends in crashes and/or user-behavior as a result of the treatments, and a list of related treatments for which information is not currently available. Where AMFs are available, a more detailed discussion can be found within the chapter body. The absence of an AMF indicates that at the time this edition of the HSM was developed, completed research had not developed statistically reliable and/or stable AMFs that passed the screening test for inclusion in the HSM. Trends in crashes and user behavior that are either known or appear to be present are summarized in this appendix.

This appendix is organized into the following sections:

- Roadway Elements (Section A.2)
- Roadside Elements (Section A.3)
- Alignment Elements (Section A.4)
- Roadway Signs (Section A.5)
- Roadway Delineation (Section A.6)
- Rumble Strips (Section A.7)
- Traffic Calming (Section A.8)
- Roadway Treatments for Pedestrians and Bicyclists (Section A.9)
- Roadway Access Management (Section A.10)
- Weather Issues (Section A.11)
- Treatments with Unknown Crash Effects (Section A.12)

A.2 ROADWAY ELEMENTS

A.2.1 General Information

Lanes

Lane width and the number of lanes are generally determined by the roadway's traffic volume and the road type and function.

In the past, wider lanes were thought to reduce crashes for two reasons. First, wider lanes increase the average distance between vehicles in adjacent lanes, providing a wider buffer for vehicles that deviate from the lane.[20] Second, wider lanes provide more room for driver correction in near-accident circumstances.[20] For example, on a roadway with narrow lanes, a moment of driver inattention may lead a vehicle over the pavement edge-drop and onto a gravel shoulder. A wider lane width provides greater opportunity to maintain the vehicle on the paved surface in the same moment of driver inattention.

Drivers, however, adapt to the road. Wider lanes appear to induce somewhat faster travel speeds, as shown by the relationship between lane width and free flow speed documented in the Highway Capacity Manual.[50] Wider lanes may also lead to closer following.

It is difficult to separate the effect of lane width from the crash effect of other cross-section elements, e.g., shoulder width, shoulder type, etc.[20] In addition, lane width likely plays a different role for two-lane versus multilane roads.[20] Finally, increasing the number of lanes on a roadway segment increases the crossing distance for pedestrians, and increases the exposure of pedestrians to vehicles.

Shoulders

Shoulders are intended to perform several functions including: provide a recovery area for out-of-control vehicles, provide an emergency stopping area, and improve the pavement surface's structural integrity.[23]

The main purposes of paving shoulders are: to protect the physical road structure from water damage, to protect the shoulder from erosion by stray vehicles, and to enhance the controllability of stray vehicles. Fully paved shoulders, however, generate some voluntary stopping. More than 10% of all fatal freeway accidents are associated with stopped-on-shoulder vehicles or maneuvers associated with leaving and returning to the outer lane. [23]

Some concerns when increasing shoulder width include:

- Wider shoulders may result in higher operating speeds which, in turn, may impact accident severity;
- Steeper side or backslopes may result from wider roadway width and limited right-of-way; and,
- Drivers may choose to use the wider shoulder as a travel lane.

Medians

Medians are intended to perform several functions. Some of the main functions are: separate opposing traffic, provide a recovery area for out-of-control vehicles, provide an emergency stopping area, and allow space for speed change lanes and storage of left-turning and U-turning vehicles.[2] Medians may be depressed, raised, or flush with the road surface.

Some additional considerations when providing medians or increasing median width include:

- Wider grassed medians may result in higher operating speeds which, in turn, may impact accident severity;
- The buffer area between private development along the road and the traveled way may have to be narrowed; and,
- Vehicles require increased clearance time to cross the median at signalized intersections.

Geometric design standards for medians on roadway segments are generally based on the setting, amount of traffic, right-of-way constraints and, over time, the revision of design standards towards more generous highway design standards.[3] Median design decisions include whether a median should be provided, how wide the median should be, the shape of the median, and whether to provide a median barrier.[24] These interrelated design decisions make it difficult to extract the effect on expected average crash frequency of median width and/or median type from the effect of other roadway and roadside elements.

In addition, median width and type likely play a different role in urban versus rural areas, and for horizontal curves versus tangent sections.

The effects on expected average crash frequency of two-way left-turn lanes (a type of "median") are discussed in *Chapter 16*.

A.2.2 Roadway Element Treatments with no AMFs - Trends in Crashes or User Behavior

A.2.2.1 Increase Median Width

On divided highways, median width includes the left shoulder, if any.

Freeways, and expressways

Increasing median width appears to decrease cross-median collisions.[24] However, no conclusive results about the crash effects for other collision types were found for this edition of the HSM.

A.3 ROADSIDE ELEMENTS

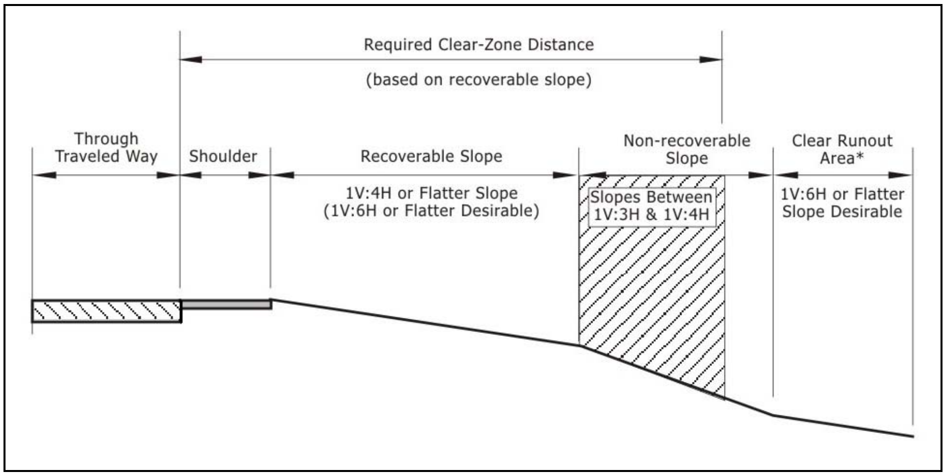
A.3.1 General Information

Roadside Geometry

Roadside geometry refers to the physical layout of the roadside, such as curbs, foreslopes, backslopes, and transverse slopes.

The AASHTO *Roadside Design Guide* defines the "clear zone" as the "*total roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area.*"[3] The clear zone is illustrated in Exhibit 13-72.

Exhibit 13-72: Clear Zone Distance with Example of a Parallel Foreslope Design[3]



NOTE: * The Clear Runout Area is additional clear-zone space that is needed because a portion of the required Clear Zone (shaded area) falls on a non-recoverable slope. The width of the Clear Runout Area is equal to that portion of the Clear Zone Distance located on the non-recoverable slope.

Designing a roadside environment to be clear of fixed objects with stable flattened slopes is intended to increase the opportunity for errant vehicles to regain the roadway safely, or to come to a stop on the roadside. This type of roadside environment, called a “forgiving roadside”, is also designed to reduce the chance of serious consequences if a vehicle leaves the roadway. The concept of a “forgiving roadside” is explained in the AASHTO Roadside Design Guide.[3]

The AASHTO Roadside Design Guide contains substantial information that can be used to determine the clear zone distance for roadways based on traffic volumes and speeds. The AASHTO Roadside Design Guide also presents a decision process that can be used to determine whether a treatment is suitable for a given fixed object or non-traversable terrain feature.[3]

While there are positive safety benefits to the clear zone, there is no single clear zone width that defines maximum safety since the distance traveled by errant vehicles may exceed any given width. It is generally accepted that a wider clear zone creates a safer environment for potentially errant vehicles, up to some cost-effective limit beyond which very few vehicles will encroach.[42] In most cases, however, numerous constraints limit the available clear zone.

Roadside Features

Roadside features include signs, signals, luminaire supports, utility poles, trees, driver aid call boxes, railroad crossing warning devices, fire hydrants, mailboxes, and other similar roadside features.

The AASHTO *Roadside Design Guide* contains information about the placement of roadside features, criteria for breakaway supports, base designs, etc.[3] When removal of hazardous roadside features is not possible, the objects may be relocated farther from the traffic flow, shielded with roadside barriers, or replaced with breakaway devices.[42]

Providing barriers in front of roadside features that cannot be relocated is discussed in Section 13.5.2.5.

Roadside Barriers

Roadside barriers are also known as guardrails or guiderails.

A roadside barrier is *"a longitudinal barrier used to shield drivers from natural or man-made obstacles located along either side of a traveled way. It may also be used to protect bystanders, pedestrians, and cyclists from vehicular traffic under special conditions."*[3] Warrants for barrier installation can be found in the AASHTO Roadside Design Guide. The AASHTO Roadside Design Guide also sets out performance requirements, placement guidelines, and a methodology for identifying and upgrading existing installations.[3]

Barrier end treatments or terminals are *"normally used at the end of a roadside barrier where traffic passes on one side of the barrier and in one direction only. A crash cushion is normally used to shield the end of a median barrier or a fixed object located in a gore area. A crash cushion may also be used to shield a fixed object on either side of a roadway if a designer decides that a crash cushion is more cost-effective than a traffic barrier."*[3]

The AASHTO Roadside Design Guide contains information about barrier types, barrier end treatment and crash cushion installation warrants, structural and performance requirements, selection guidelines, and placement recommendations.[3]

Roadside Hazard Rating

The AASHTO *Roadside Design Guide* discusses clear zone widths related to speed, traffic volume, and embankment slope. The Roadside Hazard Rating (RHR) system considers the clear zone in conjunction with the roadside slope, roadside surface roughness, recoverability of the roadside, and other elements beyond the clear zone such as barriers or trees.[19] As the RHR increases from 1 to 7, the crash risk for frequency and/or severity increases.

Exhibit 13-73 through Exhibit 13-79 are photographs illustrating the seven RHR levels. In the safety prediction procedure for two-lane rural roads (*Chapter 10*), roadside design is described by the RHR.

Exhibit 13-73: Typical Roadway with Roadside Hazard Rating of 1

Clear zone greater than or equal to 30 ft sideslope flatter than 1V:4H, recoverable.

Exhibit 13-74: Typical Roadway with Roadside Hazard Rating of 2

Clear zone between 20 and 25 ft; sideslope about 1V:4H, recoverable.

Exhibit 13-75: Typical Roadway with Roadside Hazard Rating of 3

Clear zone about 10 ft; sideslope about 1V:3H, marginally recoverable.

Exhibit 13-76: Typical Roadway with Roadside Hazard Rating of 4

Clear zone between 5 and 10 ft; sideslope about 1V:3H or 1V:4H, marginally forgiving, increased chance of reportable roadside crash.

Exhibit 13-77: Typical Roadway with Roadside Hazard Rating of 5

Clear zone between 5 and 10 ft; sideslope about 1V:3H, virtually non-recoverable.

Exhibit 13-78: Typical Roadway with Roadside Hazard Rating of 6

Clear zone less than or equal to 5 ft; sideslope about 1V:2H, non-recoverable.

Exhibit 13-79: Typical Roadway with Roadside Hazard Rating of 7

Clear zone less than or equal to 5 ft; sideslope about 1V:2H or steeper, non-recoverable with high likelihood of severe injuries from roadside crash.

A.3.2 Roadside Element Treatments with no AMFs - Trends in Crashes or User Behavior

A.3.2.1 Install Median Barrier

Freeways

Installing a median barrier appears to have a positive crash effect in narrow medians up to 36-ft wide. The crash effect appears to diminish on wider medians.(24) However, the magnitude of the crash effect is not certain at this time.

A.3.2.2 Increase Clear Roadside Recovery Distance

Rural two-lane roads

Increasing the clear roadside recovery distance appears to reduce related accident types (i.e., run-off-road, head-on, and sideswipe accidents).[40,42] The magnitude of the crash effect is not certain at this time but depends on the clear roadside recovery distance before and after treatment. Current guidance on the roadside design and clear zones is provided in the AASHTO Roadside Design Guide.[3]

A.3.2.3 Install Curb

The AASHTO Policy on Geometric Design of Highways and Streets states that *"a curb, by definition, incorporates some raised or vertical element."*[20] Curbs are used primarily on low-speed urban highways, generally with a design speed of 45 mph or less.[20]

There are two curb design types: vertical and sloping. Vertical curbs are designed to deter vehicles from leaving the roadway. Sloping curbs, also called "mountable curbs," are designed to permit vehicles to cross the curbs readily when needed.[1] Materials that may be used to construct curbs include cement concrete, granite, and bituminous (asphalt) concrete.

While cement concrete and bituminous (asphalt) concrete curbs are used extensively, it should be noted that the appearance of these types of curbs offers little visible contrast to normal pavements particularly during foggy conditions or at night when surfaces are wet. The visibility of curbs may be improved by attaching reflectorized markers to the top of the curb. Visibility may also be improved by marking curbs with reflectorized materials such as paints and thermoplastics in accordance with MUTCD guidelines.[1]

Urban arterials and suburban arterials

Installing curbs instead of narrow (2 to 3-ft) flush shoulders on urban four-lane undivided roads appears to increase off-the-road and on-the-road accidents of all severities.[25] Installing curbs instead of narrow flush shoulders on suburban multi-lane highways appears to increase accidents of all types and severities.[25] However, the magnitude of the crash effect is not certain at this time.

A.3.2.4 Increase Distance to Utility Poles and Decrease Utility Pole Density

Rural two-lane roads, rural multi-lane highways, freeways, expressways, urban and suburban arterials

As the distance between the roadway edgeline and the utility pole, or utility pole offsets, is increased and utility pole density is reduced, utility pole accidents appear to be reduced.[35] Relocating utility poles from less than 10-ft to more than 10-ft from the roadway appears to provide a greater decrease in crashes than relocating utility poles that are beyond 10-ft from the roadway edge.[35] As the pole offset increases beyond 10-ft, the safety benefits appear to continue.[35] However, the magnitude of the crash effect is not certain at this time.

Placing utility lines underground, increasing pole offsets, and reducing pole density through multiple-use poles results in fewer roadside features for an errant vehicle to strike. These treatments may also reduce utility pole accidents.[53] However, the magnitude of the crash effect is not certain at this time.

A.3.2.5 Install Roadside Barrier along Embankment

Rural two-lane roads, rural multi-lane highways, freeways, expressways, urban and suburban arterials

Installing roadside barriers along embankments appears to reduce the number of fatal and injury run-off-road accidents and the number of run-off-road accidents of all severities.(13) However, the magnitude of the crash effect is not certain at this time.

It is expected that the crash effect of installing roadside barriers is related to existing roadside features and roadside geometry.

The AASHTO Roadside Design Guide contains information about barrier types, barrier end treatment and crash cushion installation warrants, structural and performance requirements, selection guidelines, and placement recommendations.(3)

A.4 ALIGNMENT ELEMENTS

A.4.1 General Information

Horizontal Alignment

Several elements of horizontal alignment are believed to be associated with crash occurrence on horizontal curves. These elements include internal features (e.g., radius or degree of curve, superelevation, spiral, etc.) and external features (e.g., density of curves upstream, length of preceding tangent sections, sight distance, etc.).(22)

Vertical Alignment

Vertical alignment is also known as grade, gradient, or slope. The vertical alignment of a road is believed to affect crash occurrence in several ways. These include:(21)

- Average speed: Vehicles tend to slow down going upgrade and speed up going downgrade. Speed is known to affect accident severity. As more severe accidents are more likely than minor accidents to be reported to the police and to be entered into crash databases, the number of reported accidents likely depends on speed and grade.

- Speed differential: It is generally believed that accident frequency increases when speed differential increases. Since road grade affects speed differential, vertical alignment may also affect accident frequency through speed differentials.

- Braking distance: This is also affected by grade. Braking distance may increase on a downgrade and decrease on an upgrade. A longer braking distance consumes more of the sight distance available before the driver reaches the object that prompted the braking. In other words, the longer braking distances associated with downgrades require the driver to perceive, decide and react in less time.

- Drainage: Vertical alignment influences the way water drains from the roadway or may pond on the road. A roadway surface that is wet or subject to ponding may have an effect on safety.

For some of these elements (e.g., drainage) the distinction between upgrade and downgrade is not necessary. For others, e.g., average speed, the distinction between upgrade and downgrade may be more relevant, although for many roads, an upgrade for one direction of travel is a downgrade for the other.

Grade length may also influence the grade's safety. While speed may not be affected by a short downgrade, it may be substantially affected by a long downgrade.[21]

In short, the crash effect of grade can be understood only in the context of the road profile and its influence on the speed distribution profile.[21]

A.4.2 Alignment Treatments with no AMFs - Trends in Crashes or User Behavior

A.4.2.1 Modify Tangent Length Prior to Curve

When a long tangent is followed by a sharp curve (i.e. radius less than 1,666-ft), the number of accidents on the horizontal curve appears to increase.[21] The crash effect appears to be related to the length of the tangent in advance of the curve and the curve radius. However, the magnitude of the crash effect is not certain at this time.

A.4.2.2 Modify Horizontal Curve Radius

Urban and suburban arterials

Increasing the degree of horizontal curvature has been shown to increase injury and non-injury off-the-road accidents on urban and suburban arterials.[25]

A.5 ROADWAY SIGNS

A.5.1 Roadway Sign Treatments with no AMFs - Trends in Crashes or User Behavior

A.5.1.1 Install Signs to Conform to MUTCD

The MUTCD defines the standards highway agencies nationwide use to install and maintain traffic control devices on all streets and highways, but not all signs meet MUTCD standards. For example, the signs may have been installed several years ago.

Urban local street

Replacing older, non-standard signs to conform to current MUTCD standards has been shown to reduce the number of injury accidents.[7] The crash effect on non-injury accidents may consist of an increase, decrease, or no change in non-injury accidents. [7]

A.6 ROADWAY DELINEATION

A.6.1 Roadway Delineation Treatments with no AMFs - Trends in Crashes or User Behavior

A.6.1.1 Install Chevron Signs on Horizontal Curves

Curve radius and curve angle are important predictors of travel speed through horizontal curves.[6] Driver responses indicate that the deflection angle of a curve is more important than the radius in determining approach speed.[6]

For these reasons, chevron markers which delineate the entire curve angle are generally recommended on sharp curves (with deflection angles greater than 7 degrees) and are preferable to RPMs on sharp curves.[6]

Urban and suburban Arterials

Installing chevron signs on horizontal curves in an urban or suburban arterials appears to reduce accidents of all types. However, the magnitude of the crash effect is not certain at this time.

A.6.1.2 Provide Distance Markers

Distance markers are chevrons or other symbols painted on the travel lane pavement surface to help drivers maintain an adequate following distance from vehicles traveling ahead.[13]

Freeways

On freeways (with unspecified traffic volumes) this treatment appears to reduce injury accidents.[13] However, the magnitude of the crash effect is not certain at this time.

A.6.1.3 Place Converging Chevron Pattern Markings

A converging chevron pattern marking may be applied to the travel lane pavement surface to reduce speeds by creating the illusion that the vehicle is speeding and the road is narrowing. The chevron is in the shape of a “V” that points in the direction of travel.

Urban and suburban Arterials

On urban and suburban arterials with unspecified traffic volumes, converging chevron pattern markings appear to reduce all types of accidents of all severities.[16] However, the magnitude of the crash effect is not certain at this time.

A.6.1.4 Place Edgeline and Directional Pavement Markings on Horizontal Curves

Rural two-lane roads

On rural two-lane roads with AADT volumes less than 5,000, edgeline with directional pavement markings appear to reduce injury accidents of the single-vehicle run-off-road type.[13] However, the magnitude of the crash effect is not certain at this time.

A.7 RUMBLE STRIPS

A.7.1 Rumble Strip Treatments with no AMFs - Trends in Crashes or User Behavior

A.7.1.1 Install Continuous Shoulder Rumble Strips and Wider Shoulders

Freeways

On freeways, this treatment appears to decrease accidents of all types and all severities.(17) However, the magnitude of the crash effect is not certain at this time.

A.7.1.2 Install Transverse Rumble Strips

Transverse rumble strips (also called "in-lane" rumble strips or "rumble strips in the traveled way") are installed across the travel lane perpendicular to the direction of travel to warn drivers of an upcoming change in the roadway. Transverse rumble strips are designed so that each vehicle will encounter them. Transverse rumble strips have been used as part of traffic calming or speed management programs, in work zones, and in advance of toll plazas, intersections, railroad-highway grade crossings, bridges and tunnels.

There are currently no national guidelines for the application of transverse rumble strips. There are concerns that drivers will cross into opposing lanes of traffic in order to avoid transverse rumble strips. As in the case of other rumble strips, there are concerns about noise, motorcyclists, bicyclists, and maintenance.

Rural two-lane roads

Installing transverse rumble strips in conjunction with raised pavement markers on rural two-lane roads on the approach to horizontal curves appears to reduce all accident types combined, as well as wet and nighttime accidents of all severities. However, the magnitude of the crash effect is not certain at this time.(4)

A.7.1.3 Install Centerline Rumble Strips and Centerline Markings

There is debate about the effect of placing centerline markings on top of centerline rumble strips. According to some, the retroreflectivity of the centerline marking is not reduced if the line is painted on top of the rumble strip; it may even be enhanced. Others conclude it can make it harder to see the centerline marking, particularly if debris (e.g. snow, salt, sand) settles in the rumble strip groove. No conclusive results about the crash effects of the placement of centerline markings in relation to centerline rumble strips were found for this edition of the HSM.

A.8 TRAFFIC CALMING

A.8.1 General Information

Traffic calming elements are generally applied to two-lane roads with a speed limit of 30 to 35 mph. The environment is urban, often consisting of a mixture of residential and commercial land use. The road segments treated are typically about 0.6 miles long with two lanes and a high access density. Common traffic calming elements include:

- Narrowing driving lanes;

- Installing chokers or curb bulbs (curb extensions);
- Using cobblestones in short sections of the road;
- Providing raised crosswalks or speed humps;
- Installing transverse rumble strips, usually at the start of the treated roadway segment; and,
- Providing on-street parking.

A.8.2 Traffic Calming Treatments with no AMFs - Trends in Crashes or User Behavior

A.8.2.1 Install Transverse Rumble Strips on Intersection Approaches

Urban and suburban arterials

On urban and suburban two-lane roads, this treatment appears to reduce accidents of all severities.(13) However, the magnitude of the crash effect is not certain at this time.

A.8.2.2 Apply Several Traffic Calming Measures to a Road Segment

Urban arterials

Applying traffic calming measures on two-lane urban roads with AADT traffic volumes of 6,000 to 8,000 appears to decrease the number of accidents of all severities and of injury severity.(13) Non-injury accidents may also experience a reduction with the implementation of traffic calming.

Accident migration is a possible result of traffic calming. Drivers who are forced by traffic calming measures to slow down may try to "catch up" by speeding once they have passed the traffic calmed area. However, the crash effects are not certain at this time.

A.9 ROADWAY TREATMENTS FOR PEDESTRIANS AND BICYCLISTS

A.9.1 Pedestrian and Bicycle Treatments with no AMFs - Trends in Crashes or User Behavior

A.9.1.1 Provide a Sidewalk or Shoulder

"Walking along roadway" pedestrian crashes tend to occur at night where no sidewalks or paved shoulders exist. Higher speed limits and higher traffic volumes are believed to increase the risk of "walking along roadway" pedestrian crashes on roadways without a sidewalk or wide shoulder.(39)

Urban arterials

Compared to roadways without a sidewalk or wide shoulder, the provision of a sidewalk or wide shoulder (4-ft or wider) on urban roads appears to reduce the risk of "walking along roadway" pedestrian crashes.(39) Providing sidewalks, shoulders or walkways is likely to reduce certain types of pedestrian crashes, e.g. where pedestrians walk along roadways and may be struck by a motor vehicle.(30)

Residential streets and streets with higher pedestrian exposure have been shown to benefit most from the provision of pedestrian facilities such as sidewalks or wide grassy shoulders.[33,39]

Compared to roads with sidewalks on one side, roads with sidewalks on both sides appear to reduce the risk of pedestrian crashes.[48]

Compared to roads with no sidewalks at all, roads with sidewalks on one side appear to reduce the risk of pedestrian crashes.[48]

A.9.1.2 Install Raised Pedestrian Crosswalks

Raised pedestrian crosswalks are applied most often on local urban two-lane streets in residential or commercial areas. Raised pedestrian crosswalks may be applied at intersections or mid-block. Raised pedestrian crosswalks are one of many traffic calming treatments.

Urban and suburban arterials

On urban and suburban two-lane roads, raised pedestrian crosswalks appear to reduce injury accidents.[13] It is reasonable to conclude that raised pedestrian crosswalks have an overall positive effect on crash occurrence since they are designed to reduce vehicle operating speed.[13] However, the magnitude of the crash effect is not certain at this time.

Combining a raised pedestrian crosswalk with an overhead flashing beacon appears to increase driver yielding behavior. [27]

A.9.1.3 Install Pedestrian-Activated Flashing Yellow Beacons with Overhead Signs

Urban and suburban arterials

Pedestrian-activated yellow beacons are sometimes used in Europe to alert drivers to pedestrians who are crossing the roadway. Overhead pedestrian signs with flashing yellow beacons appear to result in drivers yielding to pedestrians more often.[28,43,44] The impact appears to be minimal, possibly because:

- Yellow warning beacons are not exclusive to pedestrian crossings, and drivers do not necessarily expect a pedestrian when they see an overhead flashing yellow beacon.
- Drivers learn that many pedestrians are able to cross the road more quickly than the timing on the beacon provides. Motorists may come to think that a pedestrian has already finished crossing the road if a yielding or stopped vehicle blocks the pedestrian from sight.

A.9.1.4 Install Pedestrian-Activated Flashing Yellow Beacons with Overhead Signs and Advance Pavement Markings

Urban and suburban arterials

Pedestrian-activated yellow beacons with overhead signs and advance pavement markings are sometimes used to alert drivers to pedestrians who are crossing the roadway. The pavement markings consist of a large white “X” in each traffic lane. The “X” is 20-ft long and each line is 12 to 20 inches wide. The “X” is positioned approximately 100-ft in advance of the crosswalk. The crosswalk is at least 8-ft wide with edgelines 6 to 8 inches wide.[9]

Compared to previously uncontrolled crosswalks, this type of pedestrian crossing may decrease pedestrian fatalities.[9] However, the magnitude of the crash effect is not certain at this time. The following undesirable behavior patterns were observed at these crossings:[9]

- Some pedestrians step off the curb without signaling to drivers that they intend to cross the road. These pedestrians appear to assume that vehicles will stop very quickly.
- Some drivers initiate overtaking maneuvers before reaching the crosswalk. This behavior suggests that improved education and enforcement are needed.

A.9.1.5 Install overhead electronic signs with pedestrian-activated crosswalk flashing beacons

Urban arterials

Overhead electronic pedestrian signs with pedestrian-activated crosswalk flashing beacons are generally used at marked crosswalks, usually in urban areas.

The overhead electronic pedestrian signs have animated light-emitting diode (LED) eyes that indicate to drivers the direction from which a pedestrian is crossing. The provision of pedestrian crossing direction information appears to increase driver yielding behavior.[41,51] This treatment is generally implemented at marked crosswalks, usually in urban areas.

Pedestrian-activated crosswalk flashing beacons located at the crosswalk or in advance of the crosswalk may increase the percentage of drivers that yield to pedestrians in the crosswalk. Two options for this treatment are:

- An illuminated sign with the standard pedestrian symbol next to the beacons; and,
- Signs placed 166.7-ft before the crosswalk. The signs display the standard pedestrian symbol and request drivers to yield when the beacons are flashing.

Both options appear to increase driver yielding behavior. Both options together appear to have more effect on behavior than either option alone. Only the second option appears to be effective in reducing vehicle-pedestrian conflicts.[51]

The effectiveness of specific variations of this treatment is likely a result of:

- Actuation: By displaying the pedestrian symbol and having the beacons flash only when a pedestrian is in the crosswalk, the treatment may have more impact than continuously flashing signs.
- Pedestrian crossing direction information: By indicating the direction from which a pedestrian is crossing, the treatment prompts drivers to be alert and to look in the appropriate direction.
- Multiple pedestrians: By indicating multiple directions when pedestrians are crossing from two directions simultaneously, the treatment prompts drivers to be alert and to be aware of the presence of multiple pedestrians.[51]

A.9.1.6 Reduce Posted Speed Limit through Schools Zones during School Times

Rural two-lane road, rural multi-lane highway, urban and suburban arterial

Reducing the posted speed through school zones is accomplished using signage, such as "25 MPH WHEN FLASHING," in conjunction with yellow flashing beacons.(9) No conclusive results about the crash effects of this treatment were found for this edition of the HSM. The treatment appears to result in a small reduction of vehicle operating speeds, and may not be effective in reducing vehicle speeds to the reduced posted speed limit.(9) In rural locations, this treatment may increase speed variance which is an undesirable result.(9)

School crossing guards and police enforcement used in conjunction with this treatment may increase driver compliance with speed limits.(9)

A.9.1.7 Provide Pedestrian Overpass and Underpass

Urban arterials

Overpass usage depends on walking distances and the convenience of the overpass to potential users.(9) The convenience of using a pedestrian overpass can be determined from the ratio of the time it takes to cross the street on an overpass divided by the time it takes to cross at street level. It appears that about 95% of pedestrians will use an overpass if this ratio is 1, meaning that it takes the same amount of time to cross using the overpass as the time to cross at street level. It appears that if the overpass route takes 50% longer, very few pedestrians will use it. Similar time ratios suggest that the use of underpasses by pedestrians is less than the use of overpasses.(9)

Pedestrian overpasses and underpasses provide grade-separation, but they are expensive structures and may not be used by pedestrians if they are not perceived to be safer and more convenient than street-level crossing.

Providing pedestrian overpasses appears to reduce pedestrian crashes, although vehicular accidents may increase slightly near the overpass.(9) However, the magnitude of the crash effect is not certain at this time.

A.9.1.8 Mark Crosswalks at Uncontrolled Locations, Intersections, or Mid-block

Urban and suburban arterial

At uncontrolled locations on two-lane roads and multi-lane roads with AADT less than 12,000, a marked crosswalk alone, compared with an unmarked crosswalk, appears to have no statistically significant effect on the pedestrian crash rate, measured as pedestrian crashes per million crossings.(9) Marking pedestrian crosswalks at uncontrolled locations on two- or three-lane roads with speed limits 35 to 40 mph and less than 12,000 AADT appears to have no measurable effect on either pedestrian or motorist behavior.(34) Crosswalk usage appears to increase after markings are installed. Pedestrians walking alone appear to tend to stay within the marked lines of the crosswalk, especially at intersections, while pedestrian groups appear to take less notice of the markings. There is no evidence that pedestrians are less vigilant or more assertive in the crosswalk after markings are installed.(34)

At uncontrolled locations on multi-lane roads with AADT greater than 12,000, a marked crosswalk alone, without other crosswalk improvements, appears to result in a statistically significant increase in pedestrian crash rates compared to uncontrolled sites with an unmarked crosswalk.(54)

Marking pedestrian crosswalks at uncontrolled intersection approaches with a 35 mph speed limit on recently resurfaced roadways appears to slightly reduce vehicle approach speeds.(52) Drivers at lower speeds are generally more likely to stop and yield to pedestrians than higher-speed motorists. (7)

When deciding whether to mark or not mark crosswalks, these results indicate the need to consider the full range of other elements related to pedestrian needs when crossing the roadway .(54)

A.9.1.9 Use Alternative Crosswalk Markings at Mid-block Locations

Urban and suburban arterials

Crosswalk markings may consist of zebra markings, ladder markings, or simple parallel bars. There appears to be no statistically significant difference in pedestrian crash risk between the alternative crosswalk markings available.

A.9.1.10 Use Alternative Crosswalk Devices at Mid-block Locations

Urban and suburban arterials

Zebra and Pelican

Signalized Pelican crossings allow for the smooth flow of vehicular traffic in areas of heavy pedestrian activity. Both traffic engineers and the public seem to feel that Pelican crossings reduce the risk to pedestrians because drivers are controlled by signals.

Replacing Zebra crossings with Pelican crossings does not necessarily cause a reduction in crashes or increase convenience for pedestrians, and may sometimes increase accidents due to increased pedestrian activity at one location, among other factors.(12) In traffic-calmed areas, Zebra crossings seem to be gaining in popularity as they give pedestrians priority over vehicles, are less expensive than signalization, and are more visually appealing.

Exhibit 13-80 and Exhibit 13-81 present examples of Zebra and Pelican crossings.

Exhibit 13-80: Zebra Crossing

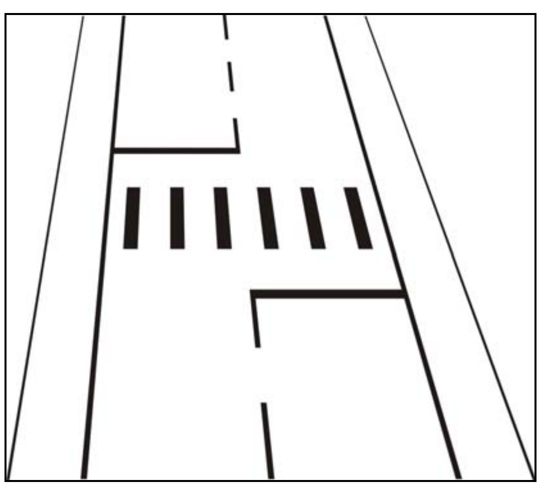
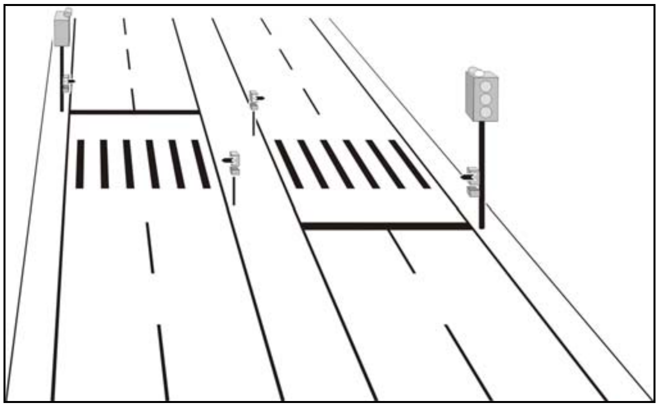


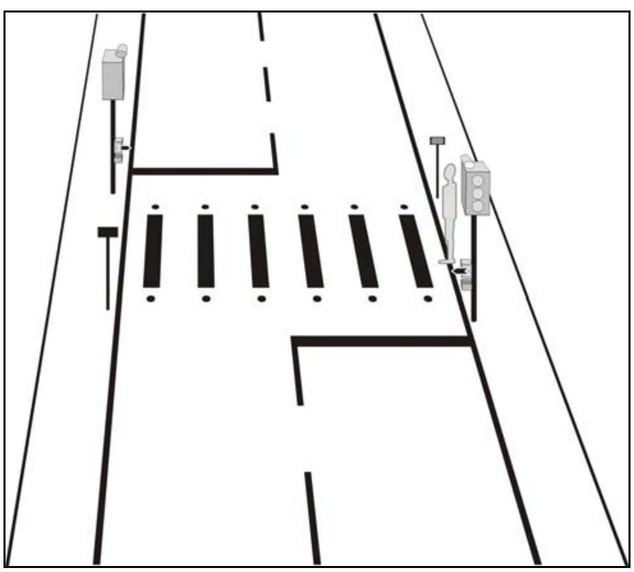
Exhibit 13-81: Pelican Crossing



Puffin

It appears that, with some modifications at Puffin crossings, pedestrians are more likely to look at on-coming traffic rather than looking across the street to where the pedestrian signal head would be located on a Pelican crossing signal.(12) Puffin crossings may result in fewer major pedestrian crossing errors, such as crossing during the green phase for vehicles. This may be a result of the reduced delay to pedestrians at Puffin crossings. Minor pedestrian crossing errors, such as starting to cross at the end of the pedestrian phase, may increase.(12) Exhibit 13-82 presents an example of a Puffin crossing.

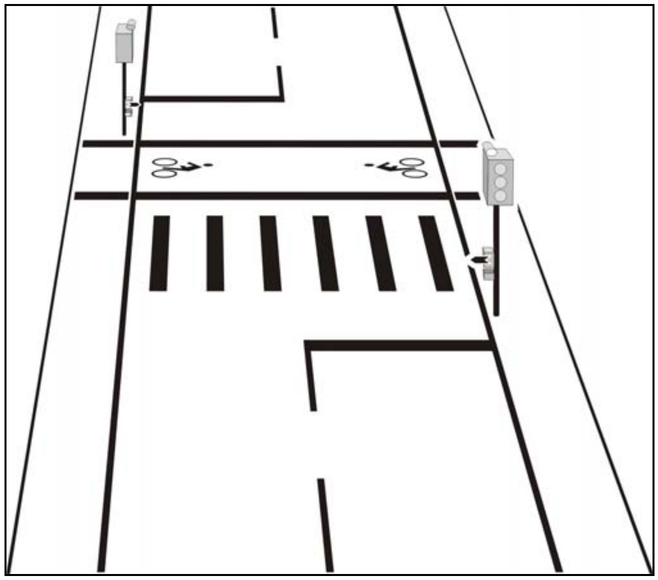
Exhibit 13-82: Puffin Crossing



Toucan

Responses from pedestrians and cyclists using Toucan crossings have been generally favorable despite problems with equipment reliability. No safety or practical issues have been reported for pedestrians where bicyclists are allowed to share a marked pedestrian crosswalk.[12] Exhibit 13-83 presents an example of a Toucan crossing.

Exhibit 13-83: Toucan Crossing



A.9.1.11 Provide a Raised Median or Refuge Island at Marked and Unmarked Crosswalks

Urban and Suburban Arterials

On multi-lane roads with either marked or unmarked crosswalks at both midblock and intersection locations, providing a raised median or refuge island appears to reduce pedestrian crashes.

On urban or suburban multi-lane roads with marked crosswalks, 4 to 8 lanes wide with an AADT of 15,000 or more, the pedestrian crash rate is lower with a raised median than without a raised median.[54] However, the magnitude of the crash effect is not certain at this time.

For similar sites at unmarked crosswalk locations, the pedestrian crash rate[3] is lower with a raised median than without a raised median.[54] However, the magnitude of the crash effect is not certain at this time.

A.9.1.12 Provide a Raised or Flush Median or Center Two-way Left-turn Lane at Marked and Unmarked Crosswalks

Urban and Suburban Arterials

A flush median (painted but not raised) or a center two-way-left-turn lane (TWLTL) on urban or suburban multi-lane roads with 4 to 8 lanes and AADT of 15,000 or more do not appear to provide a crash benefit to pedestrians when compared to multi-lane roads with no median at all.[54]

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[3] Pedestrian crash rate is calculated as the number of pedestrian crashes per million crossings

Suburban arterial streets with raised curb medians appear to have lower pedestrian crash rates as compared to TWLTL medians.[(8)] However, the magnitude of the crash effect is not certain at this time.

Replacing a 6-ft painted median with a wide raised median appears to reduce pedestrian crashes.[(11)] However, the magnitude of the crash effect is not certain at this time.

A.9.1.13 Install Pedestrian Refuge Islands or Split Pedestrian Crossovers

Urban and suburban arterials

Raised pedestrian refuge islands (PRIs) may be located in the center of roads that are 52-ft wide. The islands are approximately 6-ft wide and 36-ft long. Pedestrian warning signs alert approaching drivers of the island. Further guidance is provided by end island markers and keep right signs posted at both ends of the island. Pedestrians who use the islands are advised with "Wait for Gap" and "Cross Here" signs. Pedestrians do not have the legal right-of-way.[(5)]

Split pedestrian crossovers (SPXOs) provide a refuge island, static traffic signs, an internally illuminated overhead "pedestrian crossing" sign and pedestrian-activated flashing amber beacons. Drivers approaching an activated SPXO must yield the right-of-way to the pedestrian until the pedestrian clears the driver's half of the road and reaches the island. Like the pedestrian refuges described above, SPXOs include pedestrian warning signs, keep right signs and end island markers to guide drivers; however, the pedestrian signing reads, "Caution Push Button to Activate Early Warning System."[(5)]

PRIs appear to experience more vehicle-island crashes while SPXOs appear to experience more vehicle-vehicle accidents.[(5)]

Providing a PRI appears to reduce pedestrian crashes but may increase total accidents, as vehicles collide with the island.[(5)] However, the magnitude of the crash effect is not certain at this time.

A.9.1.14 Widen Median

Urban and suburban arterials

Increasing median width on arterial roads from 4-ft to 10-ft appears to reduce pedestrian crash rates.[(46)] However, the magnitude of the crash effect is not certain at this time.

A.9.1.15 Provide Dedicated Bicycle Lanes

Urban arterials

Providing dedicated bicycle lanes in urban areas appears to reduce bicycle-motor vehicle crashes and total crashes on roadway segments.[(10,29,32,37,45,47)] However, the magnitude of the crash effect is not certain at this time.

Installing pavement markings at the side of the road to delineate a dedicated bicycle lane appears to reduce erratic maneuvers by drivers and bicyclists. Compared to a wide curb lane (WCL), the dedicated bicycle lane may also lead to higher levels of comfort for both bicyclists and motor vehicle drivers.[(18)]

Three types of bicycle-motor vehicle accidents may be unaffected by bicycle lanes: (1) where a bicyclist fails to stop or yield at a controlled intersection, (2) where a driver fails to stop or yield at a controlled intersection, and (3) where a driver makes an improper left-turn.[37]

A.9.1.16 Provide Wide Curb Lanes (WCLs)

Urban arterials

One alternative to providing a dedicated bicycle lane is to design a wider curb lane to accommodate both bicyclists and motor vehicles. A curb lane 12-ft wide or more appears to improve the interaction between bicycles and motor vehicles in the shared lane.[38] It is likely, however, that there is a lane width beyond which safety may decrease due to driver and bicyclist misunderstanding of the shared space.[38]

Vehicles passing bicyclists on the left appear to encroach into the adjacent traffic lane on roadway segments with WCLs more than on roadway segments with bicycle lanes.[29,18]

Compared to WCLs with the same motor vehicle traffic volume, bicyclists appear to ride further from the curb in bicycle lanes 5.2-ft wide or greater.[29]

A.9.1.17 Provide Shared Bus/Bicycle Lanes

Urban arterials

Compared to streets with general use lanes, and although bicycle traffic may increase after installation of the shared bus/bicycle lane, providing shared bus/bicycle lanes appears to reduce total crashes. [29] However, the magnitude of the crash effect is not certain at this time.

Installing unique pavement markings to highlight the conflict area between bicyclists and transit users at bus stops appears to encourage bicyclists to slow down when a bus is present at the bus stop. [29] The pavement markings may reduce the number of serious conflicts between bicyclists and transit users loading or unloading from the bus. [29]

A.9.1.18 Re-stripe Roadway to Provide Bicycle Lane

Urban arterials

Where on-street parking exists, retrofitting the roadway to accommodate a bicycle lane may result in the traffic lane next to the bicycle lane being somewhat narrower than standard.

Re-striping the roadway to narrow the traffic lane to 10.5-ft (from 12-ft) in order to accommodate a 5-ft BL next to on-street parallel parking does not appear to increase conflicts between curb lane vehicles and bicycles. [29] The narrower curb lane does not appear to alter bicycle lateral positioning. [29]

A.9.1.19 Pave Highway Shoulders for Bicyclist Use

Rural two-lane road and rural multi-lane highways

A paved shoulder for bicyclists is similar to a dedicated bicycle lane. The shoulder provides separation between the bicyclists and drivers.[18]

When a paved highway shoulder is available for bicyclists and provides an alternative to sharing a lane with drivers, the expected number of bicycle-motor vehicle crashes appears to be reduced. However, the magnitude of the crash effect is not certain at this time.

Bicyclists using a paved shoulder may be at risk if drivers inadvertently drift off the road. Shoulder rumble strips are one treatment that may be used to address this issue.(14) Rumble strips may be designed to accommodate bicyclists.(49)

A.9.1.20 Provide Separate Bicycle Facilities

Urban arterials

Separate bicycle facilities may be provided where motor vehicle speeds or volumes are high.(29) Providing separate off-road bicycle facilities reduces the potential interaction between motor vehicles and bicycles.

Although bicyclists may feel safer on separate bicycle facilities compared to bicycle lanes, the crash effects appear to be comparable along roadway segments.(36) The crossing of separate bicycle facilities at intersections may result in an increase in vehicle-bicycle crashes.(29) However, the magnitude of the crash effect is not certain at this time.

A.10 ROADWAY ACCESS MANAGEMENT

A.10.1 Roadway Access Management Treatments with no AMFs – Trends in Crashes or User Behavior

A.10.1.1 Reduce Number of Median Crossings and Intersections

Urban and suburban arterials

On urban and suburban arterials, reducing the number of median openings and intersections appears to reduce the number of intersection and driveway-related crashes.(15) However, the magnitude of the crash effect is not certain at this time.

A.11 WEATHER ISSUES

A.11.1 General Information

Adverse Weather and Low Visibility Warning Systems

Some transportation agencies employ advanced highway weather information systems that warn drivers of adverse weather including icy conditions or low visibility. These systems may include on-road systems such as flashing lights, changeable message signs, static signs, e.g., “snow belt area”, “heavy fog area”, or in-vehicle information systems, or some combination of these elements. These warning systems are most commonly used on freeways and on roads passing through mountains or other locations that may experience unusually severe weather.

Snow, Slush, and Ice Control

It is generally accepted that snow, slush or ice on a road increases the number of expected accidents. By improving winter maintenance standards, it may be possible to mitigate the expected increase in accidents. A number of treatments can be applied to control snow, slush, and ice.

A.11.2 Weather Issue Treatments with No AMFs – Trends in Crashes or User Behavior

A.11.2.1 Install Changeable Fog Warnings Signs

Freeways

Traffic congestion in dense fog can lead to safety issues as reduced visibility results in following drivers being unable to see vehicles that are moving slowly or that have stopped downstream. In dense fog on freeways, crashes often involve multiple vehicles.

On freeways, installing changeable fog warning signs appears to reduce the number of accidents that occur during fog conditions.[26,31] However, the magnitude of the crash effect is not certain at this time.

A.11.2.2 Install Snow Fences for the Whole Winter Season

Rural two-lane road and rural Multi-Lane Highway

Snow fences may be installed on highways that are exposed to snow drifts. On mountainous highways, installing snow fences appears to reduce all types of crashes of all severities.[13] However, the magnitude of the crash effect is not certain at this time.

A.11.2.3 Raise the State of Preparedness for Winter Maintenance

The crash effect of raising the state of preparedness during the entire winter season - for example, putting maintenance crews on standby or by having inspection vehicles drive around the road system - is shown to increase, decrease or cause no change in crash frequency.[13]

A.11.2.4 Apply Preventive Chemical Anti-icing During Entire Winter Season

Salt, also known as chemical de-icing, is generally used to prevent snow from sticking to the road surface. As the salt is cleared from the road by melting snow, a jurisdiction may have to reapply salt through the winter season depending on the amount and frequency of snowfall. In cold winter climates, de-icing treatments are not feasible as salt is effective only at temperatures above about 21F (-6°C). [13]

Preventive salting or chemical anti-icing refers to the spread of salt or liquid chemicals before snow starts in order to prevent snow from sticking to the road surface.

Rural two-lane roads, rural multi-lane highways, freeways, expressways, urban and suburban arterials

The use of preventive salting or chemical anti-icing (i.e., application of chemicals before the onset of a winter storm), in contrast to conventional salting or chemical de-icing (e.g., application of chemicals after a winter storm has begun) appears to reduce injury accidents.[7] The crash effects of applying preventive anti-icing and terminating salting or chemical de-icing do not show a defined trend.

A.12 TREATMENTS WITH UNKNOWN CRASH EFFECTS

A.12.1 Treatments Related to Roadway Elements

- Increase lane width at horizontal curves;
- Increase shoulder width at horizontal curves;
- Change median shape, e.g., raised, level or depressed, or median type, e.g., paved, turf;

A.12.2 Treatments Related to Roadside Elements

- Remove roadside features, e.g., trees;
- Delineate roadside features;
- Install cable guardrails between lanes of opposing traffic;
- Modify backslopes;
- Modify transverse slopes;
- Install curbs and barriers;
- Change curb design, e.g., vertical curb, sloping curb, curb height, or material;
- Replace curbs with other roadside treatments
- Modify drainage structures or features including ditches, drop inlets and channels
- Modify location and support type of signs, signals, and luminaires
- Install breakaway devices
- Modify location and type of driver-aid call boxes, mailboxes, fire hydrants
- Modify barrier end treatments, including breakaway cable terminal (BCT) and modified eccentric loader terminal (MELT).

A.12.3 Treatments Related to Alignment Elements

- Increase sight distance
- Modify lane and shoulder width at curves

A.12.4 Treatments Related to Roadway Signs

- Install active close-following warning signs
- Install limited sight distance warning signs
- Install changeable warning signs on horizontal curves
- Install advance curve warning signs

- Modify sign location, e.g., overhead or roadside;
- Install regulatory signs, such as speed limits;
- Install warning signs, such as stop ahead;
- Increase the daytime and nighttime conspicuity of signs;
- Modify sign materials, e.g., grade sheeting material, and retroreflectivity; and,
- Modify sign support material.

A.12.5 Treatments Related to Roadway Delineation

- Install flashing beacons at curves or other locations to supplement a warning or regulatory sign or marker
- Mount reflectors on guardrails, curbs, and other barriers
- Add delineation treatments at bridges, tunnels and driveways
- Place transverse pavement markings
- Install raised buttons
- Install non-permanent or temporary pavement markers

A.12.6 Treatments Related to Rumble Strips

- Install mid-lane rumble strips;
- Install rumble strips on segments with various lane and shoulder widths;
- Install rumble strips with different dimensions and patterns;

A.12.7 Treatments Related to Passing Zones

- Different passing sight distances;
- Presence of access points/driveways;
- Different length of no-passing zones;
- Different frequency of passing zones;
- Passing zones for various weather, cross-section and operational conditions;

A.12.8 Treatments Related to Traffic Calming

- Install chokers/curb bulb-outs
- Use pavement markings to narrow lanes
- Apply different textures to the road surface

A.12.9 Treatments Related to On-Street Parking

- Eliminate on-street parking on one side of the roadway
- Convert parallel parking to angle parking
- On-street parking with different configurations and adjacent land use

A.12.10 Roadway Treatments for Pedestrians and Bicyclists

- Modify sidewalk or walkway width
- Provide separation between the walkway and the roadway ("buffer zone")
- Change type of walking surface
- Modify sidewalk cross-slope, grade, curb ramp design
- Change the location of trees, poles, posts, news racks, and other roadside features
- Provide sidewalk illumination
- Presence of driveways
- Provide signage for pedestrian and bicyclist information
- Trail planning and design
- Install illuminated crosswalk signs
- Install in-pavement lighting at uncontrolled marked crosswalks
- Provide advance stop lines or yield lines
- Provide mid-block crossing illumination
- Modify median type
- Modify traffic control devices at refuge islands/medians, e.g., signs, striping, warning devices
- Widen bicycle lanes
- Install rumble strips adjacent to bicycle lane
- Provide bicycle boulevards

A.12.11 Treatments Related to Access Management

- Modify signalized intersection spacing

A.12.12 Treatments Related to Weather Issues

- Install changeable weather warnings signs (e.g., high winds, snow, freezing rain, low visibility)

- Install static warning signs for weather or road surface (e.g., bridge road surface freezes before road, high winds)
- Implement assisted platoon driving during inclement weather
- Apply sand or other material to improve road surface friction
- Apply chemical de-icing as a location-specific treatment

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